**Advances in Welding and Joining Technologies**
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**Lecture - 23**
**Metal Transfer in Welding and Metal Printing**

Good morning everybody. Today, we will discuss last module of our course advances in welding and joining technologies. So, we will see what is in the last module.

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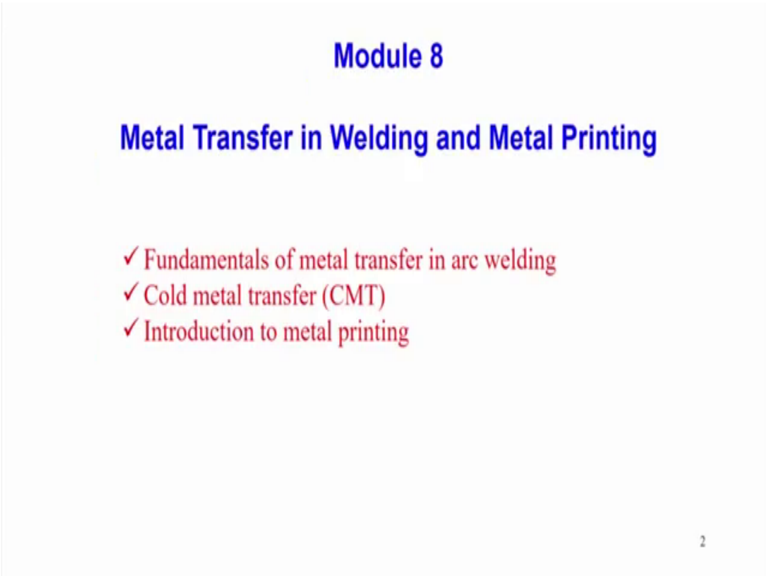


So, this is related to metal transfer in welding and that how this welding process can be link with the metal printing process, which is one of the most significant manufacturing process is nowadays. It is also called the additive manufacturing as well, but we will try to focus on the very basic parts of additive manufacturing processes in this module.

If we see before start of this module in details we have the subsections of this module is the; first is the fundamentals of metal transfer in arc welding process. Second one is the cold metal transfer, which is also one of the recent development technology and that very much related to gas metal arc welding process.

And then finally, introduction to metal printing or we can say that additive manufacturing process and very specific to metallic materials not for the polymers or polymeric materials. So, first we will start with the fundamentals of metal transfer in welding processes.

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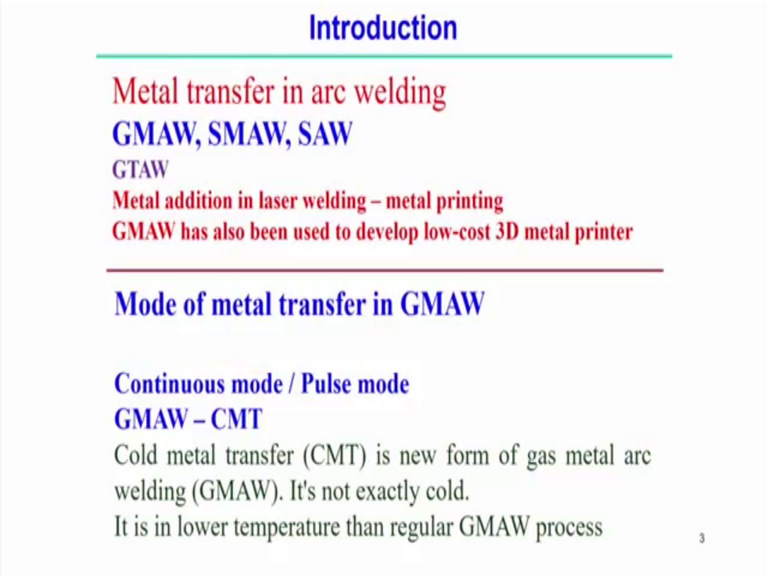


So, although we have covered in very few things in the very module one, that was the fundamentals of welding process, but we will try to recap all this metal transfer technologies or metal transfer techniques , specific welding processes here also.

So, metal transfer in arc welding process means we understand that the common or few conventional arc welding process. For example, gas, metal, arc welding process, shielded metal, arc welding process, submerged arc welding process. These all are related to metal transfer phenomena and all this processes actually uses some consumable electrode and then this consumable electrode or we can say integral part of the whole machine or may be within the system itself.

And apart from this common manufacturing processes, common welding processes, there is also a non-consumable electrode, we general use in case of gas metal arc welding process, but still we can analyse some metal transfer phenomena in case of gas tungsten arc welding process.

If we externally use some electrode material or may be some wire that actually fit with the process, in that case there may be some material deposition there, but normally we do not use. In the welding process the gas tungsten arc welding with some external additive kind of a material.

So, definitely in gas tungsten arc welding process along with the metal transfer actually, this metal transfer phenomena is happens externally and it is controls it in externally; such that its may not be the integral part of the whole system; like gas metal arc welding or shielded metal arc welding processes. Here we always need control the metal transfer externally. So, that is one aspect, but apart from that the metal transfer in welding processes.

If we look into just the similar kind of mechanisms; like for example, we use the metallic powder and we use the source of the heat as a laser, then that technology can be used in additive manufacturing process and that is that most of additive manufacturing process. Actually developed based on the laser wave based system where we can use some extra material addition to the system and that in the form of the powder or may be in the form of a, in the form of electrode wire.

So, that is the technology has been developed now, but till the mechanism of gas metal transferring gas metal arc welding process can also be used to develop the very low cost 3 D metal printing technology or we can say the material additive manufacturing process, but difference is that in gas metal arc welding process when we that metal transfer mechanism happens in such a way and the printing technology developed in such a way that, we may not achieve a very good surface finish as compared to what we can get or what we can expect in laser base system, where we use the extra fitting material in the form of a powder.

So, in that sense it is a different, is a laser base printing system as compared to the gas metal arc welding base 3D metal printing system, but still this technology not fully developed, till this technologies are evolving. So, our focus is to today is that first is the metal transfer in the welding processes, and this how this metal transfer actually help to understand the metal printing technology that nowadays it is a evolving gradually or very rapidly and old manufacturing system or technology, actually transferring from the old system to the new system. New system means the additive manufacturing process

So, now mode of metal transfer in gas metal welding, we have some idea from basic idea about the metal transfer gas metal welding processes and normally we use the gas metal arc welding processes that we use the continuous mode; that means, continuous current or sometimes we use the pulse current mode also. So, continuous current mode metal, transfer mode is well understood and lot of development also happens and still we are using mainly for the welding processes and we will try to understand this metal transfer mechanism in case of the continuous mode of gas metal arc welding process

But when we add pulse mode of current in gas metal arc welding process, there is a development or are as acts as a basis for the development of CM to that I called cold metal transfer technology. So, this CMT is basically well control metal transfer mechanism actually exist and we can say, it is a actually part of the gas metal arc welding process, but this what we are using here.

Cold metal transfer is not exactly cold process, but normally the metal transfer or mechanism actually happens as a very low temperature as compared to the conventional gas metal arc welding processes. So, that is why it is called cold metal transfer technology. So, we will see that in details about the CMT, and as well as the conventional metal transfer mechanism in gas metal arc welding process.

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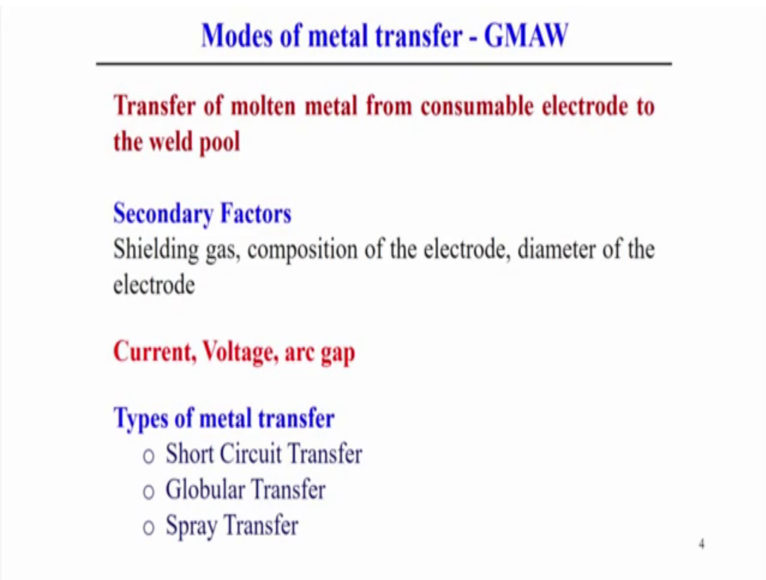


So, here if you see that modes of metal transfer actually happens in case of gas metal arc welding from a consumable electrode and mostly by using the continuous mode of current, but if we look into that what are the factors that actually influence the metal transferring gas metal arc welding process, apart from the primary factor, the secondary factors that actually shielding gas composition of the electrode material diameter of the electrode.

All actually decides the type of metal transfer in gas metal arc welding process, but of course, the primary variable or we can say the primary factors that actually responsible different type of the metal transferring gas metal arc welding process that actually the current; that means, what we are using the current or current density using during the process, either low current or high current, the metal transfer mechanism are different.

At the same time this low voltage, voltage low or voltage high that actually influence in the metal transfer and at the same time the arc gap; that is maintaining the arc gap between the electrode and the workpiece material, this also influence mode of metal transfer. So, these are the all primary variables; that means, current voltage and arc gap, but apart from this primary variable, the secondary variable also influence the metal transfer in gas metal arc welding process.

Typically, we know the three different types of the metal transfer. Of course, there is another metal transfer mechanism, just skipping that we have discussed in the very first module one, but these three make main metal transfer mode in gas metal arc welding processes are short circuit transfer, globular transfer and the spray, spray type of the metal transfer. We will see in details what is this type of metal transfer.

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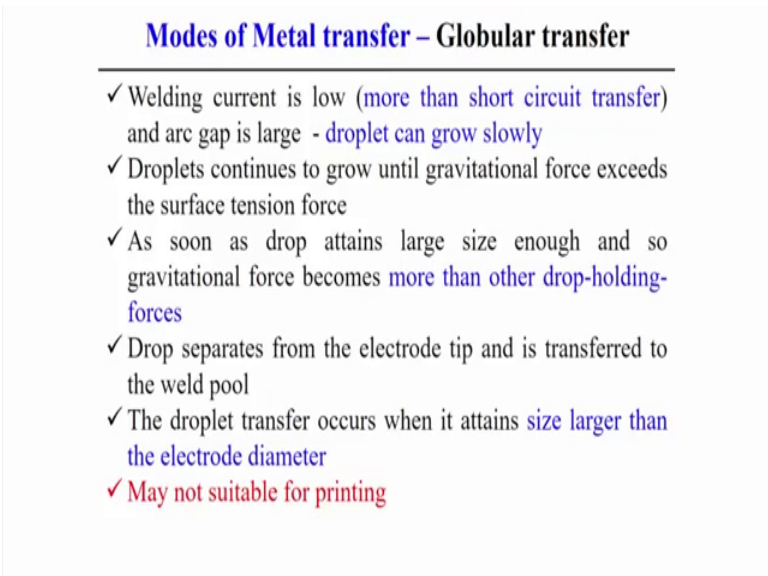


So, first is the globular transfer. Definitely the welding current is low, in this case the conditions required here and that welding current is, but more than that of, the short circuit transfer metal transfer cases and of course, the here the arc gap is very large; such that droplet can grow slowly and it can takes the size sufficient size; that is why arc gap is maintained and say relatively large in this case and once the droplet grows and sufficient size and then detach due to the gravitational force and when the, when the detachment occurs the, actually the gravitational force exceeds the surface tension force and then after detachment this becomes part of the molten pool.

But during the growing of the size of the molten pool, in this case the two different forces is actually acts; one is the gravitational force and another is the drop holding force in with this case, until when it gravitational force actually exceeds, exceeds the drop holding force, then detachment of the droplet actually happens from the electrode. So, once the drops separates from the electrode tip and it transfer to the weld bottle, then the repetition of the similar phenomena occurs.

So, in general, the droplet size, actually the diameter or we can say the size of the droplet is normally more than that of the electrode diameter, but of course, this type of metal transfer actually happens very slowly and of course, the size is bigger than that of the electrode. So, this type of metal transfer is may not be suitable for additive manufacture or we consider metal printing technology.

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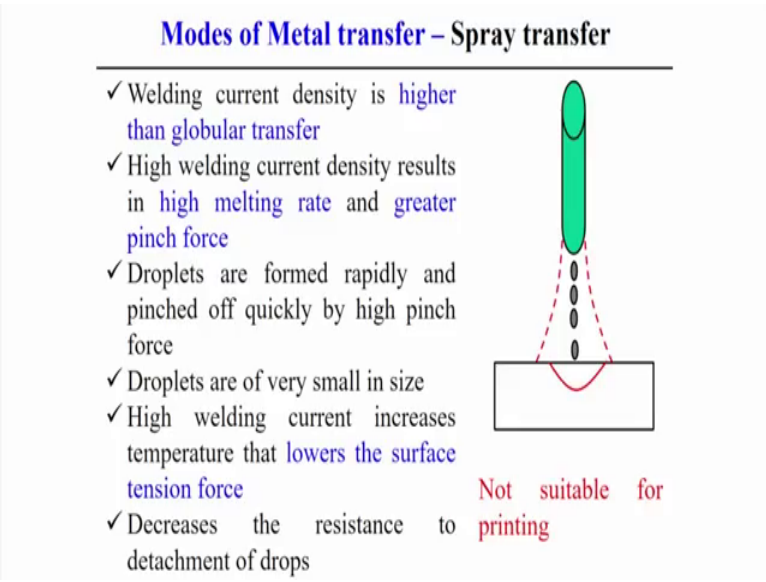


If you look into that another type of metal transfer; that is the spray type of the metal transfer and the favourable conditions of the, this type of metal transfer is actually happens, where welding current density is very high. And of course, this welding, current density is more than that of the globular type of the metal transfer. And since welding current density is very high, there is may be the formation of the several drops per unit time and we can say the melting rate is very high and it creates greater pinch force and such that, so many droplet us can be created and droplet us are forms very rapidly and pinch up quickly, by the high pinching force.

And since number of metal transfer and number of droplet is also very high, so size of the droplet us is very small in this case. And high welding current, actually if you try to explain the mechanism for that so high is, if high current density and may be regeneration of the increases the temperature and when there is increment of temperature that actually lowers the surface tension force, once lowers the surfaces tension force. So, there is a decrease in resistance to the droplet, to the detachment of the droplet

So, typical characteristics of this spray type of the metal transfer is the so many droplet us created per unit time, as size is small at the same time, it actually detachment also happens very rapidly from the electrode. So, this type of metal transfer is probably different from the globular type of the metal transfer mechanism, but still this type of metal transfer is may not be suitable for the printing technology.

Because in, when there is a spray type of metal transfer is more suitable to create, kind of wide profile of the, wide profile of the molten pool. So; that means, it is a very difficult to focus or concentrate or a very small part of the object. So, that is why it may not be suitable for the metal printing technology.

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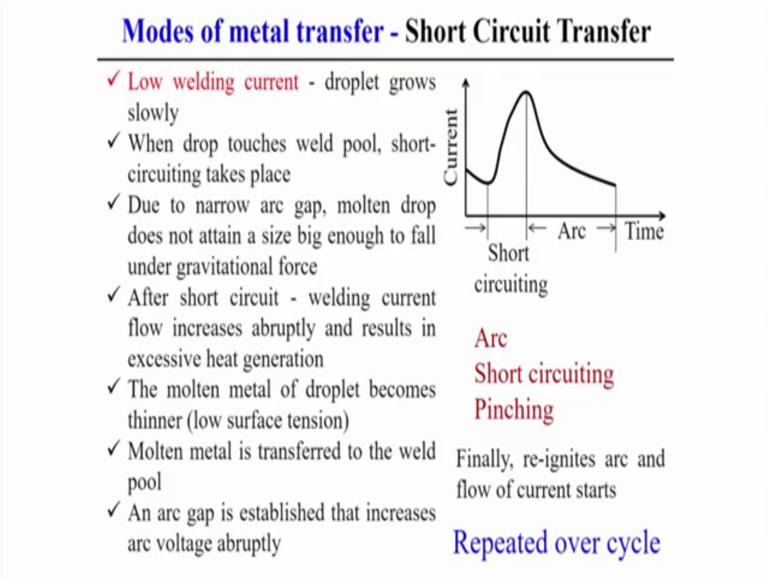


If you look into the other type of mode of the metal transfer; that is call the short circuit type of metal transfer technology. So, it is typical characteristic by the low welding current, droplet grow slowly and at the same time its, its control of the metal transfer is happens by a typical current versus the current versus time profile we can see in the picture.

So, first the when the, actually when the drop touches the weld pool that actually short circuit takes place. Now, when there is a short circuit takes place there is a reduction of the arc gap. So, therefore, molten drop not having the chances to grow or to maintain big size enough to fall under gravitational force. Therefore, once the short circuit happens, there is a incremental of the welding current abruptly, abruptly increment and that actually results in a very high excessive heat generation ah.

Once there is a excessive heat generation that actually lowers the surface tension force and droplet us becomes very thinner and detach from the electrode. And then molten metal is actually transferred to the weld pool, and once the that is a detachment of the weld pool, there is a arc gap. Again the there is a establishment of the arc gap and that increases the, again the arc voltage abruptly and finally, its again reignites the arc and the flow of the current occurs and this process repeated over cycle.

So, several times occurs basically during the cycle. So, this type of transfer is, this type of metal transfer we can see little bit control as compared to globular spray type of metal transfer. So, this type of metal transfer basically suitable for the metal printing technology

But overall if you see the phenomena of the metal transfer in gas metal in this short circuit type of metal transfer, is basically creates sequence of the creation of the arc short circuit, short circuiting happens and then pinching force and transfer of the metal to the work piece material. So, this cyclic order all this three phenomena, actually happens during this type of the metal transfer.

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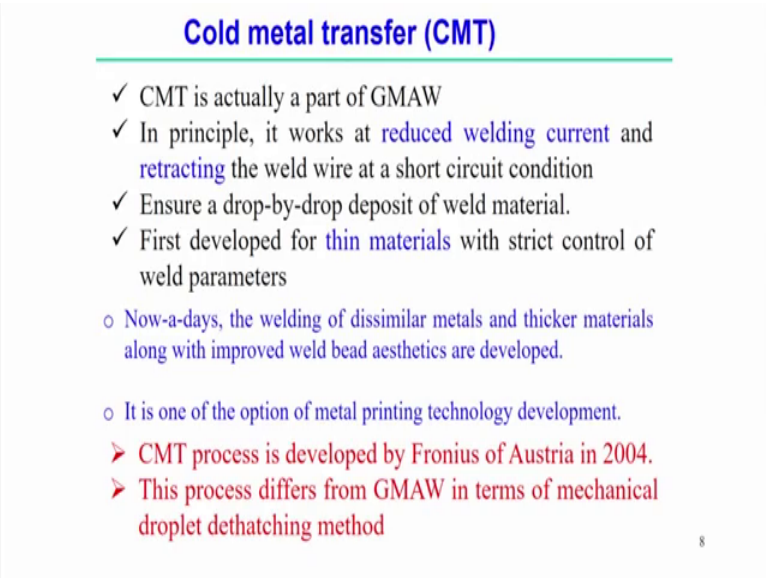


Now, we come ship to the that metal transfer that actually happens that is in. Its in case you can say that development actually occurs from conventional gas metal arc welding process to cool metal transfer, actually CMT; cold metal transfer is actually is subset we can say or a part of the gas metal arc welding process in principle.

It actually works as very reduced welding currents that we have observed in, which is the short circuit mode of the metal transfer and the mechanism is different in the sense that how the retracting the weld wire at the short circuit conditions. In that way it is different from the conventional metal transfer in gas metal arc welding process.

So, it actually ensure drop by drop deposit of the weld material and this type of metal transfer, actually first developed for the solving of the problems in the very thin materials and of course, thin materials, because in this case very strict control of the weld parameters actually happens.

But nowadays the welding of the dissimilar materials and very thick material and when there is a need of aesthetic part of the weld, will save in that cases the. This process has also been developed; that means, this cold metal transfer technology also has been developed, as well as the very thicker materials using nowadays, where using this technology for this two cases.

Since this is, this by this technology there is a well control metal transfer. So, it is more suitable in case of the metal printing technology development. So, base, this based on the cold metal transfer. Still there is a developing the different additive manufacturing technology by this process using the concept of the metal transfer in the welding process by using some consumable electrode.

So, actually this process cold metal transfer process is actually developed by Fronius of Austria in 2004 and this process differs from the GMAW gas metal arc welding process, is straightforward in terms of the how the mechanical detachment of the molten droplet occurs. So, in that sense it is different from the conventional metal transfer mechanism of the gas metal arc welding process. We can see in details that, what is the, what are the differences of CMT from GMAW process

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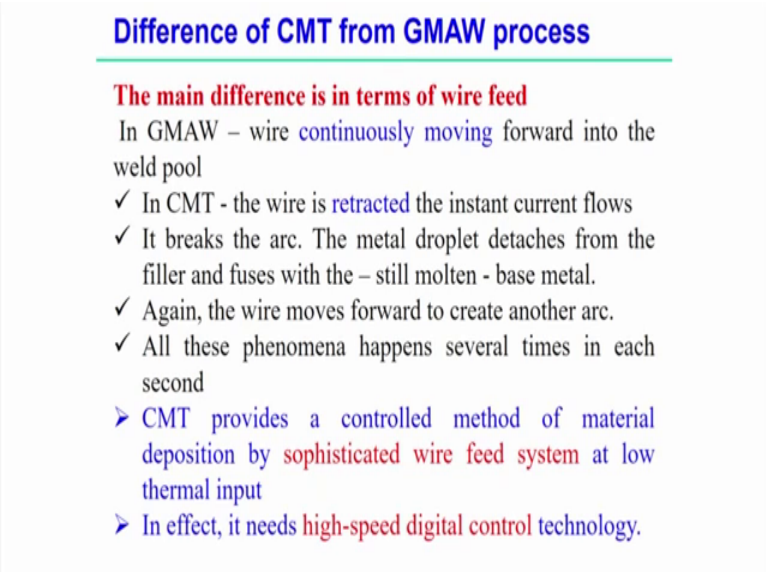


The main difference is in terms of the wire feed. Basically in gas metal arc welding process, there is a continuously feeding of the wire and that wire is always feeding in the giving the forward motion into the weld pool and accordingly there is a rate of melting occurs of the consumable electrode, but if you look into that CMT, the wire is actually retracted at some point of time and such that when there is a wire is retracting when is drawing back the heat breaks the arc and then molten metal droplet actually detach from the filler and fuses with the becomes part of the steel molten base metal

Once we detect, once this phenomena, once it one droplet is forms and detach from the electrode and becomes the part of the final weld pool again wire, actually moves to forward motion and to create the another arc. So, this, this phenomena, basically these two phenomena actually happens several times in each second or per unit time, several time this phenomena occurs. So, therefore, we can say in general that CMT provides a control method of the metal transfer or control method of the material deposition by a sophisticated wire feed system and of course, this phenomena happens at actually at very low thermal input

So, in effect high speed digital control technology is required to understand or to get that see control metal transfer in case of the CMT technology. So, this high speed digital control technology that; that is actually development as compared to the conventional gas metal arc welding process, and that with this development the CMT cold metal transfer mechanism actually comes into the market and still it is evolving nowadays.

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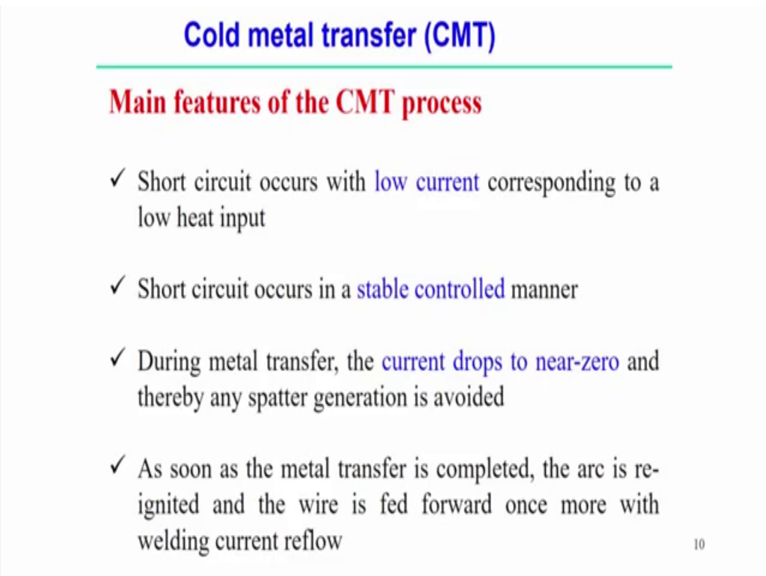

So, what are the more main features of the CMT process; cold metal transfer process if we look in to that, the typical features short circuit occurs at very low current corresponding, at the same time corresponding to a very low heat input that is a one of the features, that short circuit occurs also in the very stable controlled manner. So, that is the main significant features. So, stable controlled manner that is why it is possible to control the metal transfer, may be precisely as compared to the other existing metal transfer technology.

So, during metal transfer, the current drops actually near to zero and thereby any spatter is avoided and this phenomena. Because of this phenomena this technology is very much suitable for the metal printing technology, as compared to the gas metal arc welding process. So, as soon as the metal transfer is completed, the arc is reignited and the wire feed is again give the forward motion once again and, when this with the welding current reflow.

So, this process is basically repeated; that means, a mechanically how we are giving the wire feed. Once I giving the backward feed and next part we are giving the forward feed of the wire and this and, and wire basically the it is helping the metal transfer to the molten pool to the base material. So, that is why it is different as compared to the conventional metal transfer mechanism.

So, if we see that the electrical signal cycle the, how it consist of the basically three phases and overall if we seeking the metal transfer mechanism in this case. The one phase is the current phase; second phase is the background current phase and short circuiting phase in overall structure.

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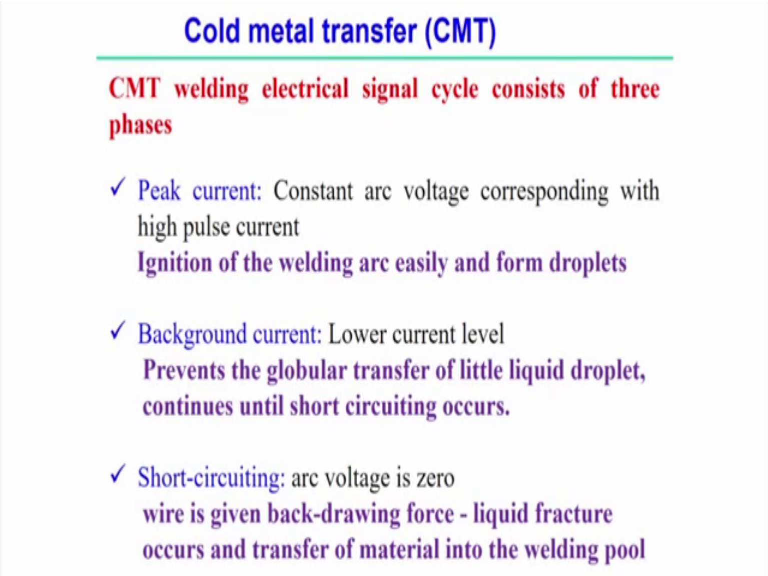


But what are the phenomena is actually happens or what phenomena occurs during the these three different phases; If we see the peak current. In the phase constant arc voltage is maintained and as the time corresponding to the high pulse current, that actually helps the ignition of the welding arc easily and actually forms the droplet.

What is the role of the background current? So, background current is the current level is kept very low, but it actually prevents the globular type of the metal transfer, even the metal size droplet size is very small, but at the same time it continues that; that means, this phase is continues until the it reaches to the short circuit, short circuit phase. So, once we reach the short circuit phase, definitely in this case the current is low level, at the same time the arc voltage is also kept as zero.

So, wire is given some mechanically driven back, back drawing force; such that liquid fraction of the molten material occurs and then this helps to transform the molten material to the welding pool. So, overall structure, these three phases is the basic structure of the cold metal transfer mechanism.

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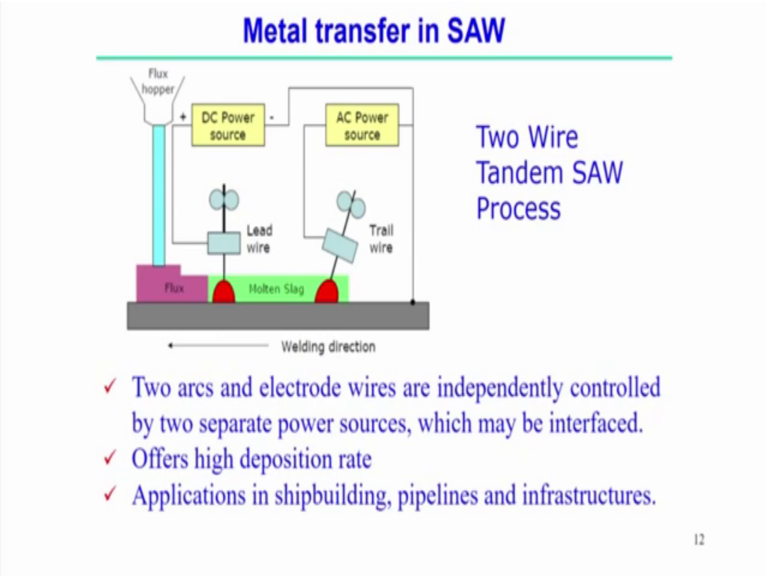


You know apart from the CMT mechanism, we will just here few words about the metal transfer in the submerged arc welding process. So, we know in submerged arc welding process normally use the single wire to feed the, it acts as a consumable electrode or consumable wire and that becomes part of the welded join. And submerged arc welding is mainly used basically when there is a need for the very high thickness material or may be very high volume of the metal deposition is required, in that case normally we use the submerged arc welding process

But apart from the single wire, submerged arc welding process, there are development of two wire, tandem submerged arc welding process. So, in this case two different source are used and the two different wire are individually controlled or may be two different electrodes are individually controlled by the separate power sources and which can give the very high deposition to the weld, to the molten material, but of course, here the discussion comes based on the metal deposition in case of the welding, but this is not no link or maybe not related to the metal printing technology.

So, this application actually if we see the figure that degree centigrade power source, the when you try to look into the forward; that means, lead wire and they use the DC power source and if you look in the trail wire; that means, in the backward wire, we generally use the actually AC power source and definitely the AC power source actually control in this case, the penetration as well as the weld depth in case of the two wire tandem submerged arc welding process. And we can see this application of this welding processes, we generally happens in case of the shipbuilding pipelines and infrastructure. There is a heavy section has to be joined in that cases, this type of welding process is more suitable.

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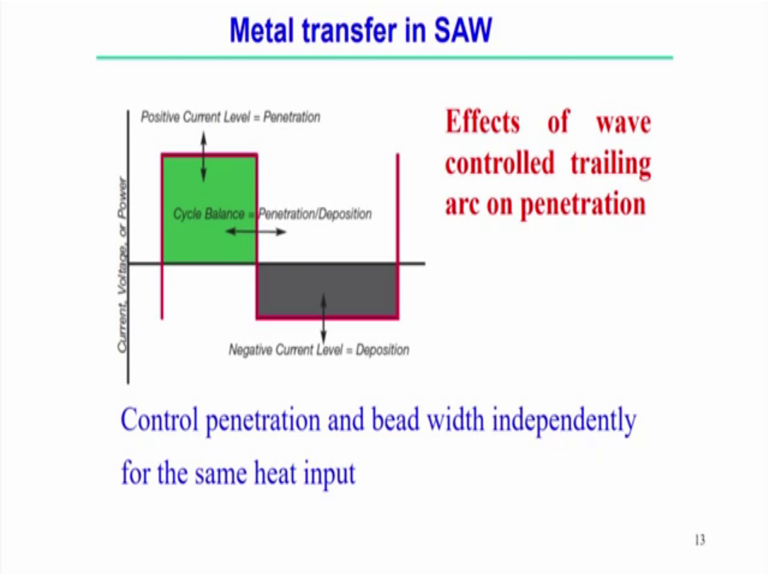


And if we see the figure also, in metal transfer of submerged arc welding process, we can see the first bead in the trail wire or we can use the AC current and the positive current actually create the balance or may be influence on the increase the penetration of the weld.

But backward current; that means, negative current actually level the control of the deposition. So, based in that way it actually make the balance, penetration, as well as deposition by using trail wire and in that is why it is advantageous to use the secondary wire or second wire in case of the submerged arc welding process.

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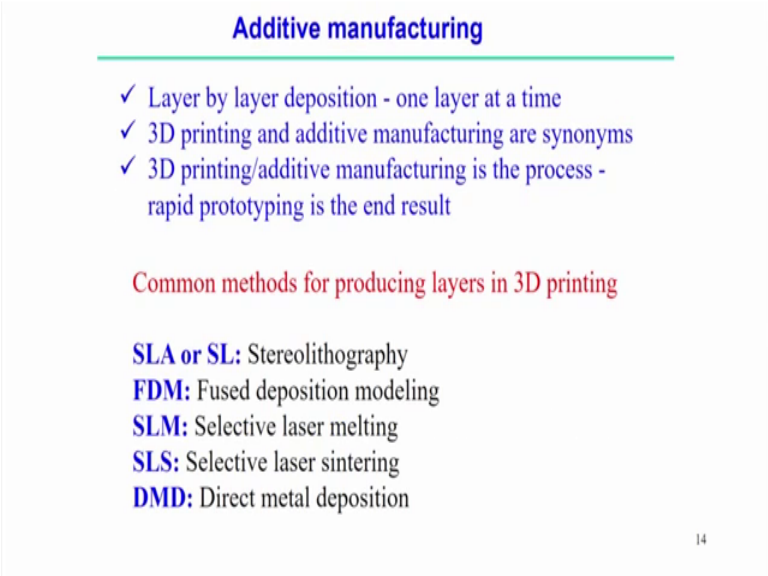


Now, once we look back all the different material , material transfer or metal transfer and welding process and that actually use some consumable electrode to feed the weld material and that is the typical characteristics of the welding process, but the similar concept can be used in case of additive manufacturing process. So, that is why it is having some link with the, well understanding of the welding technology, specifically the metal transfer in the welding technology

So, additive manufacturing is based on the layer by layer deposition and one layer at a time, and of course, sometime we use the word 3D printing and additive manufacturing. Actually both are synonyms, and this 3D printing or additive manufacturing actually used where the rapid prototype, prototyping is the end results

So, in additive manufacturing instead of both metal transfer, how the metal transfer happens in the welded process, that concept we can use in a additive manufacturing and that metal transfer in welding process is mainly related to the, we use the consumable electrode or we use the consumable wire. Actually the additive manufacturing technology developed initially based on the consume wire based feeding system to the system, but here the, we can control the deposition and the deposition happens the single layer and then next deposition happens from the next layer.

So, maybe we can relates with the multi-pass welding process. Multi-pass welding process that actually is having the very high thickness of the material that is not possible, that type of thickness of the metal it is not possible to use the single pass welding process. So, it actually resembles that type of the welding process

But of course, the technology has been now, has been shifted or, have been developed using as a laser source, but the base material we use, do not use consumable electrode rather than we can use the in the base material as a in the form of a powder or sometimes we can use in the form of a electorate wire also, to find out the or to develop the additive manufacturing technology

So, common method of producing the layers in 3D printing; we can see that there are several technology has been developed in 3D printing process, it may be applicable for the polymer as well as metals also. So, one is the very basic old technology that is called the SLA or SL; that means, a stereolithography. So, that is one of the very first 3D printing technology based on this process

Then FDM; fused deposition modelling selective laser modelling, a selective laser melting SLM and SLS selective laser sintering and DMD, so direct metal deposition. All are the different technologies has been developed and as a 3 dimensional metal printing technologies which is a, which we can say that it is a additive manufacturing technologies

We will discuss some basic concept, basic understanding of or all different types of the additive manufacturing technologies and how these technology is basically link the with the metal transfer mechanism. So, if we see that additive manufacturing is, we can say that layer by layer manufacturing process, because and it actually creates a 3 D objects, but not by the subtractive methods; that means, 3D objects has been created not required any machining or removal of the material is not required.

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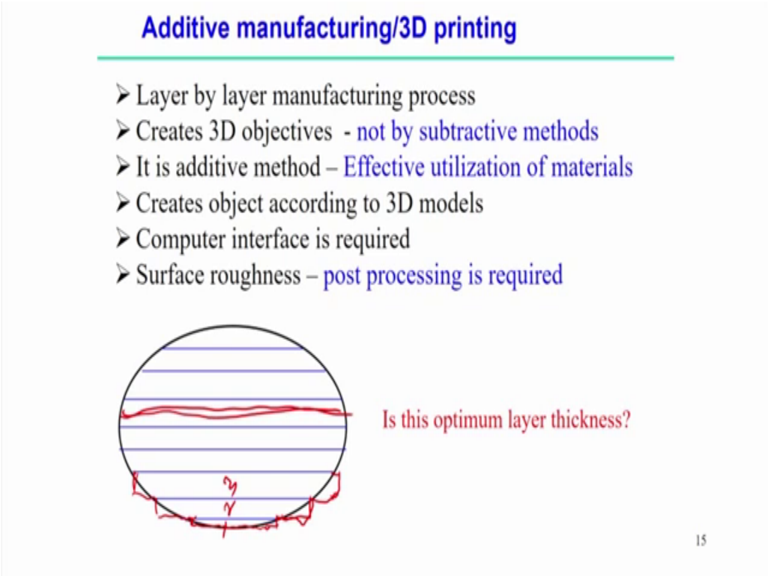


So, that is just opposite, it is a additive techniques and, but in this case the one advantage is that, effective utilisation of the materials is actually happens this in the additive manufacturing process, because we are not using the subtractive, we are not subtracted any material to form a 3D object. So, that is why effective utilisation of the materials happens in this case.

And of course, when you try to produce certain object the, there is a need to create the model of this 3D object and that computer interfaces required to phase the data of this 3D objects and to give the instruct to the printer, to get to define the thickness of the layer and what was expected the; that means, expected shape of the final object. Of course, one of the significant point in case of additive manufacturing process; that is called the that the surface finish of the end product.

So, definitely it is not possible to directly that surface finish we achieve, what we achieve in case of the metal finishing process; that means, finishing process, even for micro finishing nano-finishing what type of finishing we can expect during the machining process.

So, that type of surface finish may not possible to obtain using this additive technology. So, therefore, post processing is, mostly the machining process or some other processes heat treatment process. This type of post processing technology also required once we produce an object, 3D object by layer by layer deposition

Now, if you look into this object. Suppose we want to define one oval shape objects, we want to produce using the additive manufacturing technology. So, bottom line is that, first is to define that layer by layer deposition. So, first it start from the first layer, deposition of the first layer, then deposition of the second, this deposition of the third layer. So, gradually it develops, but if you look into that each and every layer, the size and size of the layer may not be the same. Thickness may be the same, but size length width of the layer may not be same or volume of the layer may not be the same

So, therefore, this we need to, we need to decide the thickness of the layer such that we can achieve the exactly as possible as to get the shape of the 3D objects. Now if we see that if this is the layer deposition. So, if layer deposition is actually happened this way. So, and if we see this is also rectangular section, if you want to complete in that way it is possible to deposit the layer and it is of, is of rectangular section.

So, we may not expect that a what kind of the smooth surface; that is not possible to achieve, if we or exactly achieve by layer by layer deposition, but we can get as near as possible, if it if it is possible to do, particle to deposit the layer it is a layer thickness is very small in this case from the figure. If we do the thickness of the layer is very small, then we can achieve to the nearer shape of the 3D objects. Therefore, it is necessary to decide what may be the optimum layer thickness; such that we can achieve the near shape of the 3D object.

And of course, the post processing requirement, what post processing requirement that. That means, in this case the machining process can be as less as possible, then we will get the complete benefit of the additive manufacturing technology. Therefore, apart from this the, when you try to interface with a computer and to the actual process and slicing um, deciding layer thickness and expected surface roughness of the final object, that actually control with the several parameters. We will see that what are the different parameters is basically is useful in case of the additive manufacturing to finish.

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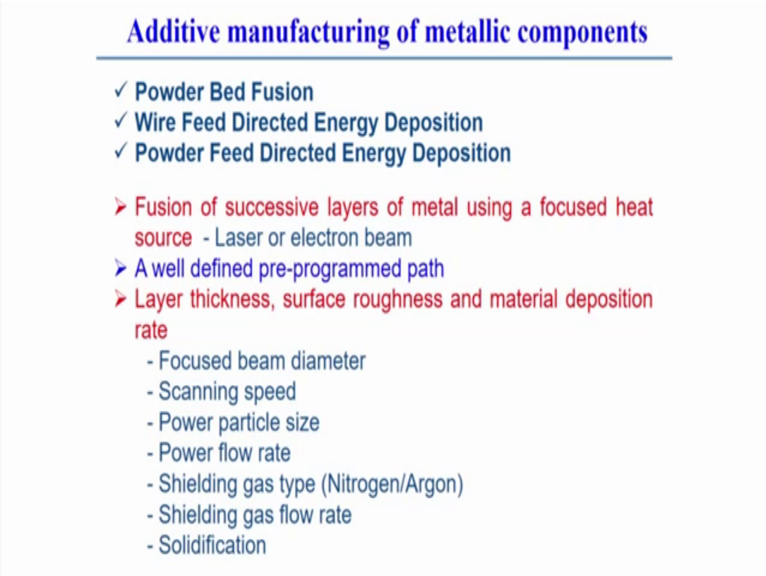


But before that if we shift as already mentioned, that additive manufacturing technology is developed for the metallic components. Not only the metallic components it is also developed for the polymeric material. Actually first this technology has been developed for polymeric material and later on, now the this technology is still evolving in case of the metallic, metallic components. In metallic component so far the development happens in the metal printing technology we can say the or additive manufacturing technologies, that actually based on the three different system

One is the powder bed fusion; that means, the there is a complete deposition of the powder over and certain area and then according to the shape or layer thickness, the powder bed is actually form, depending upon the thickness of the layer. So, once that has been deposited one phase, then using some laser source. We can selectively melt the certain position to get the shape of the single layer and second one is the wire feed directed energy deposition.

So, instead of using the powder form of the material, here we can use the wire and that wire is actually fused at the just exit of the nozzle and then when its forms the molten metal, and that molten metal becomes part of the actual layer and that molten metal is actually creates the layer and becomes part of the one layer of the part of the final shape of the object.

But if you look into third type; powder free directed energy deposition. In this case, so instead of using the powder bed or fusion; that means, the phase is completely filled with a powder according to the layer thickness here, we can use the at the selective point, we can focus that laser source as well as the by using some nozzle we can just deliver the powder and the specific position and at the same time this powder has been fused by the laser.

So, at the selective point the molten material actually forms. So, in that way it is different from the powder bed fusion process. So, this three different system we normally use in case of the development of the metal printing components. So, definitely fusion of the successive layers happens metal using the fused heat source, that heat source can be lasers in some cases.

There is a development of using the electron beam as well, but if you want to , if you want to do the melting of a selective path therefore, is well-defined, well-defined pre-programming path is also requires; such that the heat source can travel through this path and creates the object and definitely that, main features of this additive manufacturing technology that is the layer thickness or surface roughness and the material deposition rate and all this the final product, the aesthetic part of the final product surface roughness is an actually is a complex function of all the several parameters.

So, one is the focused beam diameter. For example, if you want to improve the surface roughness of the 3D printer object. Therefore, the beam should be focused on a very small diameter, it is. Nowadays, it is possible to focus in a very around 50 micrometer focused beam diameter.

Second is the scanning speed, actually the scanning speed decide the what is the, what speed generally, it is possible to move the laser source. Actually scanning, that actually decided what is the rate of the solidification happens on the specific metal, but at the same time is a, what is the need of the rate of production; that means, what is the amount of the material, volume of the material actually solidified per unit time.

And then powder particle size that also actually influence the melting of the or making the final shape or roughness of the final product, because powder particle means, whether it is spherical, size should be very small based on that, there is a fusion of the material occurs efficiently. Powder flow rate, rate of the powder flow is actually, if there is a powder flow rate is very high there may be unfused material can also be there. So, in that way the there may be some optimum powder flow rate.

And shielding gas type, depending upon the type of the material, type of the shielding gas can be used, but it is can be, normally we can use the argon nitrogen environment to fuse the material. Then shielding gas flow rate that actually influence the shape and size of the layer; that means, surface roughness of the layer and finally, the solidification rate of solidification happens, that act, that can also be , that can also decides what way the laser source can be scanning through the deposited material.

So, if you see that apart from this parameters, there are several other parameters that actually control good product from a 3D laser printed material. So, this phenomena or; that means, this all these parameters actually having its a complex interaction between them and it is very difficult to find the range of the parameters and which reaches lot of trials and errors to get the range of the parameters. And of course, this parameters shape should be different for the, different type of the materials.

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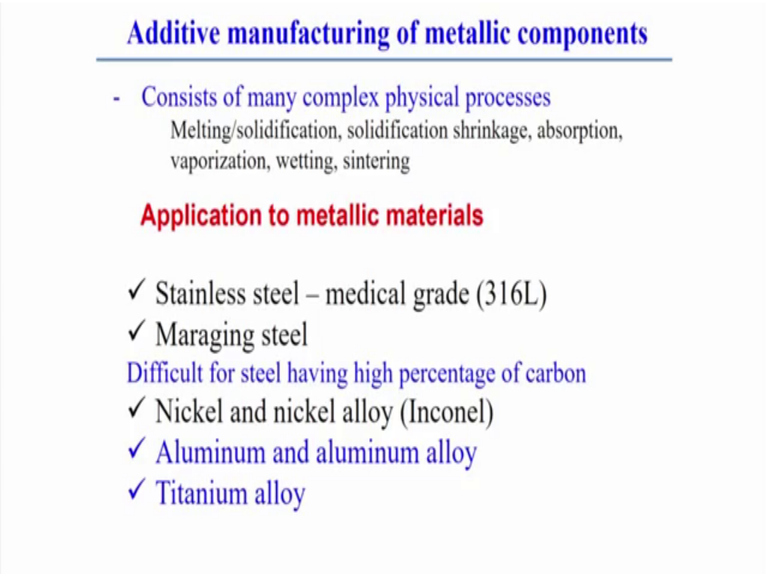


So, if we see general that additive manufacturing or metallic component, its a consist of many complex physical processes and interactions of the different physical phenomena, melting solidification, solidification shrinkage need to consider also, absorption of the laser, absorptivity by the laser of a specific material, whether it is happening vaporization if the laser power density is too high then vaporization may also happen, waiting phenomena is good or sintering can also occurs within the materials or is there is a lack of sintering, there may be the or maybe even with the sintering process, there may be the possibility of the creation of the porosity in the object.

So, that are the typical issues in the in case of additive manufacturing process, but so far if you look into the development happens in case of metallic materials. So, with the following materials, if you see that stainless steel, specifically the medical grade three Ss 316L, this metal printing technologies is quite developed in that area, apart from the this grade steel there is also other kind of steel also has been developed.

Merging steel, the metal printing technology has also been developed, but the difficult for steel having the high percentage of the carbon. Steel having the carbon not has been developed so far of metal printing technology, because there is other issues for the, when there is material steel contains the carbon percentage, that actually creates the fumes, and it there is a we cannot expect very good surface finish and of course, lot of fumes can be generated within the chamber that can.

That are the issues actually with the steel having the higher percentage of carbon. That is why in this area the metal printing technology has not been well developed, but still scientist are also trying to develop this technology by, for this particular this type of steels

But nickel and nickel base alloy, specifically for different grades of inconel, this technology has been developed, aluminium and aluminium alloy has also been developed titanium alloy, but aluminium alloy or aluminium material and titanium alloy. The main issues, is that the titanium and aluminium is very much reactive with the surface environment. So, in this cases the, choosing of the shielding gas is a one of the issue, to get the very good surface finish of this kind of product or maybe not all the manufacturing.

All the different types of the metal welding technology is not suitable for the processing of the aluminium or aluminium alloy, as well as the titanium alloy.

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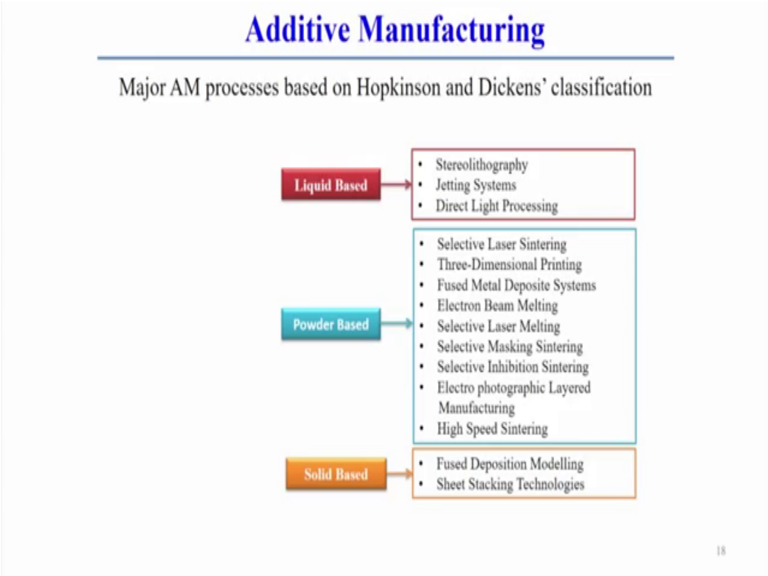


In general if we see the major additive manufacturing processes based on the Hopkinson and dickens classifications. Also we can classify the different additive manufacturing process, mainly in the three category; liquid base, powder base and the solid base. If you see the liquid base; stereolithography jetting system that there actually belongs to the liquid base system, and powder base selective laser sintering; that means, see in this cases metallic powder is used that, then three dimensional printing fused metal deposition system electron beam, melting, selective laser melting, selective masking sintering selective inhabitation sintering, electro photographic layered manufacturing and high speed sintering.

These are the typical names of the additive manufacturing process, but all these cases we use the powdered based system. And solid based system also used as in case of additive manufacturing, in this case the fused deposition modelling, where we generally use the solid wire to get the, to develop the printing technology. Sheet stacking technology these twos are the technology where additive manufacturing technology, where we can use the solid base material to develop the this additive manufacturing technology.

So, it is not necessary to go in depth in details and specifically this courses, all this technology, just to know the naming of this different technology is exist in case of the additive manufacturing processes or we can say the metal printing processes

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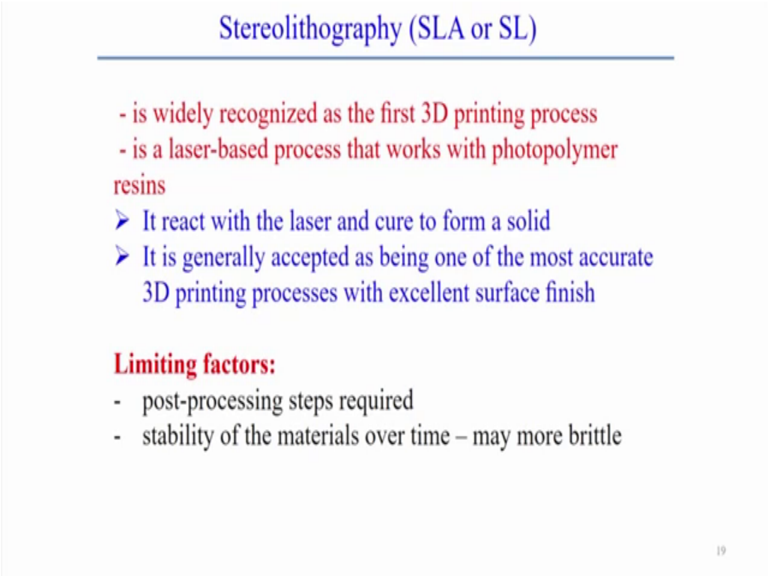


So, now if you look into that some basic, basics of the different additive manufacturing, not all the technology, but very few selective temperatures we can go for basics. One is the stereolithography, you can use either SLA or sometimes you can SL, is basically widely recognise, it is at the as the very first 3D printing process and it is actually laser base system and that works actually photopolymer resins, actually that photopolymer resins that specific since is very sensitive to the laser lights.

So, when it reacts with the laser light and after curing it, it becomes the solid and based on this principle this process has been developed. It is basically generally accepted for the one of the most accurate 3D printing processes with excellent surface finish, but limiting factor is that post processing is very much is required in this case. And of course, stability of the materials over time is one issue, because material may become more brittle after curing

But this type of technology is mostly applicable for the polymeric materials. This is not suitable for the metallic components. And if you see that other 3D metal printing technology in general that mostly use the metal printing technology and the general process of all this metal printing technology.

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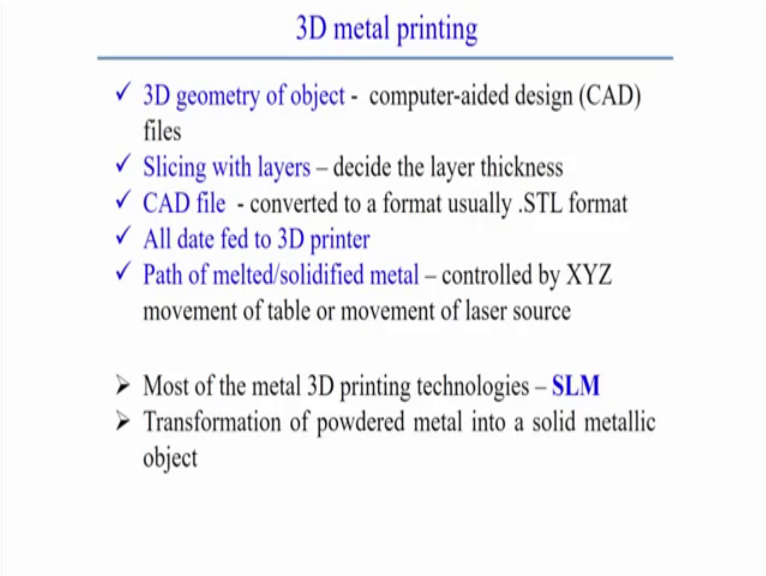


The first step is that 3 dimensional geometry of the object should be created and that with the help of the computer design. So, cad model of the 3D geometry is required to first develop and which we are supposed to make as a 3D object as the outcome for the, after the of the metal printing technology.

So, once we decide the object and we create the geometry object and we using the cad model. Then once we create the whole cad model of any object, 3D object, then it is necessary to decide the slicing process and the slicing process of the layers. Basically we have to decide the size of the layer and all the geometry, geometry; that means, all geometrical size of the layer is required, but most important is the thickness of the layer is required; that is called the slicing process.

So, that slicing wants after the cad model, then the slicing process is generally done. And of course, after the slicing process it is converted to a some dot STL file format and all the data actually fed to the 3D printer. Now 3D printing taking all these data, start the printing process and following the path, and following the path of the.

This path is actually created or may be this path is actually control by xyz movement of the table or either movement of the table or by movement of the source of the laser or electron beam. So, that way it is control the parts.

So, very precision control of the path is actually required. Most of the cases we can use the cnc control xyz table movement. And of course, once layer is formed then the table, on the base table once one layer is formed, then table is makes the downward motion to form the next layer that way layer by layer deposition, but each and every layer, each and every slicing is are the geometry shape will be different, depending upon the 3D object

But most of the metal, most use of the metal 3D printing technologies is the most use of the selective laser melting. Definitely it is having some advantage of selective laser melting or development happens for the metal printing technology is, it is up to certain extent in case of the selective laser melting process.

So, finally, in overall we can say that 3D metal printing process is the transformation of the powder metal into a solid metal; that is the basic philosophy of the additive manufacturing process or 3D metal printing process.

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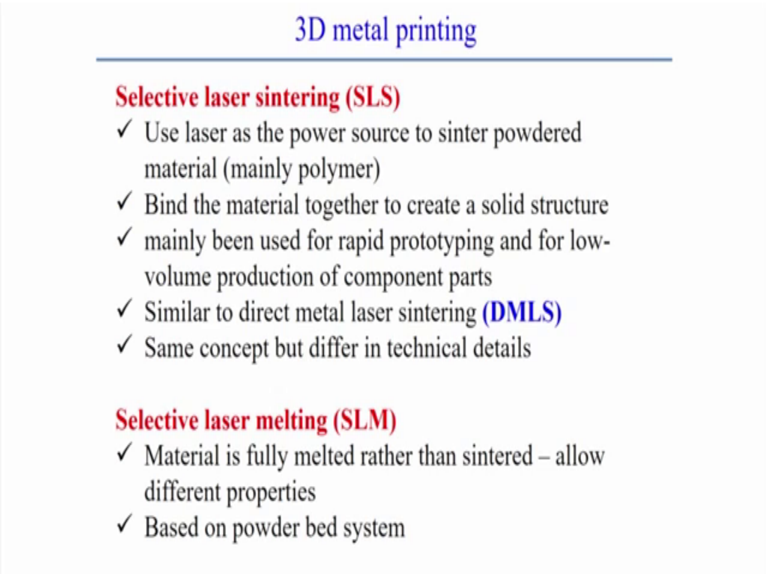


If you look in to other melt metal printing process exist; that is called selective laser sintering. In this case there is a use of the laser as the power source to sinter the powder material and this technologies mainly used for the polymeric material. Once the, during the sintering process there is a need for the binding of the materials together to create the solid structure, but all happens over layer by layer

Mainly been used for the SL, SLS process is mainly used for the rapid prototyping and for there is a low volume of the production of the component parts, this type of technology is used, but direct metal laser sintering, which is related to the metallic material, the concept is the same as the selective laser sintering, but technological details are different or may be technology different in, as when we use the polymeric material as compared to the metallic material in case of the laser sintering process.

Next is the selective laser melting. So, definitely instead of the sintering here we allow the melting of the material or melting of the powder by the application of the laser source, but the selective laser metallic is basically based on the powder bed system.

Powder bed system means in the simplified we can explain like that, if there is a layer of the powder over the phase, and depending upon the size of the object within that layer, there is a direct deposition, direct focusing on the laser on the selective part of the hole, on the layer of the powder and that part only on the is fused basically and the remaining metal, unfused metal powder can be reused later on. So, in that way the selective laser melting is actually works

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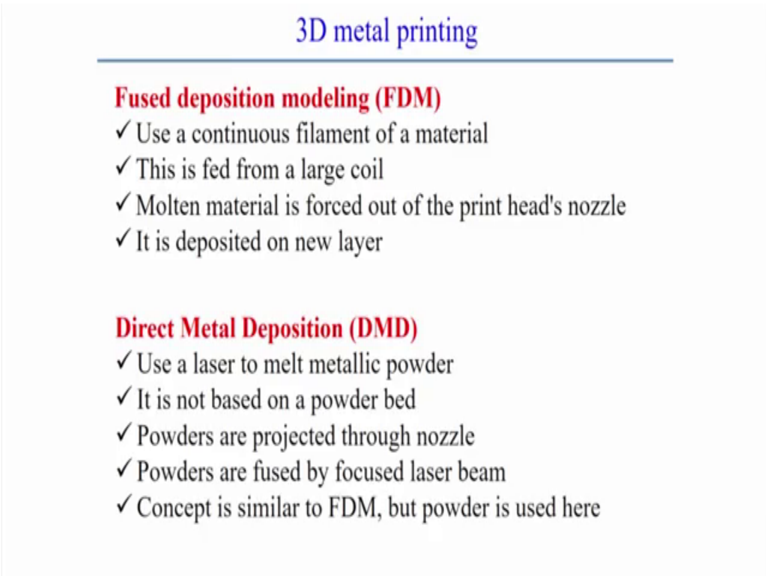


Next is that fused deposition modelling. So, in this case instead of the powder, there is use of the continuous filament or continuous wire of a material and definitely this continuous source of the metal is comes from a specific large coil and molten metal is actually forced out of the nozzles head, and then the molten metal actually deposited to form a new layer. So, that is the fused deposition modelling process

So, but direct metal deposition instead of using the filament wire, there is a direct use of the laser to melt the metallic powder, but the difference from the selective laser melting is that. Here we do not use any; there is a no need of the powder bed system. So; that means, not necessarily to make the arrangement of the layer of the, complete layer of the powder, but instead of the at the local position we can directly fed the powder, as well as the laser source and at that point there is a melting of the powder occurs and at the same time there is a deposition of the laser, molten metal occurs over the bed.

So, powders are actually projected through the nozzle and powder is actually are fused by the focus laser beam and concept is similar to fused deposition modelling, but instead of the continuous wire, here there is a use of the powder.

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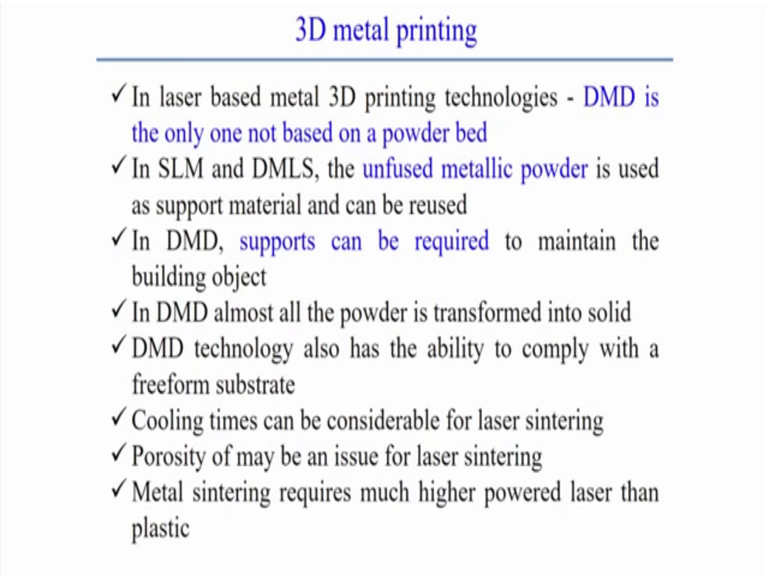


Now, if we look into that typical features of the are some overall general idea of the different printing technologies, we normally used nowadays, that first is that in a 3D laser based, 3D metal printing technology DMD is the only that actually not based on, do not use the any case of power bed system.

But if you use the SLM and DMLS, in that two cases the unused metallic powder is basically again used reused on that actually used as a support depth for the build-up of the layer by layer, and at the same time the unused powder can also be reused also, but in case of the DMD. In this case the supports can be required to maintain the building objects and once there is a development of the object, the support actually can be removed by the, by cutting of the support or may be separated out through the.

Normally you can use the wire radium process to separate out the, the 3D printer object as is with respect to the base material, but different from the SLM selective laser melting process in DMD. All powder is transform into solid; almost all powder is transform into the solid. But in case of SLM, we just over the powder base, the there is a laser source actually, select the material and based on that there is a fusion of the powder actually, occurs over the bed. So, it is in that way, it is different from the, there is a difference in the SLM and DMD.

So, DMD technology has the little ability to comply with the, free from structure. So, that is in DMD technology also having um, the ability to form the free form structure and of course, the with respect to the recent development happens, in the DMD technology, the surface finish is, may not be as good as compared to the SLM process. So, SLM process, we can expect the surface. This is very good as compared to the, DMD technology, but definitely the still, this technology are involving nowadays also.

But if you look into the laser sintering process, the cooling times is the one of the issue for the laser sintering process and that is considerable as compared to the other, melting process, laser melting process, but in, another issue in case of the laser sintering that can be the porosity. Porosity can be an use in case of the laser sintering process, but metal sintering requires the much higher power as compared to the plastic.

So, definitely when the sintering process use in the 3D metal printing to which the power source or may be power of the laser source should be different in case of metal metallic powder, then normally it is, power requirement is very high as compared to the polymeric material, but of course, this technology is successful 3D metal, technology.

There is a need of lot of trails to get the optimum set of the parameters and of course, all these cases, that we can expect the, different surface finish for the different kind of the metal printing technology. So, in this module we have tried to discuss that the very basic component of the metal printing technology and how it is related to the metal transfer or how you can be linked with the metal transferring the, in the welding processes.

Thank you very much for your kind attention.