Finite Element modeling of Welding processes

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Module - 01
Introduction to welding processes
Lecture - 07
Additive manufacturing processes

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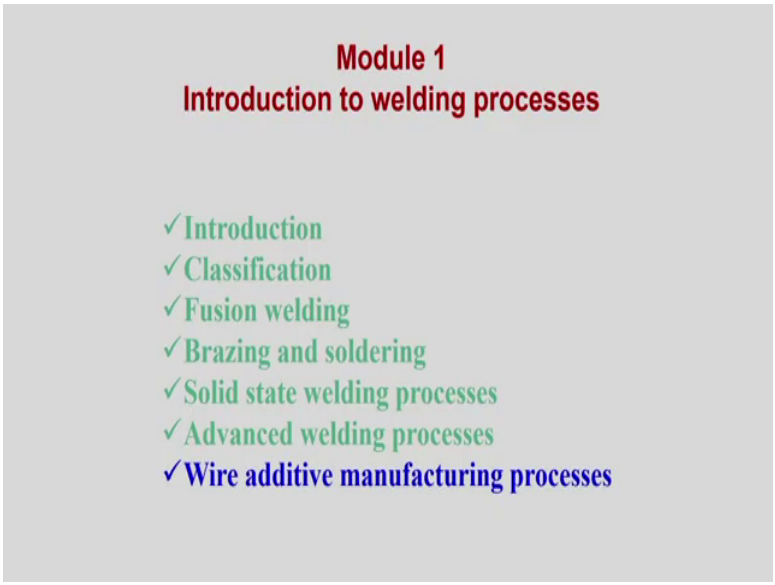

Hello everybody. Now, we look into the last part of the module 1 that is introduction to Welding Process. This part we well discuss about the wire Additive Manufacturing Process in specific, but in general I will try to explain the additive manufacturing process materialistic in to the metallic material. So, additive manufacturing process now one of the most important and significant or advanced, advanced technology has been developed on this particular process.

So, till there are some research is going on this particular technology mainly I am talking about the additive manufacturing technology. So, some sort of analysis of this particular technology is required, to make the completeness of this of this subject. And maybe I can say there are some link between the welding and this additive manufacturing technology. So, that was the reason to introduce this part in this in this course.

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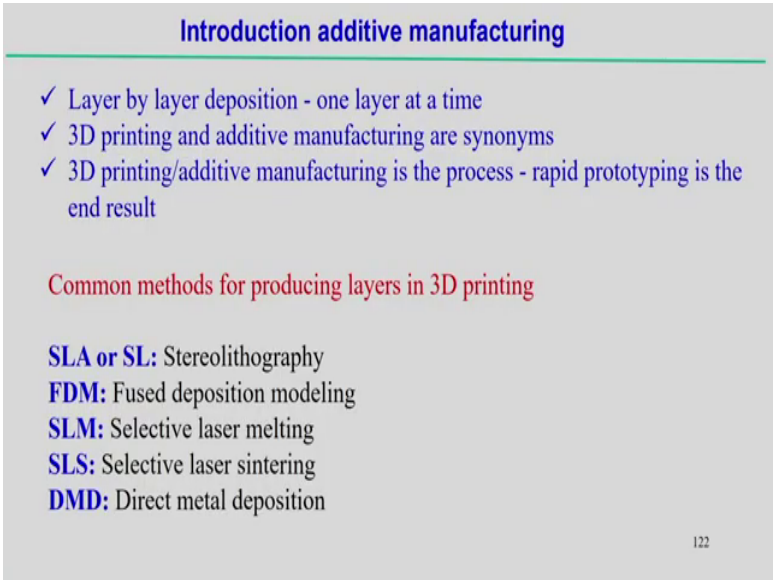

So, additive manufacturing process simply understand the layer by layer deposition process. And then there is a formation of the 3 D object, which is completely opposed as subtractive manufacturing process. So, layer by layer deposition, but one layer at a time and this that layer by layer deposition can be it can be possible by using simply, just simply melting the powder. Or some wire can be deposited by melting the wire, or can be deposited on a substrate material and they build the 3 D object.

And by following the repetition of the similar kind of layer by layer deposition on the 3 D object. But, in these cases of course, some interface with the computer is computer control, is required to decides the path. That means, at which path metal has to be deposited, and what may be the shape what may be the and particular layer what maybe the thickness all there are so many parameter which is associated that has to be digitally controlled to develop this particular process.

So 3 D printing and additive manufacturing sometimes synonyms in these cases, sometimes we can say its a 3 D printing process, sometimes we can we can say the additive manufacturing process. But, additive manufacturing process is well developed in case of the polymeric material, but for metallic material still evolving this particular subject.

3 D printing and additive manufacturing is the process is the technology and the rapid prototype is the end result. So, using this 3 D printing additive manufacturing is by using this process, we can produce some kind of the 3 D product, it is possible to develop. And of course, this concept is completely different from the which is the conventional manufacturing process, we observe in case of the casting machining and maybe and welding processes.

So, that its having since there is a material deposition in this process though to some extent it is having some similarity, with the welding process. And, it is having even if you look into the wire or additive manufacturing process; that means, which we use simply welding technology process. But, in the different way to control the welding process to make the printing technology will see what way the wire or additive manufacturing works.

But, if we look into in general the common methods for producing the 3 D printing, these are the simple most widely used the method. One is the which is a very old process the stereo lithography, which is called SLA or SL in short form we can say like that. Then, FDM fused deposition modeling, and then selective laser melting and selective laser sintering.

Both melting and sintering principle can be used such that powder can be sintered or powder can be melt to deposit a particular layer, even direct metal deposition can also be used.

We will discuss the this basics of these three all these processes, but first we start with we can so, the classification. That means, additive manufacturing processes can be classifying in the several way; that means, its a liquid based technology and powder based technology or solid based technology. Liquid based technology means; the raw material in the form of a liquid can be used.

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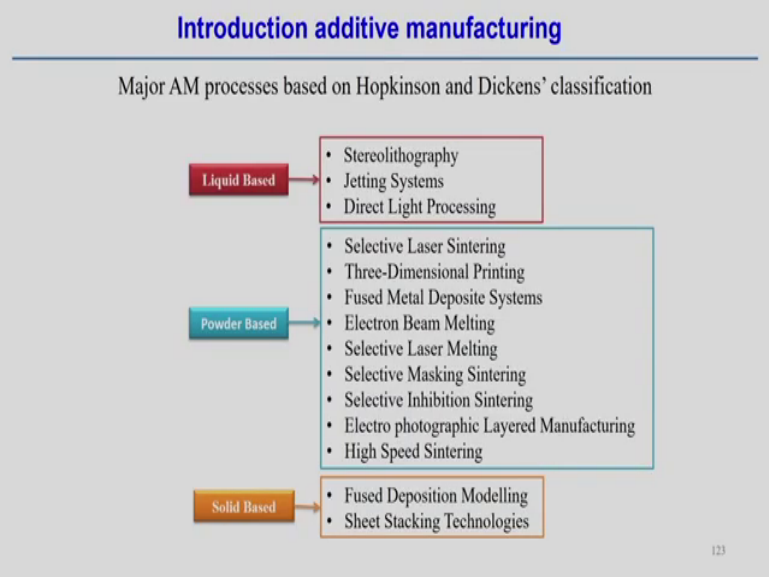

And then, the liquid has been its can be binding and the making this thing a liquid can be solidify such that the one layer can be deposited. So, liquid based the technology you can see the stereo lithography base, liquid base or its simply that some kind of the resin can be used. And the resin can be solidify using some, it can be laser or some ultra violet ray can also be used. So, that it can solidify to get the desired shape.

Jetting system and direct light processing is a the material we use, which is sensitive to the light or which may be sensitive to the ultraviolet rays such that. Once the we focus this particular light and on this material. Then, its solidify and take the required shape. So, that is the liquid based technology has been developed additive manufacturing technology.

Then, powder based technology there are so, many technology has been developed selective laser sintering 3 D sometimes, it is called the three dimensional printing, fused metal deposit system.

The several names are there, but in principle a powder based technology its simply like that where we use the raw material in the form of a powder. And then, once this powder either powder can be kept in a bed and such that within this bed, if we melt or sinter the particular layer. And then, that layer only will be solidify and then it becomes one become the solid parts in the may be part of the 3 D object.

That is in that way it can be powder can be used or powder can be injected and focused on a particular position, and on the where the powder has been focusing in that position at the same time, energy can be deposited in the for example, laser energy can be deposited on this and that melt the powder. Such that it will be at the same time powder ejecting at the melting, and it is basically depositing on a substrate material.

So, that is why powder can also be used and if it is follows from layer by layer process then it finally, produce the 3 D object. So, there are several variants of this method that have been listed there are so, many methods, but its basic principle is the raw materials is used in this case powder based technology, in the form of a powder.

Similarly, solid based technology can be used in additive manufacturing processes. Its simply the fused deposition modeling yeah in that sense means; we can wire we can use the solid wire. And solid its just fuse just means and then at the same time, it is deposited that is called the fused deposition modeling.

Even a seed stacking some solid seed can also be used in that we will stack this particular sequence, and the remove the unnecessary; that means, which is not required that particular seed. So, in that way solid based technology can be used or has been developed in additive manufacturing technology.

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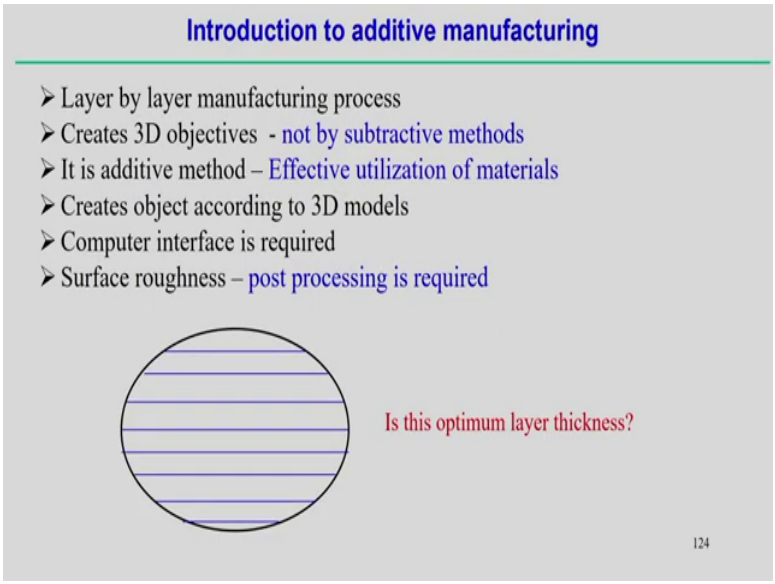

So, we can see that its simply additive manufacturing technology is simply layer by layer manufacturing process that is well known fact. And it finally, creates the 3 D objects and not by the subtractive materials rather, by depositing the material under different way it is a control way basically.

And it say additive method so, effective utilization of the raw material. So, wastage of the materials can be minimized which we normally observed in case of machining process, or other manufacturing process. And its creates the object according to the 3 D models.

So, before starting up the process and or layer by layer deposition it is necessary to create, the 3 D object CAD model of this 3 D object. And then, the slicing of the object is also required such that slicing will decide what maybe the in a particular when we are depositing the layer, what may be the layer thickness in a particular process.

And of course, computer interfaces requires tools get the or to develop this process. And sometimes after layer by layer deposition process, it is quite possible the surface roughness add may not be as smooth, as compared to the once other processes other conventional technologies. So, that can be one limitation of the additive manufacturing process. So, therefore, some sort of surface finishing or machining is required to get the desired shape

But, if we use the powder base most of the powder base technology and maybe depending upon the what is the powder particle size. So, surface finish is appears, but sometimes it may not be required the surface finish operation. But, if we look into the wire additive manufacturing definitely, we need to go for some machining process to get the desired surface finish for a particular product.

We will see one by one. Now, if we look into this figure so, if we want to get this kind of the shape 3 D object maybe oval shape. So, then what way we can create this 3 D object by layer by layer deposition process. And of course, we can see that we deposited the several layer. So, we divide this from the figure it is very clear, that several layer has been created thickness of the layer.

But, if we particular design if we decide that layer thickness. And now, if we deposit first layer, then second layer, then third layer is that possible to achieve the what are the surface finish you are achieving in this in a particular oval shape. I think the this depends on the how

close we can reach to the surface appearance, what is exactly figure it is showing. Then, in that case the layer thickness would be very small ok.

And then of course, if we want to compromise the surface finish, then maybe layer thickness can also be increased. So, depends on this requirement, but finally, we need some sort of surface finish operation apply to get the smooth surface appearance of 3 D object created by layer by layer deposition process.

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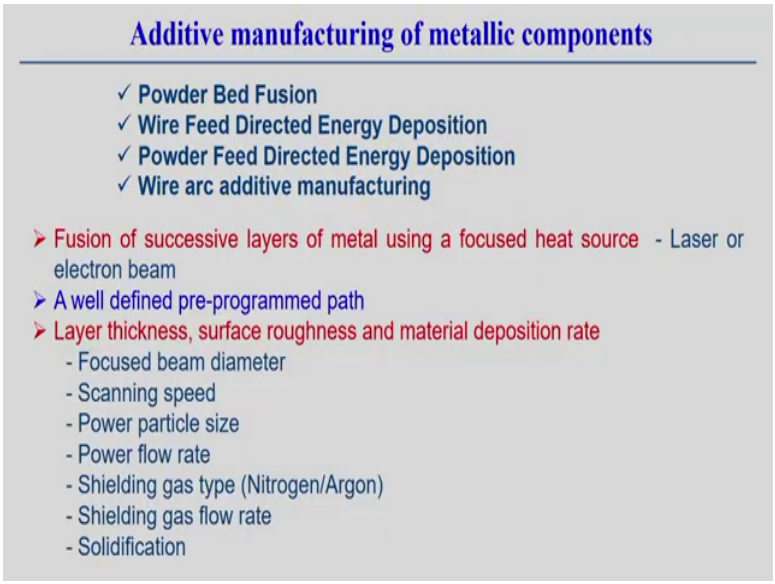

Now, if we look into in simply the additive manufacturing of the metallic component, normally there are four system can be used in general. One is the powder bed fusion powder bed fusion can be used then, wire feed directed energy deposition. Then, powder feed directed energy deposition and sometimes its a variant of these things wire feed directed energy deposition, that can be the wire arc additive manufacturing process.

So, in this case powder bed fusion means its a simply over a particular bed. The over which there is a layer of powder. Powder is already the particular thickness layer its already there. Now, what happens? In this case we can move the laser according to the move the laser according to the geometric shape and size of the object.

Then, at this particular through which the laser has been scanned, at this particular point the powder will be fused and at the same time solidify.

So, remaining will be there in the form of a powder. Then, once we deposited one first layer, then it just lift this first layer. Then, we fill the powder in for the next layer then we follow the similar procedure, then next layer will be deposited. And that is deposited thickness what will be the width and the thickness, it entirely depends on the strategy we want to follow develop particular 3 D object. And that is called the powder bed based fusion.

Then, wire feed directed energy deposition; that means, directly wire can be used, and then wire can we melt, and then this wire can be deposited in the different way. And, there are several way that which cases the fused deposition modeling can work in this cases.

Next powder feed directed energy deposition. In this case powder is not exactly keeping on the bed rather; powder can be through this through some nozzle. Powder can be projected in particular position and at the same time, at which position power is focusing and the same positions laser source can also be focused.

Such that the at this focal point with the application of the laser the powder can be melt, as well as they deposited on the substrate material. So, that is the principle of the powder feed directed energy deposition. Now, there is wire arc additive manufacturing process is simply means that, we use the simply the welding process. So, welding process, which is associated with some kind of the material deposition. For example, gas metal arc welding process.

If, we know the principle of the gas metal arc welding process so, that is simple gas welding arc welding process principle the material deposition process can be controlled or may be

automated this process. Such that it can be used for the layer by layer deposition of the metal and the 3 D object can be created by controlling the gas metal arc welding process.

So, therefore, fusion of the successive layer of metal using the focused heat source, laser or electron beam is the most widely used. And this laser source and electron source, and this is normally used in case of the powder based technology. So, to fuse the powder this laser or electron beam can be used.

Well defined pre programming path is required. Actually once laser can be very precisely controlled maybe focused in the very small even, less than 200 micrometer focused beam diameter can be created by using the laser. So, therefore, laser path has to be well defined pre programming path is required, that is why I am telling in that way. That that path can be well defined, such that the repetitive way the laser can be scanned in the particular path within the bed and such that 3 D object can be created.

It means that before we have to create the object file we have to create the data before start of the actual process. So, it is like that only first we have to create the 3 D model of a particular component, if we want to produce that object. Then, next step will be the following the slicing; that means, we decide the what will be the thickness of these things.

Then, suppose there are several slicing several thickness and each and every layer can have some different path, depending upon the shape and size of the object. And then this all information has to be pre program, and such that laser will be move according to the pre programming paths. Now, if we look into this process the layer thickness, surface roughness and the metal deposition that it depends on the so, many parameters.

So, once is the fused focused beam diameter what is a laser focused beam diameter. Second is the scanning speed what may be the speed, accordingly what will be the energy required per unit length, will be decided what is the laser scanning speed. Powder particle size, whether it is very bigger size, smaller size or some optimum size is required such that it will be able to melt, this particular powder.

And at the same time the powder particle size is very small then, it is possible to achieve good surface finish also. So, therefore, it depends on the powder particle size.

Then, powder flow rate can also be what is the melting rate can be decided accordingly what maybe the powder flow rate, and that powder flow rate can be decided what is the power available by the laser also. That is also required shielding gas type; definitely powder has to be shielded when it is melting by using some laser. And maybe for example, in case of titanium alloy also, it is very much sensitive to the outside environment.

So, therefore, which purpose we use the shielding gas in a welding process the same purposes, we can use the shielding gas. Even in this additive manufacturing process as well nitrogen, environment, basically powder based wire technology it is normally produced within a closed chamber. So, sometimes this chamber can be filled with the some kind of the shielding gas, it can be nitrogen or under the environmental argon.

So, with the presence of the shielding gas the melting behavior or solidification behavior can be different, which is which normally happens in the presence of the in the open or atmosphere. For example, in this case the we use the powder bed based fusion at the same times powder feed directed energy deposition.

Powder feed directed energy deposition is a simply the welding process, simply we use the heat source and that is which part is melting that is surrounded by the shielding gas and that is comes through the nozzle.

That is the open system, but in case of the powder bed based fusion this everything bed is inside a chamber. So, there also the chamber is filled its basically closed system and chamber will fill with the some kind of the shielding gas. So, that is the difference between using use of the shielding gas, in these two particular technology or in the particular processes.

Then, shielding gas flow rate definitely shielding gas flow rate having some influence on the melting rate efficiency of the melting it depends on that. And finally, the solidification and

the behavior of the particular material and of course, the solidification time is also one of the important parameter, in case of 3 D manufacturing 3 D in additive manufacturing technology.

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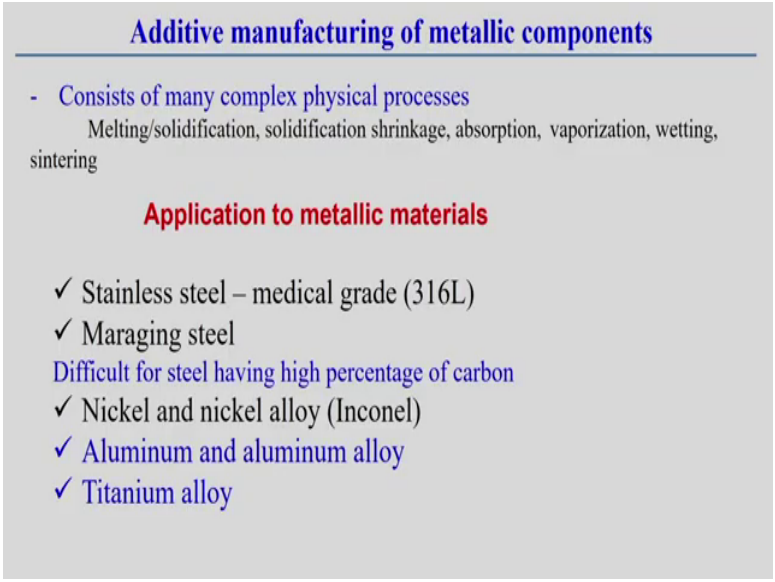

Therefore, its consist of the many complex physical process. If we look into the what are the physical process involved in the additive manufacturing process? One is the melting and solidification is there, then solidification shrinkage may be associated with this thing.

Because, we normally use the powder particle so, maybe associated with the its powder, when the even deposited as compared to the solid metal. When using the powder particles, it may be associated some amount of the shrinkage solid.

Once the solidification occurs then some shrinkage may produce. Absorption of the laser for a powder particle and absorption of the laser in case of simple laser welding, when the laser is

focus on a sheet it can be different. So, therefore, this is one of the parameter is involved there.

So, the absorption coefficient is maybe different in case of the when you handling the powder particles. Then, vaporization may also happens this whitability property, then what way the sintering happens with the application of the laser. All this parameters all this phenomena is basically involved in case of the additive manufacturing process, and when we use the laser as a source of the heat.

So, in this case the powder bed based technology is widely developed, now these things and application of the most of the metallic materials. For example, stainless steel and medical grade stainless steel; we can wide application of the powder based bed technology. Then, maraging steel we the powder based technology has been developed in case of the maraging steel, And, but difficulty for steel with the steel having the high percentage of carbon the metallurgical stability of the structure is maybe an issue, the carbon percentage is very high.

So, that is why most of the powder based bed technology has been developed with the steels, not having very low percentage of carbon or almost having no carbon percentage in this particular steel component.

Then, nickel and nickel based alloy has also been developed, this additive manufacturing technology and even for aluminum, aluminum alloy also and also titanium alloy. So, all this material the additive manufacturing technologies has been developed for all this kind of metallic material.

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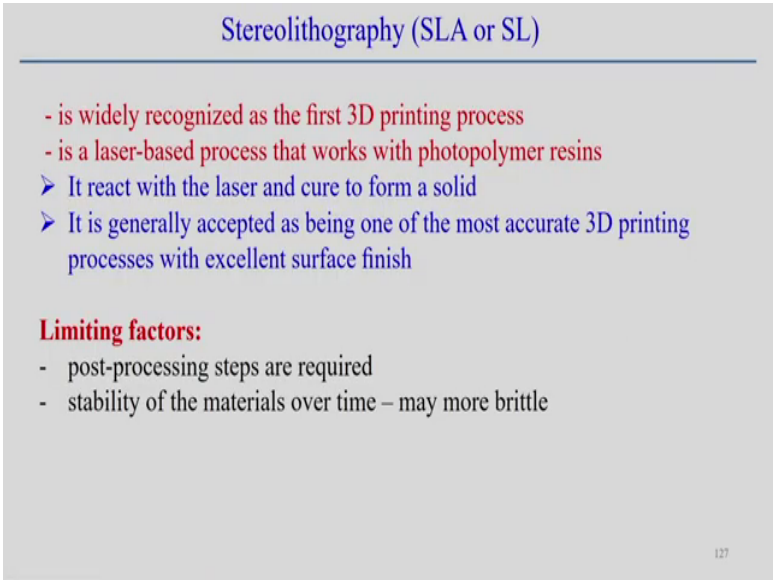

Now, we look into that process some idea about the different processes. So, we start with the stereolithography of course, the stereolithography is not exactly applicable for metallic material rather polymeric material. So, it is the widely recognized at the first 3 D printing process. And its a laser based system can be used process that works with the photopolymer resin.

So, once the laser is interact with the photopolymer resin, the resins becomes harder. So, at this part it becomes harder as compared to the this other part. So, it react with the laser and the cure to the form of a solid component, it is generally accepted as being one of the most accurate 3 D printing processes with excellent surface finish normally as it using the stereolithography. My limiting factor post processing steps are required because, which part is solidified which part is not solidified remaining.

So some sort of post processing is required in this cases and of course, since the curing of this material happens with the application of the laser. So, then stability of the material over a long time period may be an issue. So, with respect to time the materials becomes more brittle. So, that may be the one issue associated with the stereolithography process.

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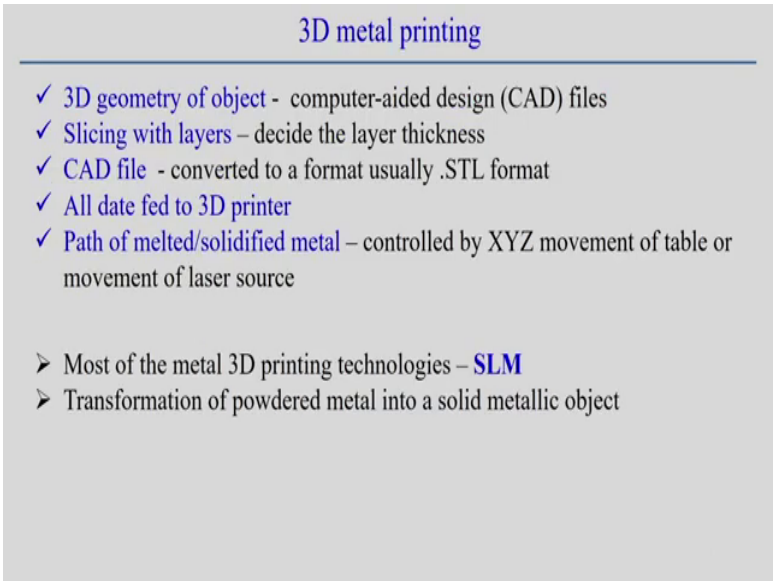

So, if we come back to this 3 D metal printing process, though it is specifically 3 D geometry of the object. We normally use the computer design, to design the particular object and CAD model has to be defined beforehand. Then, slicing with the layers we decides the layer thickness, these are the steps associated with the metal printing process. Then, generate the CAD file its converted to a format usually in the dot STL format. So, once from the CAD file, after slicing the layer we generate the dot STL format file.

Now, this file format has to be fed to the computer which is basically handling or basically controlling the printer. So, all data fed to the 3 D printer, which is simply basically with the computer interface required at this point. Then, once we get this data then path of the solidified metal has to be decided here, and this path has been controlled by the XYZ moment of the table or movement of the laser source. It sometime we can use the robotic arm also, to control the movement of the laser source.

So, that is somehow XY 3 D movement of the source is required, either we can move the source by using the robotic arm, laser source or lasers that can be keep fixed simply the we can use the XYZ table. So, movement in the XY and Z direction is possible to do these things. And sometimes we can use additional degrees of freedom, simply rotation of a particular axis can also be added.

So that will bring the flexibility now with the rotational degrees of freedom, as well as the linear movement of in three direction XYZ can bring the flexibility of a 3 D system. Most of the metal 3 D printing technologies has been developed following this thing selective laser melting technique. So, selective laser melting technique is that its a simply the at the selective position, a laser is follow some scanning path. So, its a selective position the laser used it and it melts the substrate material.

So, that is the principle of the selective laser melting. So, it simply transformation of the powder metal into a solid metaling material, through the once the powder has been melt, then it solidify it becomes a solid metal and solid object is created. So, selective laser melting is the well established for metallic component. And of course, it use the powder based technology.

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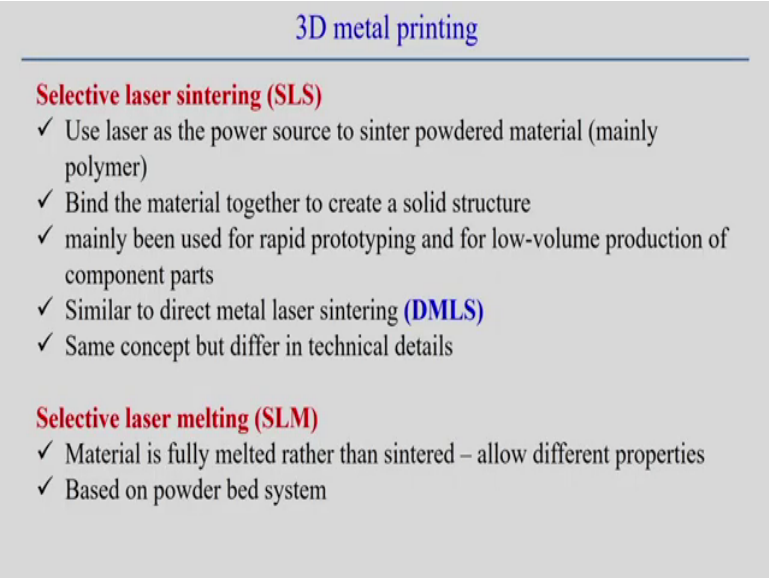

And we can see and we can make some overall idea of the different additive manufacturing technologies. One is the one is the selective laser sintering process. So, in selective laser sintering process, we use the laser as a power source and to sinter the powdered material. Mainly the polymer actually the laser selective laser sintering, it is the simply user scanning this laser is a selective position. And this selective laser sintering is normally mostly applicable in case of the polymeric material.

And bind the material together to create the solid structure with the application of the laser by in the principle of the sintering process. Mainly been used for rapid prototyping, if we want to make a object. And for the low volume production of the component parts, its a low volume where precision is required in this cases we can use the selective laser sintering process.

Similar to the direct metal laser sintering, its the same its the similar to the direct metal laser sintering process, but same concept, but different in the technical details.

So, direct metal laser sintering process is different with respect to the selective laser sintering process. We will see the basically direct metal sintering and the selective laser sintering having some differences, we will discuss on. Similarly sintering the following the sintering principle, at the same melting principle cannot same for; that means, simply melting the powder. So, that is called the selective laser melting, at the selective position laser melt the powder.

And thus in this cases its a uh metal is fully melted rather than the sintered and allow different property. So, as compared to the sintering instead of sintering the metal can be allowed to the completely melting all this thing. And based on the powder bed system; powder bed system means, in this case the powder is basically predefined layer thickness powder is deposited on the particular bed. And then, we use the at the selective position with the scan the with the laser light so, that laser light melt the substrate material.

And this is the this happens and the since once one layer is formed, then we focus for the next layer by filling this zone by using a powders. This is simply called the powder bed based technology. But, it use the selective laser melting technology, it is called the SLM techniques.

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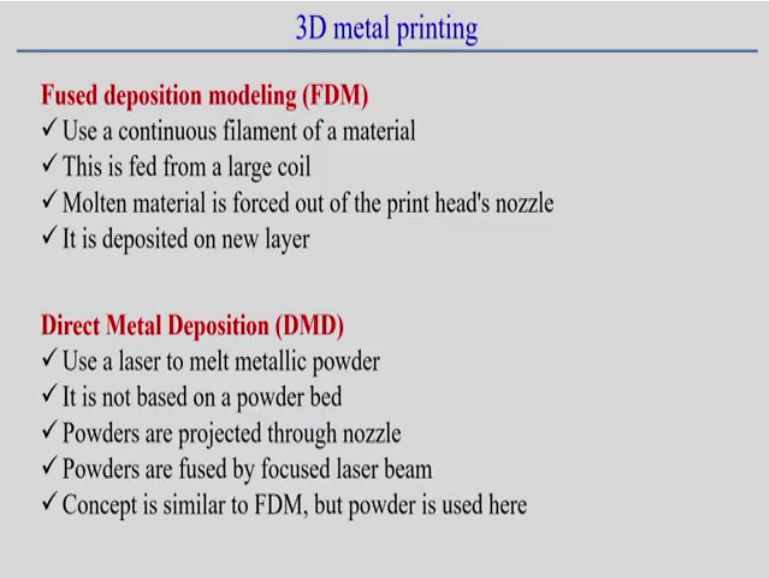

Similarly, fused deposition modeling can also be used in this cases continuous filament of the of a material particular. And this is fed from a large coil, and molten material is forced out of the print heads nozzle, because at the nozzle. Normally heated in such a way that it just melt, and then molten materials come out this thing and deposit on the substrate material.

And it is deposited on a new layer so, layer by layer deposition can be followed in this thing by moment of this nozzle. So, in this case some material the some coil of the materials should has to be used in this cases. So, that continuously feeding of the material is possible. .

So same thing we normally follow in case of the gas metal arc welding process, but it is called the fused deposition modeling. Because, in this cases about to just melt the substrate material, and not much without much superheating of this particular material and it deposited.

Because, actually fused deposition modeling is most widely developed in case of polymeric material.

Now, direct metal deposition in this case the use a laser to melt the metallic powder, but instead of using some kind of the powder bed based system. Its a we can use the powder can be kept in particular chamber, and from that chamber the supply the powder along with the shielding gas. And that powder is projected in a on the substrate material, at which point it is powder is projected at the same point the laser can be focused, such that laser can melt the substrate material and this substrate material deposited on the subs layer.

So this is called the direct metal deposition, use laser to melt the metallic powder it is not based on the powder bed, it is not required in these cases. And powder are actually projected through the nozzle, and powder are fused by the fused laser beam. Concept is similar to fused deposition modeling, in this cases the powder is used instead of the solid wire in this in this particular process. So, that is um; that means, in case of direct metal deposition process.

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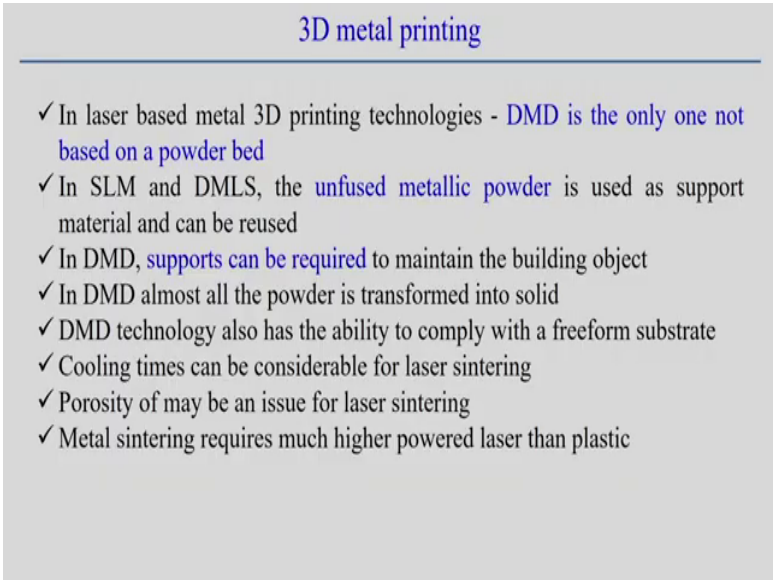

Now, in the laser based 3 D metal printing technology, in this case DMD is the only one are not based on a powder based. That means, direct metal deposition technology which is not on the powder based bed technology. In SLM selective laser melting, similarly and D DMLS direct metal laser sintering, the unfused metallic powder is used as a support material and can be reused.

That means, in this cases selective laser melting over a powder bed based technology, the we use the selective position in the melter and remaining powder act as a support. But, that can be reused for the deposition for the next or successive layers also. But, in DMD direct metal deposition, supports can be required; that means, once you develop buildup from the one particular object depending upon the geometric shape of the object. Some sort of supports can we start its at least it should be start from the base.

So, it means supports are required to maintain building the object. In DMD direct metal deposition almost all powder is transformed into the solid, but of course, some powder can be lost during the when powder is project in particular zone, and some powder maybe losing. But, as compared to the powder bed based technology, this direct metal in case of DMD the requirement of the powder at a time is less.

Because, in powder bed based technology you have to fill the bed beforehand. Even you are not using this powder, but selective position all you are melting. But, we have to fill this chamber; that means, we have to bed fill the bed, which is unused powder required is more in this cases.

DMD technology also has the ability to comply with the freeform substrate, it means that even if we look into that selective laser melting or selective laser sintering, which is developed under the close chamber. In the powder bed based technology the size of the component is is particularly limited to the size of the chamber. But, in case of DMD its open system and like welding process, it is open system.

So, it can it can move in any direction any object its not having size limitation because, it is not its we will not be develop in a close chamber in this direct DMD technology. Cooling times can be considerable for laser, there is one important parameter the cooling time in case of laser sintering process. And porosity maybe one of the issue in case of laser sintering process, but optimum set of parameter which is required to reduce the porosity formation in the sintering process.

And metal sintering requires much powder, much power laser than the plastic. Of course, if we sinter for the sintering principle in case of the metallic powder. As compared to the plastic, component of polymeric material the metallic powder require the much more laser power. Even, if we follow the sintering process.

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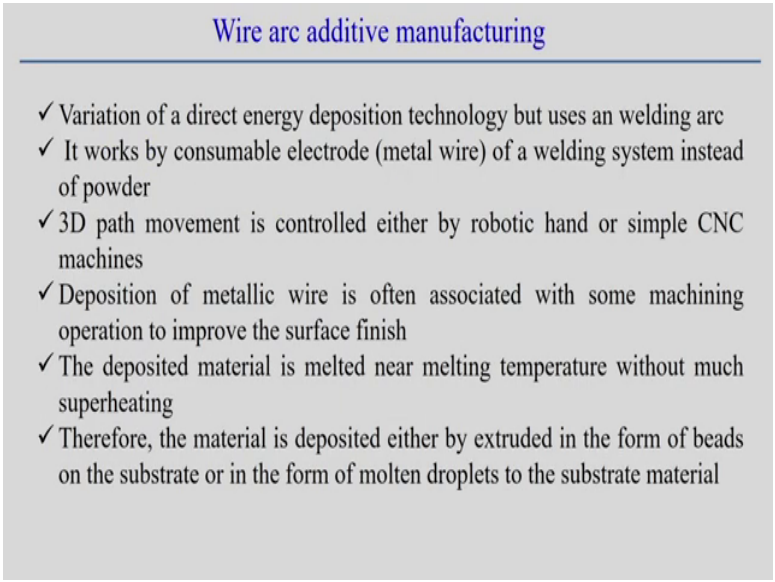

Now, we come to that apart from the laser based system. Because, laser based system mostly developed and so, many developments normally happens, even nowadays its possible to produce very precisions small component. Normally we produce using the and powder bed based technology, using the powder and laser as a source or sometimes we use the electron beam as a source, that technology has been developed.

Now, point is that in case of the wire additive manufacturing process, which is normally follow the principle of the welding process. And it is having some advantages as well as the limitation, we will see how it is different from the powder based technology. Variation of the direct energy deposition technology uses, but uses an welding arc. Definitely direction which is deposition what principle we follow direct energy deposition using the laser is focused on a particular zone and the powder is melt.

So, here instead of powder we use the solid wire and that is the that we use in case of which is similar to the welding process, like gas metal arc welding process. But, in these cases we use the welding arc; normally in this cases there is a necessary to use the welding arc. It works by consumable electrode or consumable electrode, mainly the metallic wire metal wire of a welding system instead of the power that is true in case of the wire arc additive manufacturing process.

And 3 D part movement is controlled either by the robotic arm, or some CNC machines or some XYZ table; it will be control the 3 D moment of the welding torch in this case. Or either welding torch can be moved or substrate metal over which the material is deposited that can be moved in this particular process.

So, deposition of the welding wire is open associated with some amount of the machining operation to improve the surface finish. So, in this case so, metallic deposition of the metallic wire is, what kind of the geometric say it will produce. And, if we look into some edge or surface appearance. So, if we compare the surface finish as compared to the powder based technology, definitely we cannot achieve that much of surface finish even if using the metallic wire when it is deposited.

So, therefore, mostly it is associated with some sort of the machining operation, in layer by layer deposition process by using some kind of the welding arc. Therefore, the deposition metal is melted, near the melting, melting temperature without much superheating that is the most desirable, then if we want to control the deposition of the molten wire.

So, its as much as close to the just to reach the melting point then, it will be more controlled deposition can be done, rather than superheating of the material. Once the superheating of the material is; that means, too much of superheating of the welding material is happens. Then, it will be more difficult to deposit the wire to control the bead geometry, in this particular process.

Therefore, the metal is deposited either extruded in the form of a beads on the substrate; that means, extruded we simply extruded just melt near the melting point. And then, try to extruded it and deposits it this on the substrate, or just clear the molten droplets of the substrate material. Both are possible where molten droplets, it will be more the deposition might be more controlled in this particular additive manufacturing technology. If, they just melt the substrate material without much supporting.

The wire additive manufacturing process, the benefits and limitation we can see in this way that. Suitable for manufacturing large scale metallic parts and components definitely, if we want to produce very large scale component then wire arc additive maybe more beneficial, in the in terms of the cost saving also.

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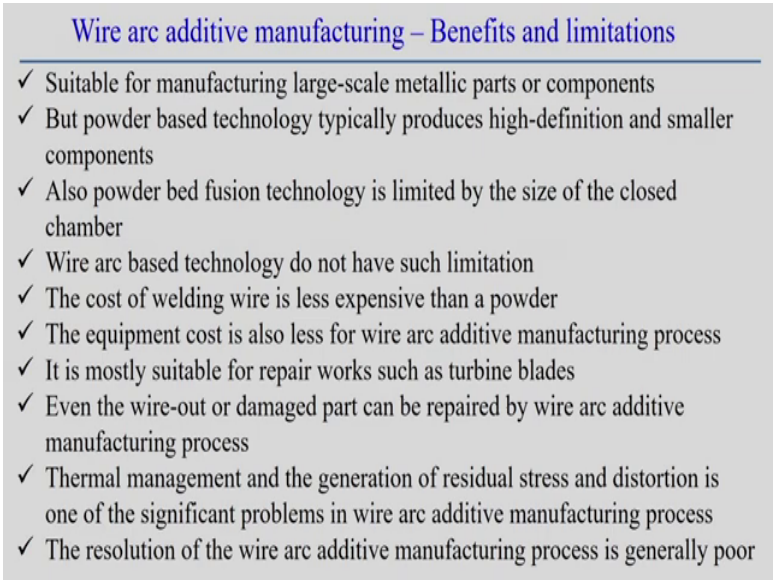

And, at the same time powder based technology typically produce the high definition and the smaller components, see if there is a small components and high deficient, very precision and costly equipment is required. In this case the powder bed based technology, powder based technology is more suitable in this case.

Also powder based technology bed fusion technologies also limited the size of the chamber that is also one limitation of the power based technology. Because, this complete buildup is normally happens within this close chamber.

So, in this wire based technology not having that kind of the limitation. But of course, the if we look into the cost also. The cost of the welding wire is less expensive than a powder of the although the material may be same. So same material, but in the form of a wire available in the market is less costlier than the material in the form of a powder.

So, at the same time the equipment cost of a welding is well established process the equipment cost for the is also less for wire arc additive manufacturing process. Because, equipment its a simple welding machine is not much costly arc welding machines. For example, in gas metal arc welding process, but if we look in some laser based, additive manufacturing, or machines then the equipment, then it is more much more costlier as compared to one simple welding machines.

That is why it is mostly suitable for repair works, they may additive arc based technology wire arc additive manufacturing technology, is most suitable for the additive work. And most quickly we can find out for repairing of the turbine blades. Even the wire out or damaged part can also be repaired by the wire arc wire arc additive manufacturing process.

If there is a requirement of the high material deposition, is there associated in a requirement in a particular process, then we can go for the wire arc additive manufacturing process. But, difficulty is the thermal management, some sort of distortion generation and the residual stress can be an issue, in case of wire arc additive manufacturing process. Even that is also issue in even in case of the simple welding process also.

So, that may be the significant problem. So, thermal management distortion management, as well as the residual stress reduction of the residual stress can be one of the most important area to work, in which associated wire arc additive manufacturing process.

Finally, the resolution of the wire arc additive picture which is developed, the printer based on the wire based technology. The resolution cannot be as much as compared to the powder bed based technology. It means that wire arc wire arc additive manufacturing process the resolution of the printer will be very resolution can be very low. It means the surface finish operation is requirement of the surface finish is much more, in case of the wire arc additive manufacturing process. .

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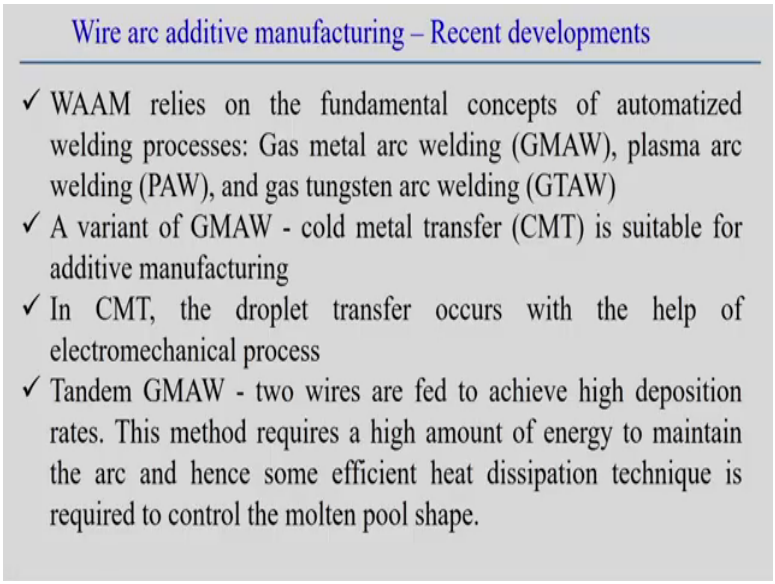

Now, recent development using the wire arc additive manufacturing process, we can see that we know are familiar with the different welding processes. But, that can be converted to or

the people are trying to look converted to into the wire arc additive manufacturing technology.

So, wire arc wire arc additive manufacturing technology actually rely on the fundamental concepts of the automatized welding process. So, what way the automatic welding process can be done, its rely the development of the wire arc actually depends on that also.

And, we know then some knowledge about the automatic process in case of gas metal arc welding process; even plasma arc welding process and gas tungsten arc welding process can be used. Simple, but in this cases gas metal arc welding process the material deposition is the integral part of the system.

But, in case of plasma arc welding process and GTAW process, there is a need to externally supply the material to melt the material and then it can be used. So, in that sense it is better possible to develop the technology using the gas metal arc welding process, because the metal deposition itself with the integrated system. But, apart from that a variant of the GMAW that is called the cold metal transfer is one of the suitable method for additive manufacturing process in these cases.

The CMT the droplet transfer is the more controlled way can happens, with the help of the electromechanical process. So, digitally possible to control the material deposition using some mechanical means, by means of mechanical system. It is associated with the cold metal transfer process. So, that is why even CMT technology has been used more, nowadays in my opinion the CMT technologies are more suitable for the development of the wire arc additive manufacturing technology, as compared to the simple gas metal arc welding process.

We will see that what are the advantages of the CMT in the later stage also? Apart from this in tandem GMAW; that means, two wires are fed to achieve the high deposition rate. But, this method requires the high amount of the energy to maintain the arc, the several issues and some efficient heat distribution technology has to be understand in this particular process to control the molten pool shape.

So, that is are the difficulty in case of the two wires are fed. The but, people are trying to look into this if one by simply with the aim to enhance the high deposition rate, two wire tandem GMAW can be used in case of the wire arc additive manufacturing technology.

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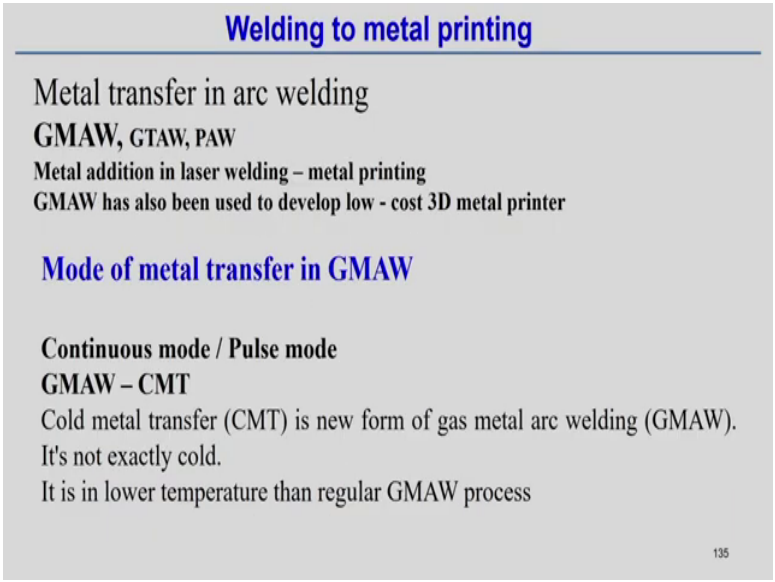

Now, welding to metal printing there is a link between the welding to metal printing technology in that way. So, to some extent we have I have discussed, but apart from that, metal transfer in arc welding process normally we have already seen the GMAW, GTAW, plasma arc welding can be used. Metal addition in laser welding can also be used, in this cases in the metal printing and instead of powder. The solid, solids wire can also be used, but in the heat source can be in the laser can use at the heat source to melt the solid wire that can also be used.

But, I am just trying to look into that GMAW has been used and people have developed the low cost, a metal printer using the symbol GMAW process gas metal arc welding principle I will see. But, in this cases it is necessary to understand what are the mod of metal transfer is very important, to develop the wire arc additive manufacturing technology.

Both continuous mode as well as the pulse mode technology can be used in case of the wire arc additive manufacturing technology. And here, we can use the CMT can be used from the variant of the GMAW process. But, in this case CMT is called the cold metal transfer, is now new form of the gas metal arc welding process, but it is not exactly called. But, metal transfer happens at relatively low temperature, what we see in case of the gas metal arc welding process. That is why it is name is like that cold metal transfer process.

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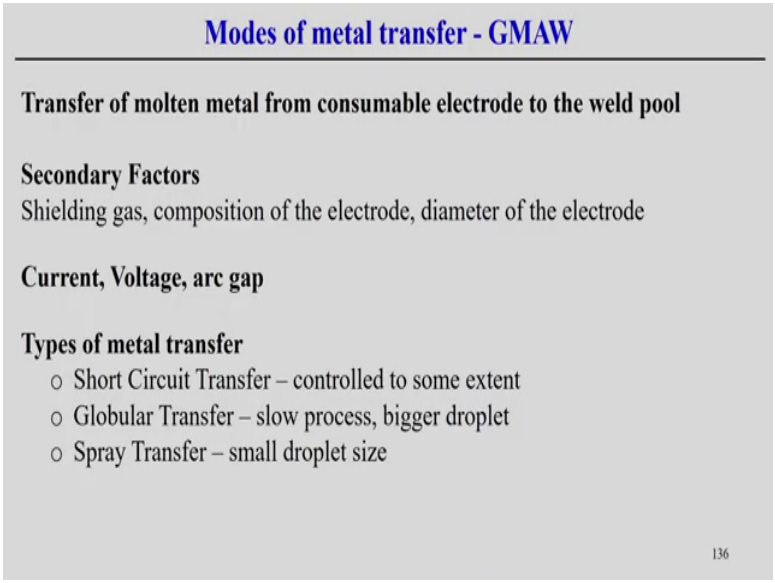

Now, definitely wire arc additive manufacturing technology the transfer of the molten metal is normally happens from the using the consumable electrodes. And, there is a need of continuous supply of the electrode. And it forms the weld pool also, what way the gas metal arc welding works.

So, apart from that there are secondary factors. So, definitely the in welding technology there are primary factor the arc, voltage that means, current all are important. That means, mainly the arc gap voltage and current mainly these are the parameters. But, apart from the secondary factors such as shielding gas composition of the shielding gas, and mix whether there is any mixing of the shielding gas and the composition of the electrode material, and the diameter of the electrode all this matters.

The secondary factor that actually influence the efficiency of the wire arc additive manufacturing technology. So, types of the metal transfer is normally associated with gas metal arc welding process, this was short circuit metal transfer, controlled to some extent, globular transfer that is a very short slow process and bigger droplet, which is more than that of the uh electro diameter is possible in globular type of metal transfer. And spray type of transfer the small droplet size, but its can spatter near about this one.

So, therefore, its not necessary all type of metal transfer is exactly suitable in case of wire arc additive manufacturing technology having. So, short circuit transfer maybe to some actually it is control the metal transfer. I think its my opinion it may be more suitable in case of wire arc, for the development of the wire arc additive manufacturing technology.

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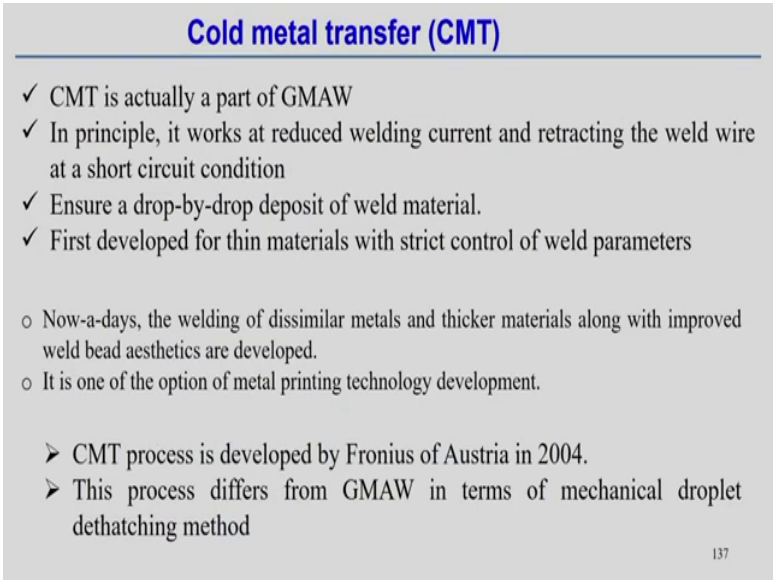

Now, cold metal transfer is one of the most significant important in associated with the wire arc additive manufacturing technology in this cases. It is actually part of GMAW process in principle, it works the reduced welding current. And retracting basically once the droplet has been kept in melting in the what if the retracting the electrode, mechanically which is by some mechanical means.

And, retracting of the electrode at the short circuit condition, it is basically helps to transfer the droplet to the substrate material. So, that ensure its a controlled way drop by drop metal transfer to the weld material. Even, first developed for the thin materials with the strict control of the welding parameters is normally developed.

But, now a days the welding of the dissimilar materials, even for very high thickness material with the improved weld bead aesthetic; aesthetic that means, its a controller metal transfer the

it is weld bead aesthetics has been developed using the CMT technology. Therefore, its one of the good option for the development of the metal printing technology using the CMT process, and actually CMT process is developed in the Fronius by the Fronius group of Austria 2004.

And of course, this process differs from GMAW in terms of the metal transfer. Because, in GMAW process the metal transfer happens, not by any kind of by not using any kind of the mechanical moment of this wire. Rather the metal droplets, droplet transfer with the process associated with the optimum set of the process parameters.

But, in case of CMT technology that some sort of mechanical movement of the wire is required. And, its a very controlled way such that droplet can be transferred more smoothly to the surface material and with the high frequency also.

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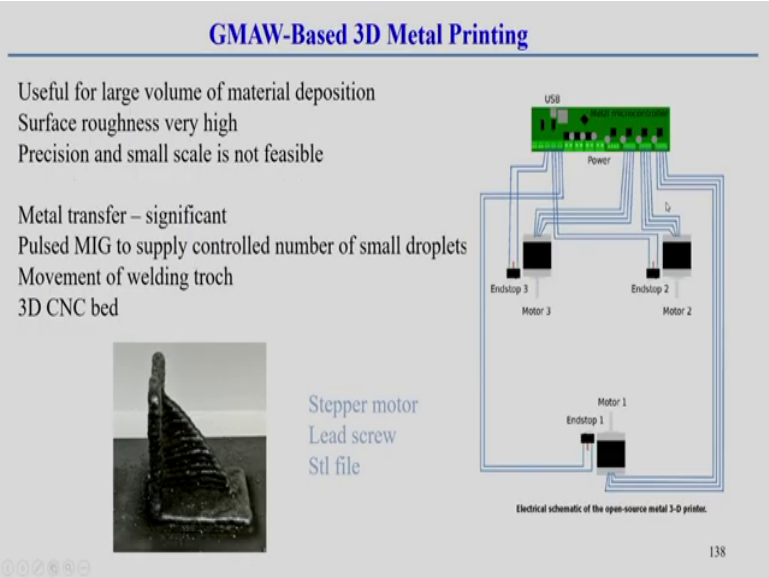

But, it is possible to develop in general, the metal printing technology using simply I am talking about the gas metal arc welding process. Here, you can see the that GMAW process is basically useful for the large volume of the material deposition, surface roughness is very high.

So definitely some sort of the machining process is required, but its most suitable if we if in case of large scale application. If we want to very larger scale, you want to produce some kind of the product by layer by layer deposition process. Then, this GMAW processes or CMT process is most suitable. But, in this case the metal transfer is very significant to understand the what way which mode of the metal transfer is required, for the development of the metal printing that is the most important parameter has to be look into that.

ah Even most continuous mode as well as even pulse MIG supply means or GMAW process can be used. Because, pulse can be used to some extent to control, the metal transfer or droplet transfer, to the substrate material. Therefore, the possibility or suitability of the pulse mode of the pulse current is basically suitable in case of the metal printing technology.

And the 3 D movement of the object can be done by simply developing some kind of the XYZ table, or we can use simply using the CNC machines to control the movement of the either welding torch or to control the moment of the substrate material both it is possible.

So is its a simple way, it is possible to develop some kind of the um metal printing that XYZ table in this moment of these things simply by using some stepper motor lead screw. And stepper motor lead screw, the XYZ table can also be developed and which is can be controlled is be controlled. Here, you can see the there are 3 stepper motor can be used, for one for X moment another for Y Z moment.

And this its possible so open source softwares also available. So, using their by using this open source software and is simple using the stepper motor and the lead screw, it is possible to develop the complete setup of course, some computer interface is also require, to control

the movement of this stepper motor. So, this is the simple way the 3 D metal printing or metal technology can be developed using one gas metal arc welding machine.

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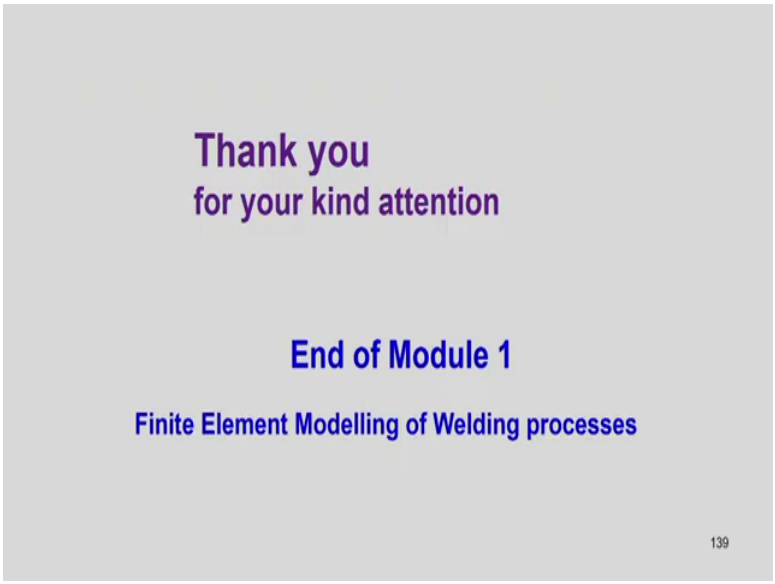

So, with this I just this is the end of this module 1, and uh I hope we have discussed the several aspect in the module 1. And, basically we have try to understand the basics of the different welding process, to touch upon the different sides and of the welding process. And may be all this to overall idea of the all the different kind of the welding process will help, to develop the mathematical model, to develop some kind of finite element model.

So, thank you very much for your kind attention.