Finite Element Modeling of Welding Processes

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Module - 07
FE Model of Metal Transfer in Welding
Lecture - 33
Fundamentals of Metal Transfer in Arc Welding

Hello everybody. Now, we will discuss about Finite Element Modeling of the metal transfer in specific to the Welding Process. So, actually this metal transfer mechanism and the modeling of this thing is it is a very complex thing. So, therefore, most of the cases, we normally follow the modeling approach for the metal transfer in associated with the arc welding process. It is a different zone wise; that means, for example, we can divide in this way also.

For example, that first there is a metal transfer from the consumable electrode. So, how droplet can be created, this is the one part. Then, second the transport of the droplet from electrode to the work piece material. So, during that and there is interaction of the shielding gas also at the same time. So, therefore, this is metal all the molten metal is surrounded by the shielding gas.

So, that under this particular medium, the transport of the droplet happens from electrode to the work piece material. Now, if we focus on the work piece material, so, there maybe is you can considered like that, within this work piece this material droplet is attached to the work piece. So, there is a addition of the mass to the domain and at the same time it can produce some kind of the free surface profile.

So, in this case the free surface profile is very important to model, as compared to the normal arc welding processes, where there is such kind of the metal transfer is involved. So, in that aspect this modeling approach is a little bit complex in using consumable electrode and in case of the arc welding process.

So, therefore, first we will try to look into this fundamentals of metal transfer in welding processes, the overall view on this thing, what are the different forces are important or what way the metal transfer mechanism we can explain that we will try to look first. Then, next what if we (Refer Time: 2:45) modeling approaches we will be doing, because in this cases the approaches is more important.

Because, if you look into each and element of the different domain of the analysis or maybe what are we can develop the model, there you need to solve to understand the there, what are the different medium is active. And, then how we can develop the model?

Because finally, we will be looking into the heat transfer analysis or maybe material flow analysis that we have already done and, a it is a very elemental way we have already know that how what are the different equations is normally used in case of the heat transfer model.

And, what are the different equation has to be solved, in case of the material flow model. At the same time what we can do some kind of the free surface modeling that we have already explained in a certain point of time. So, therefore, we will simply look into what are the approaches maybe we can follow, for the modeling of the metal transport in the arc welding process.

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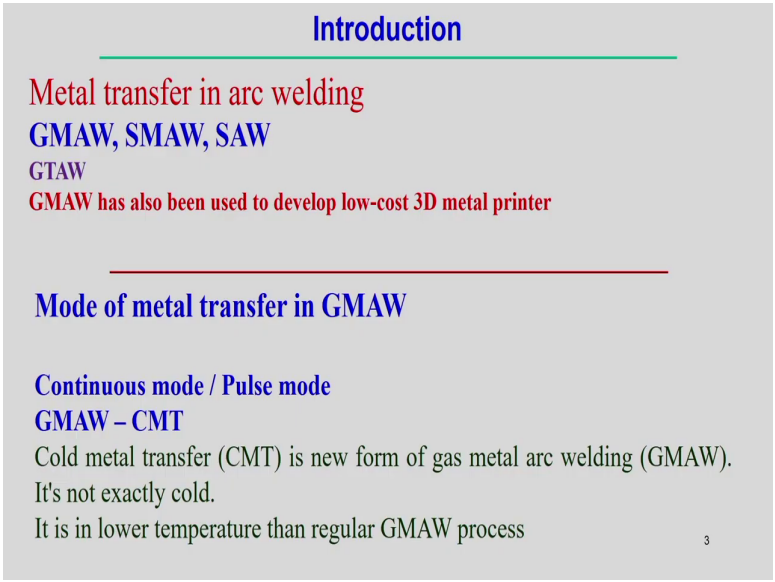

So, metal transfer in arc welding process; we know this is the typical gas metal arc welding process is involved. Then, shielded metal arc welding process, we can normally use a consumable electrode and submerge arc welding process. So, there also metal transfer happens from the electrode consumable electrode, but the processes make it different in these three cases, but in general all this kind of the welding process are normally associated with some sort of the metal transfer, or material deposition during this process.

So, why you are analyzing this metal transfer and your welding process? Because, it is very important, if we want to develop some kind of the wire arc additive manufacturing process, then we need to understand that what are the different types of the mechanism; metal transfer mechanism associated with the arc welding process.

So, GMAW, SMAV and SAW definitely they are associated with metal transfer using the consumable electrode. But, at the same time GTAW; that means, that is called the gas tungsten arc welding process. Although, gas tungsten arc welding process it is the actual process, the metal transfer thing is not an intricate part of this particular system.

But, if necessary sometimes we can use some; some external wire and that wire can be deposited in the deserved position. So, but this metal deposition is not the actual part of the welding process like; gas metal arc welding process. Because, gas (Refer Time: 5:09) has been developed in such a way that it itself the intricate part of the system the metal transfer in this case.

Then therefore, the mechanism of the metal transfer may be different in this case GMAW process as compared to the GTAW process. Evenif it is also possible if we use some kind of the laser source also, and the similar way metal deposition can be done also by feeding the external material. But, at the same thing I just I repeated the same thing that it is not integral metal transfer; it is the integral part of the system.

So, therefore so GMAW gas metal arc welding process in wire arc additive manufacturing process there also we start with this thing, the metal transfer mechanism from the gas metal arc welding process. Or, other way we can see looking into the metal transfer in gas metal arc welding process this is possible to develop some sort of the low cost metal printer using the gas metal arc welding process.

So, that, but anyway the additive manufacturing, or metal printing it is depends intuitively on this metal transfer associated with this particular welding process. So, therefore, there is a clear understanding of the metal transfer is required. Now, metal transfer there are several modes of the metal transfer. Now, we focus on the gas metal arc welding process.

So, or in a advanced welding processes, which is more involved for the metal transfer and maybe which is beneficial to develop some kind of metal printer technology also. They are

looking in by analysis of the metal transfer mechanism associated with this particular welding processes.

So, in case of gas metal arc welding process, that there are different modes of the metal transfer associated to the gas metal arc welding process. But, apart from this thing mode of the metal transfer the normally, this application of the current in gas metal arc welding process, it can be done either in the continuous mode or in the pulse mode.

So, the that kind of option is always there. So, therefore, the there may be even in pulse, when there is a we use a some kind of the pulse current or maybe pulse welding mode then, the metal transfer mechanism can be different as compared to the continuous mode of current we are using, in case of the gas metal arc welding process. That we will discuss what are the different modes of the metal transfer associated with the gas metal arc welding process.

Apart from this thing there is a development also, we can we can say the advancement of the gas metal arc welding process that is called the CMT process; CMT is the cold metal transfer process. So, here CMT process is very much relevant for the development of the additive manufacturing technology. Because, in CMT it is more controlled way the metal transfers can happen. So, that is why, we can say that the CMT is the advanced level of the gas metal arc welding process so, that we will discuss later on also.

So, cold metal transfer, but why we are talking about the; we are using this particular word the cold. Because, it is not exactly cold, but the metal transfer happens at a relatively lower temperature as compared to the gas metal arc welding process. So, in that sense, we can consider this as a cold metal transfer mechanism. So, it is in lower temperature than the regular GMAW process.

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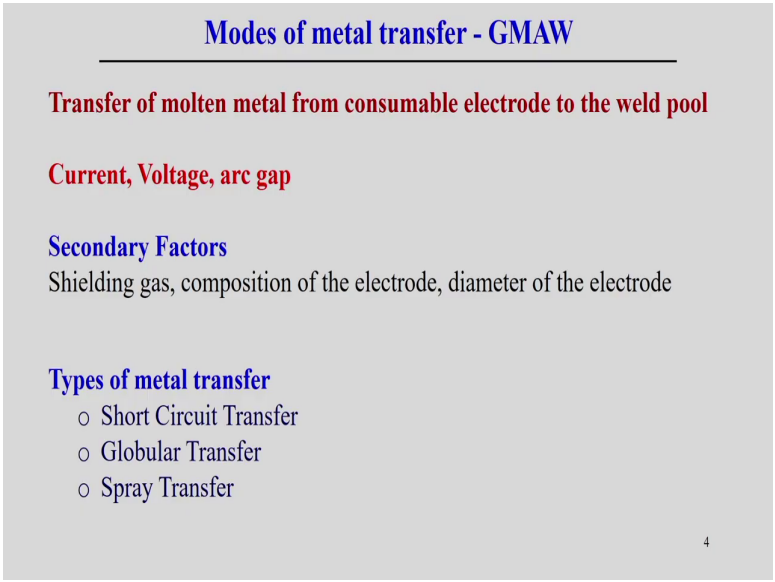

So, everything happened all the metal transfer mechanism is normally happened at the relatively low temperature, as compared to the gas metal arc welding process. Now, mode of the metal transfer in gas metal arc welding process it is basically, we understand the transfer of the molten metal from the consumable electrode to the weld pool in that is called the; there are different modes are available for the transport of the molten droplet from electrode to the weld pool.

But, the primary variable or primary process variable depends on this metal transfer it is basically, the current voltage and arc gap. So, we know that current and voltage we know this thing about arc gap also important; that arc gap maintained between the consumable electrode, or non consumable electrode and the work piece.

So, that gap is very important and what the requirement of the current and voltage for a particular process, these are the; these is the main variable or main process parameter associated with the any kind of the welding process. But, apart from this thing secondary factors are also there, because shielding gas is also having very much influence on the metal transfer will depend on the metal transfer mechanism also.

And, then sometimes the composition of the shielding gas in the sense that two different kinds of the shielding gas can be mixed with a different ratio and they are having some impact on the metal transfer also as well. Apart from this thing composition of the electrode also in the secondary factors, what kind of the electrode we are using or material of the electrode, and what are the size of the electrode, all kinds of the are the we can consider this as a secondary parameters apart from the arc that is current voltage and the arc gap.

So, these secondary factors is much influence on the metal transfer associated with the gas metal arc welding process. Normally, there are three types of the metal transfer from the consumable electrode to the, normally happens from the consumable electrode; one is the short circuit transfer. So, short circuit metal transfer is the one mode, then other are the globular kind of the transfer; that means, and third one is spray kind of the metal transfer.

So, short circuit means during the, if there is a short circuit happens then metal molten metal transfer to the work piece material. So, in that cases typically there are some certain criteria such that it can follow the short circuit kind of the metal transfer. Similarly, globular kind of the metal transfer there some criteria for the primary variable and the secondary variable always be there, that actually promote to transfer the molten droplet in the form of a globular, very big shape as compared to the electrode diameter.

This is called the globular transfer of the molten droplet to the work piece. And, third one is a spray kind of the transfer. So, in this cases the what way the spray small small droplet can be transferred to the work piece material, but each needs to achieve certain welding condition. So, in that particular condition the spray kind of the metal transfer may happen during the welding process.

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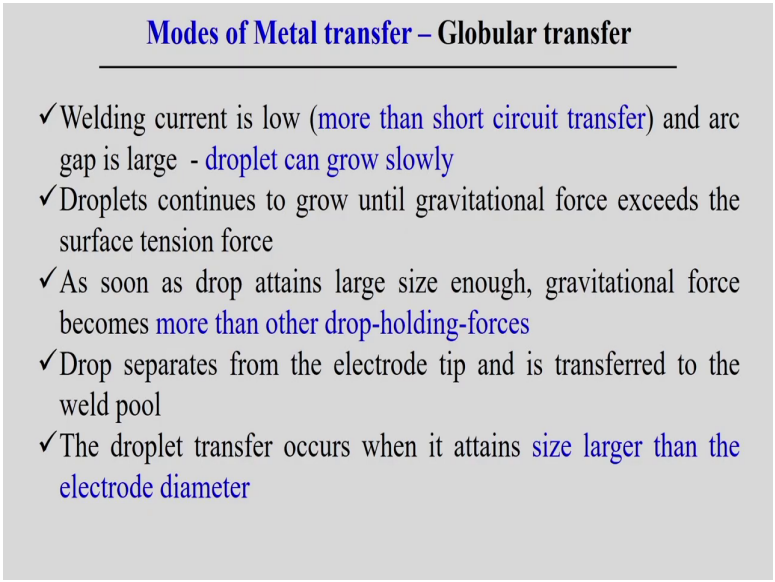

So, we will see one by one; first is the globular transfer. In this case the condition is the welding current is relatively low, but as compared to the more than that of the short circuit transfer. So, if the welding current is relatively low, but at the same time it is more than that of the short circuit transfer. And, the gap is very large, so arc gap is very large.

So, the distance between the work piece metal and the electrode the, at the end of the electrode that gap is very much, then this primarily promotes to form the globular kind of the metal transfer during this process. Because, there is a gap; if the gap is maintained bigger gap between the end of the electrode and this the work piece material, because this molten metal droplet normally forms at the end of the electrode.

So, if that gap is much more, so there is a sufficient it is it can grow, the droplet can grow relatively slowly and can make a bigger size. And, then after that mostly the when it is a

bigger size and then the gravitational force is much more, but the this thing in these cases then this droplet can be detached from the electrode and transferred to the molten pool.

So, the condition is that droplet continues to grow, until gravitational force exceeds the surface tension force. So, there are different kind of the forces is normally acting at the interface. So, such that we can explain the metal transfer phenomena. For example, surface tension force is acting this thing.

We know, if there is a different media is there. So, typically the surface tension force is very important the; we can say surface tension force between the solid and the liquid media. So, when the liquid droplet is creating the at the interface the solid electrode and the liquid droplet at the interface, some kind of the surface tension force will be acting. So, this surface tension force definitely, it influence the droplet transfer.

And, second thing is the gravitational force of the droplet so; that means, if it is bigger in size the gravitational force will be much more on this particular droplet. And, other is the pinch effect also that is electromagnetic field is also acting in arc welding process definitely there is a current flow. So, electromagnetic field will be active there.

So, that electromagnetic field is one of the driving force to that influence on the droplet detached from the electrode. So, therefore, all this the complex effect of all these different kind of the driving forces they influenced finally, to detach a droplet from the electrodes. So, we will see that how all these kind of forces is acting during the metal transfer.

Now, definitely when we are allowing to grow the droplets slowly and at the same time there is a gap between these two relatively bigger. So, therefore, there is a space to grow, subsequently with such that until or unless it is increasing the gravitational force but, when the gravitational force exceeds the surface tension force, then detachment of the droplet happens from the electrode and that it is transferred to this. This is the basic things associated with the globular kind of the metal transfer.

So, as soon as the drop attends very large size enough size the gravitational force becomes more than that of the drop holding force. So, drop holding force maybe in this case, it can be the surface tension force or it can be the sum other forces. Because, other forces is also acting the due to the magnetic field, mainly these three forces; acting the surface tension force, and forces due to the magnetic field, and gravitational force.

So therefore, if we assume that there is some drop holding force, and then effectively drop holding force, the combined effect of the other driving forces is this less than that of the gravitational force, then the droplet will transfer. Now, once the drop separates from the electrode tip and is transferred to the weld pool, once this drop holding when the gravitational force more than that of the drop holding forces.

Now, the droplet transfer occurs when it attends large size larger than that of the electrode diameter. Normally, this gravitational force will be more active, because in these cases the size should be relatively bigger in this case. So, relatively bigger in the sense that normally the thumb rule is that, the relatively bigger means, it should be more than that of the electrode diameter.

Then, droplet will transferred by the gravitational the more, effective gravitational pool will be more in this particular case, as compared to the other drop holding forces. So, this is the typical phenomena associated to the globular kind of the metal transfer. Now, modes of metal transfer is the spray kind of the metal transfer is normally happens.

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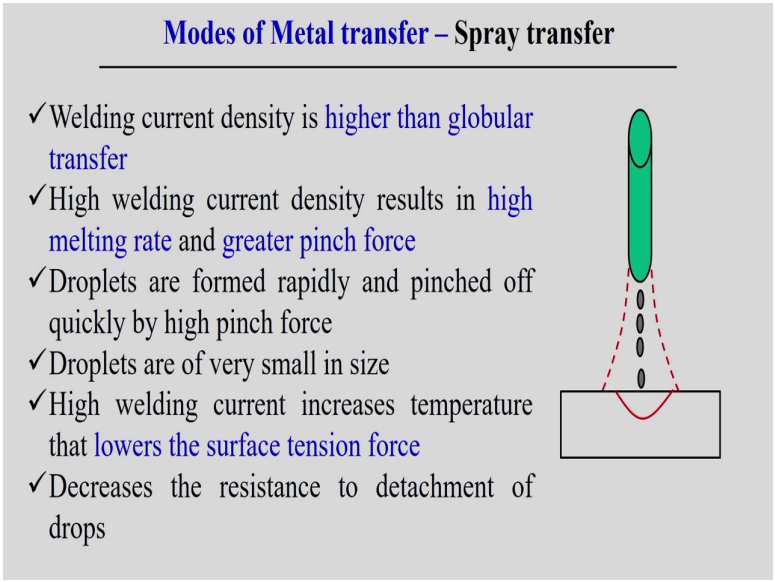

We can see from the figure also; the electrode is there, but the small small droplet can be created from the end of the electrode. And, then it can be transferred to this thing, not as a single drop transferred to the; single bigger drop transferred to the work piece metal rather than small small droplet can be created.

And, this continuously there is maybe the it is transported to the weld pool or work piece material. But, what are the typical conditions that, actually prevails such that this spray kind of the metal transfer will happen. So, in this case welding current density is higher than the globular transfer. So, welding current density is much more than that of the globular current of the transfer.

So, current density and current is different thing. Current density depends on the that, basically the density means, a per in this cases, we can say that per unit area the concentration

of current is very high, as compared to the where their existence of the globular kind of the metal transfer.

So, definitely current density is much more than we can expect that the kind of metal transfer in the form of a spray kind of the metal transfer. So, welding current density, high current density results in the melting rate becomes very high. So, very high current density means, the quickly melt this material and greater pinch force. So, greater pinch force creating the lots of droplet in these cases.

So, droplets are actually forms very rapidly, because of the very high current density and at the same time it pinch offed very quickly. So, by high pitch force so, pinch force becomes very high. So, basically when current density is becomes very high so, it current density becomes very high, so it indirectly affects the magnetic field. So, magnetic field basically with the increasing current density; the magnetic field will be affected.

And, that actually enhance the pinch force such that small small droplets can be created more frequently in this case. So, droplets are of very small size, so in this cases there is no not large time is allowed to grow subsequently the large pool rather when this small droplet can be created, because of the high pinching force and the presence of the high current density it is small small droplets can be created very rapidly and then it will be transfer to the work piece material..

Now, we can explain like this thing; high welding current at the same time high welding current increases the temperature. So, when there is a increment of the temperature at the same time it actually, lowers the surface tension force. So, when is the lowers down the surface tension force, then it becomes more easier to detach the droplet from the electrode material.

So, it other way also high current density enhance the increment of the temperature and high temperature lowers down the surface tension force and when there lowers down the surface tension force basically the holding force is basically reduces in this case. So, there is a easily

creating of the droplet to transfer, but all this stuff happens very quickly such that it may not get the sufficient time to grow in regard droplet.

So therefore, decreases the resistance to detachment these things. All this kind of the situation in this means that, high current density, very high temperature, lower the surface tension force and very rapidly the pinch force, basically increment to the pinch force, or actually cleared the situation that small small droplet can be created very frequently, as compared to the one single bigger drop..

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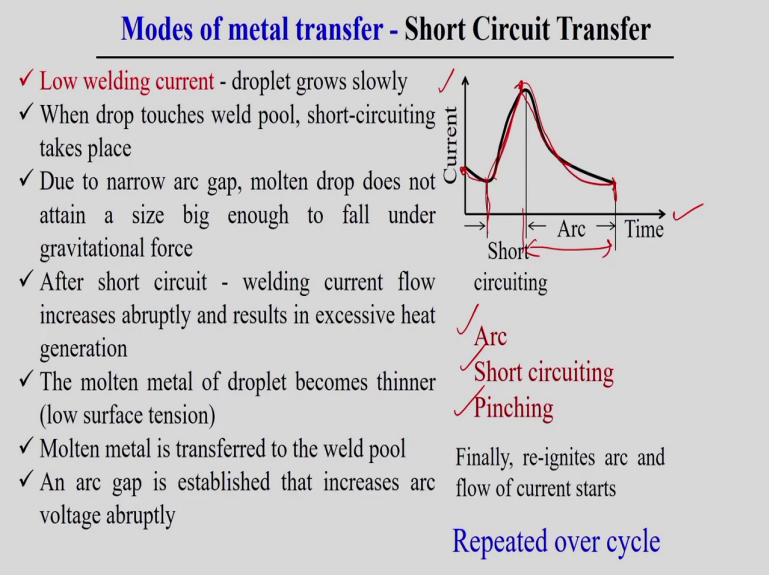

So, these are the typical condition of the spray kind of the metal transfer normally we observed, in case of the associated with the gas metal arc welding process. Now, we look into the short circuit of the another type of the metal transfer the metal transfer for circuit metal transfer. So, short circuit means, we simply understand this thing is the gap is almost 0 and

then electrode directly contact to the work piece material. Then, this kind of situation can create is a short circuit mode.

But, the how the in short circuit mode the metal droplet or metal transfer happens in welding process that we have to understand, that how there is a variation of the; the welding current during this particular mode of the metal transfer. So, it normally happens the low welding current, such that droplet grows slowly. Now, when the droplet grow slowly and the droplet touches the weld pool.

So, then droplet grow slowly and that at the same time maybe in this case the gap can be very low at the initially, such that this creation of the droplet is normally touches to the work piece. So, it is not like that, before touching to the work piece it is detached from this electrode metal not it does not happen in that way. Rather the electrode tip the droplet forms the then droplet in touch; when the droplet touch to the work piece, then short circuit mode created.

So, one short circuit takes place then the gap is since the gap is narrow, as compared to the other mode of the metal transfer. Specifically, I am talking about the with respect to the globular kind of the mode of the metal transfer. So, when arc gap is very narrow, then it touched the molten droplet touch the work piece material, then short circuit created and then molten droplet does not attain a very big size at to fall under the gravitational force.

Definitely, it is not following the mode of the metal transfer what we can observed in case of the globular kind of the this thing. So, gravitational force maybe less in these cases, because droplet size may not very big in that sense. So, therefore, once the short circuit happens then after the short circuit the welding current flow increases abruptly.

So, once the short circuit is connected these thing, then in that cases the current pass passage of the current during the short circuit period is basically, it is becomes very high because, at that time the voltage drop can be very low. So, after short circuit welding current flow increases abruptly and when there is the current flow increases very high, then excessive heat generation always be there.

So, when excessive heat generation will be there then it creates the it try to creates the more molten droplet. And, our other the if the excessive heat generation, because of the high passage of the current, it extremely lowers down the surface tension force. So, once it is lowers down the surface tension force or other we consider drop holding forces.

Then, lower surface tension force basically promote to the detachment of the droplet from the work piece material. Then, once that detachment of the droplet happens then the droplet transfer to work piece material then there is a creation of the gap. So, that some values of the arc gap is there. So, once there is arc gap we can see with respect to the arc gap there is a flow of the this thing. When the short circuit happens then against they it creates the arc.

So, once that create the arc then against melt the electrode material droplet created and then gap is very low and then this again this molten metal attached to the work piece and the repetition of the similar phenomena happens. So, these are the typical behavior of the in short circuit kind of the metal transfer.

But, remember when the short circuit happens, then voltage drop becomes very low. But, once the droplet transferred to the work piece material and there is a gap and within this gap there is a creation of the arc. So, in that cases, when there is a creation of the arc, then definitely there is the increment of the voltage drop. Then, potential difference is required to sustain the arc gap or to sustain the arc in this case.

So, an arc gap; when the arc gap is established, then the increase in the voltage are abruptly. So, there is a high increment of the voltage is there, because we know the voltage drop, or maybe the potential difference is very much sensitive to the arc gap in case of the welding process. But, what we can explain these things maybe, current nature of the current with respect to time we can see this is the current axis and this is the time axis.

So, here you can see that shorts current is initially the current is low, the once the short circuit then we touch once the short circuit created, then with the molten droplet touch to the work

piece there is a increment of the current. Now, once the increment of the current then detachment of the droplet from the electrode, then there is a decrement of the current.

And, then decrement of the current lower down, but there is a arc gap is maintained. So, arc is maintained for a particular this over this time there is arc gap is maintained. So, what is the arc gap maintained the current actually decreases, but there is a potential difference by voltage actually increases abruptly. Now, one establish these things no at this at the when you reach to this point and this correspond to this point.

So, once this reach particular point, then again the molten in between the molten droplet created and it is then droplet touch to the work piece material then similar phenomena happens. So, basically this arc short circuiting this force creation of the arc. Then, short circuiting and then pinching of the molten droplet these are the basic steps associate with the short circuit metal of the metal transfer. So, finally, reignites arc and the flow of the (Refer Time: 25:29) starts.

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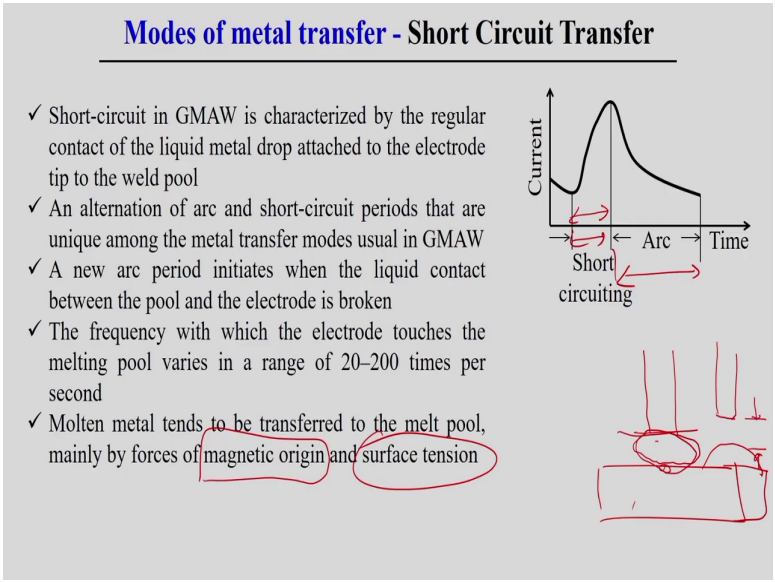

So, this phenomena actually repeated over the cycle, so this way you can explain the short circuit kind of metal transfer. Now, much more about the short circuit metal transfer we can say that short circuit in gas metal arc welding processes actually characterized by the regular contact of the liquid metal droplet attached to the work piece tip to the weld pool.

So, there is a liquid metal droplet that actually attached to the electrode that is the point, where the short circuit actually created, when there is the attachment of the liquid droplet to the work piece materials. Now, an alternation of the arc and a short circuit period. So, basically if you see there is a creation of the arc and the short circuit period the we can see that this is the short circuit period and this is the creation of the arc.

So, there is alternatively there happens this is the thing; what is the short circuiting time, short circuiting period and over the this is a arc gap or there is a maintained creation of the arc. So,

this particular time is normally maintained during the this normally associated with the mode metal transfer, or we can say the short circuit mode of the metal transfer in case of the gas metal arc welding process.

Now, a new arc period initiates when the liquid contact between the pool and the electrode is broken. So, definitely the arc is maintained once the this droplet is transferred or maybe there is a breakage of the short circuit, it means that liquid metal transfer to the work piece. So, it is something like that; maybe suppose this is the work piece material, and the electrode is there and there is a creation of the droplet. So, one it is touching this droplet and then there is a short circuit happens.

So, then short circuit happens then the detachment of the molten droplet to the work piece. So, there is a gap, so in that second time so, then there is a this is the suppose this is the work piece, so molten metal transfer. So, there is a gap between this weld pool and the electrode. So, that gap is at; when there is a creation of the gap and there is a the at the same time there is a creation of the arc will happen between these two.

So, this is the way so, but the frequency which the electrode touches the melting pool varies in a particular range of 20 to 200 times per second, in that frequency the metal transfer normally happens in case of the short circuit mode of metal transfer. So, in this case, molten metal tends to be transferred to the molten pool mainly by the forces of the magnetic origin; that means, detachment of the this things mainly magnetic origin.

The pinch force enhances and surface tension force actually decreases, and these two mechanism is responsible for the detachment of the droplet from the electrode. So, this way the short circuit metal transfer is normally work in case of the gas metal arc welding process.

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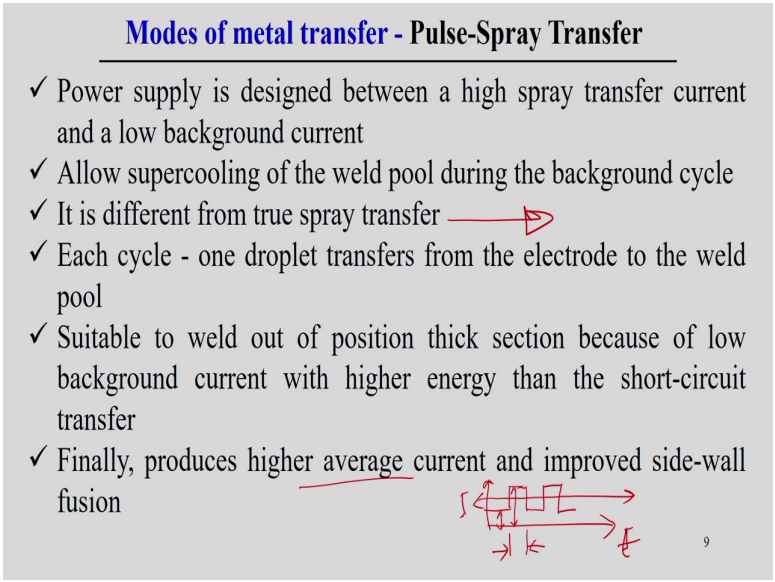

Now, there is a another kind of the mode of the metal transfer that is called the pulse spray transfer. So, pulse spray transfer is normally associated with these things, suppose in gas material arc welding process, if weuse that pulse mode of the current in that cases we can observe the pulse spray transfer.

But, how it happens? In this case the power supply is designed between the high spray transfer current and the low background current. We know that pulse characterize the I think pulse current can be something like that, this is the current and this is the time. So, it is not that the during the so; that means, some kind of the base current is there always, and design the peak current is also there, and there is a duration of the pulse.

So, this is called the duration of the pulse. So, duration of the pulse, some base current, some peak currents this is a typically characterize the pulse parameter in case of the pulse mode of

the arc welding process. So, now, so is background; low background current is very important in these cases the high spray transfer normally happens. And, the it is in these cases the spray transfer is a basically, high transfer current and the low background current is normally designed.

So, allow the super cooling of the weld pool during the background cycle. So, when there is a low background current at that period is basically these pulse of period we can say that maybe or at that low background current this thing that is actually helps to super cooling of the weld material. Now, therefore, each cycle one droplet transfer from the electrode to the weld pool.

So, from each cycle during the depending upon the very high peak current, if you observe; if you consider during the over the duration, particular duration that actually helps to the droplet transfer, creation of the one droplet, transfer from the electrode to the weld metal in particular cycle. So, accordingly the pulse is designed in such a way.

Now, this kind of metal transfer is basically the suitable for the weld out of position, very thick section out of position is in thatcases. And, this kind of metal transfer is very important, because this low background current is basically and the, with higher energy then the short circuit is basically is usable in this particular cases to handle the out of position and very thick section material.

And, this there is a particular role of the background current to cool the material. So, that is why it is out of position it is very much useful in this particular form. But, finally, produces the higher average current and the improved the sidewall fusion. But, remember it produce the finally, the higher average current.

So, higher average current is basically, depending upon the what is the background current, what is the peak current based on that we can see averaging value over the cycle create; we can find out some average current value. But, it is finally, produces the higher average current and improved sidewall fusion.

So, basically sidewall fusion, if you want to control the metal transfer all these things sidewall part, then this kind of mode of the metal transfer is very much suitable. But, remember this kind of metal transfer is basically it is different from the kind of true spray transfer. So, if you say that spray kind of the metal transfer. So, we have already discussed this thing that short circuit metal transfer; the spray transfer.

So, this spray transfer is normally there is the application of the continuous current and in this case the there are different kind of the forces are there. So, we are not modulating the current in this particular case, for the spray types of the metal transfer. But, this pulse spray transfer is basically is different, because in this case the metal transfer is basically modulated, spray type of metal transfer modulated by modulating the pulse parameter.

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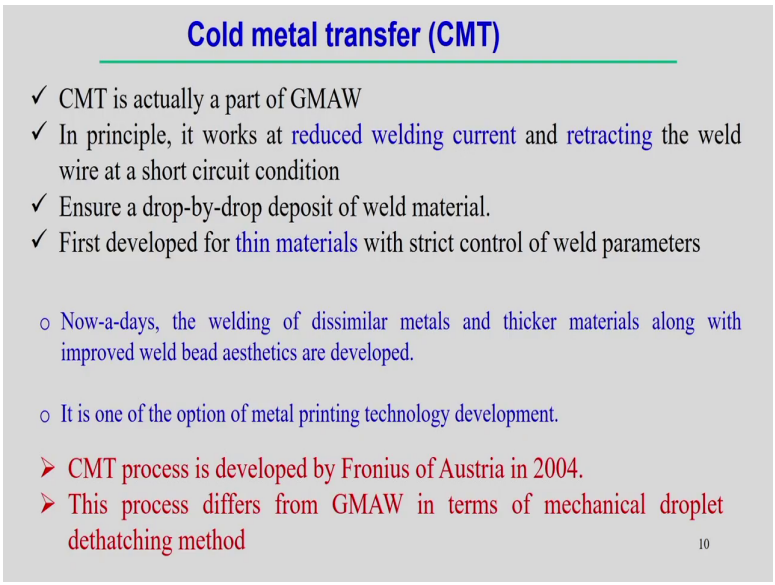

So, in this case the metal transfer is actually different from, as compared to the true spray type the metal transfer in case of the continuous supply of the welding current. Now, we look into the cold metal transfer, this is one of the metal transfer mechanism we that is called the cold metal transfer CMT, which is cold metal transfer is basically, actually a part of the gas metal arc welding process or we can say that it is a advanced level of the gas metal arc welding.

So, definitely, it works on the reduced current, so that is why it is called the use the terminology the cold metal transfer. So, reduce welding current and at the same time it is different from the GMAW in the sense that some retracting force is required at the short circuit condition.

So, basically the metal transfer mechanism is normally associated with a more controlled way by using some kind of the digitally controlled mechanical system, such that is retracted back the torch; welding torch. And, then at this time this metal transfer normally happens in the short circuit mode also. But, we will see how it is different from the gas metal arc welding process also.

Now, it ensure a drop by drop deposit of the weld material that we can it is a drop by drop deposit of the weld material. And, this drop by drop transfer is basically is very high frequency control; that means, the drop by drop transfer, but frequency can be very high also. And, weld control size and shape of the droplet in this case. So, first actually cold metal transport was developed to handle the thin material or with the strict control of the weld parameters.

So, basically strict control of the weld parameters means, basically the droplet transfer is normally happens over a narrow range of the weld parameters. But, now, the advancement of the metal transfer is done in such a way that the welding of the dissimilar material, even very thicker material allow with a very good weld bead aesthetic parts are normally developed, using this particular kind of the metal transfer..

So; that means, controllable metal transfer in other way helps to bring some kind of the aesthetic part of that weld bead profiled. So, that is why it is different from the or we can say advanced level of the gas metal arc welding process, because here we can control the metal transfer.

So, that is why it is one of the options for the development of that different printing technology using the, this mechanism of the cold metal transfer. So, CMT process is not new it is a developed by Fronius in the year 2004. And, this process is different from the gas material arc welding process in terms of the mechanical droplet detaching method.

Because, gas metal arc welding process; the detachment of the molten material is happened depending upon the phenomena, depending upon the different kind of the driving forces. So, there is no need to control some apply kind of the mechanical motion to the torch. But, in this case the some kind of the mechanical drop detaching method is normally used, in case of the CMT method.

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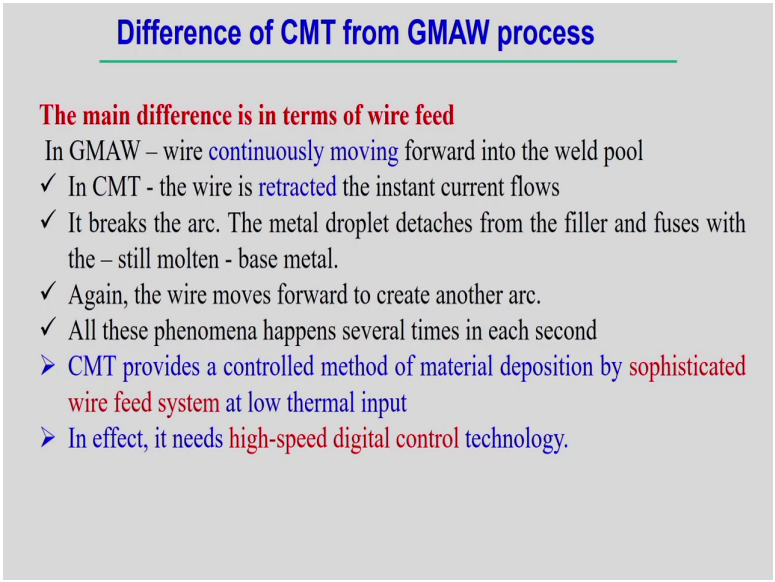

So, that is why in that point of view the metal transfer is different here also as compared to the gas metal arc welding process. Difference of the CMT process cold metal transfer from the gas metal process, by looking into the different points here. The main difference is the in terms of the wire feed. So, in terms of wire feed, because in these cases gas metal arc welding process there is a continuous moving of the wire into the weld pool.

So, there is a continuous forward motion of the wire; during the gas metal arc welding process we normally follow. But, metal are this the we normally use this particular mechanism in case of the gas metal arc welding process. But, in CMT the at some point it is there is not continuous flow of the wire, in some point there is a wire is retracted back at the instant of the current flow.

But, at the particular point which retracted back is basically the in a controlled way, and very magnitude is also very low. Such that only purpose is to the retracted wire such that it enhances the material transport to the work piece material. So, once the retracted back is there this basically in the instant of the current flow, it breaks the arc. So, once the breaks the arc; the metal droplets actually detaches from the filler wire, or from the electrode and fuses with the, steel molten with the base material.

So, it is a this way the metal is basically transfer in the in this particular process. Now, once it is done metal transfer against the wire is moves forward to create the another arc. So, move forward to create the another arc and all this phenomena normally happens several times in a one single second.

So, basically depends on the frequency the this the high frequency it is possible to maintain, this basically retracting back the molten wire such that droplet will be stick to the molten pool and, basically transport to the droplet to the molten pool. And, again next again forward motion; given the forward motion to the wire and such that for after forward motion to the wire then arc is created. So, it is a basically digitally control all this phenomena is there in associated with a CMT process.

Now, CMT provides a control method of the material deposition by sophisticated wire feed system. Very sophisticated wire feed system, because this is the main part of the CMT process. And, all this normally happens is basically metal transfer happened everything adds a more relatively low temperature, or maybe you can say adds very low thermal input.

So, basically in effect it is needs the basically high digitally controlled technology, high digital control technology for the mechanical detachment of the droplets so, retracting back and forward motion to control in this particular process. So, that is why this is the advancement of the as compared to the GMAW process.

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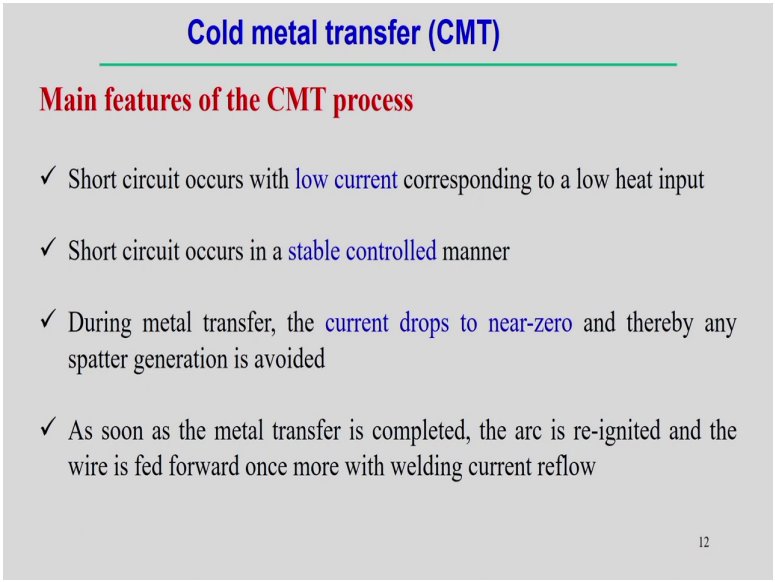

Now, what are the main features of the CMT process? If we look into this thing the main features of the CMT process is like that, that is definitely it is also associated with the short circuit metal transfer occurs but, this short circuit occurs at very low current and at the same time it is corresponds to the very low heat input.

So, at very low current and it is a very low heat input this short circuit normally happens; in case of the CMT process. And, short circuit is normally occurs, as a very controlled manner. So, that is why digitally controlled system is required. So, such to that can be successfully transferred the droplet to the work piece material. Now, during the metal transfer definitely the current drops, we have already seen that the characteristics of the short circuit more than metal transfer.

So, basically during the metal transfer the current drops to near 0. So, because it is a basically at the time of the metal transfer and thereby any spatter generation is avoided. In this particular process when the metal transfer happens the current drops near 0, because it is a retracting back to these things so, break the arc at this point. So, therefore, current tends to becomes almost 0, near the 0.

And therefore, once the metal transfer happens at a very low current or almost 0 current it means that, we can avoid the possibility of the spatter formation during this metal transfer in associated with the this particular process.

So, it is necessary to mention that even gas metal arc welding process the spatter formation is one of the problem, associate during the metal transfer also. But, it happen it is there are so many parameters influence actually this spatter formation.

But, in it is a common problem associated with a gas metal arc welding process. But, in CMT process; the metal transfer happened in such a way that is a very low current or almost 0 current that is why, the spatter formation can be avoided in the particular process. So, that is why we are talking about this thing is a very controlled way metal transport is possible in the CMT process. And, that is why it is also very much suitable for the development of the metal printing technology.

So therefore, as soon as the metal transfer is completed; once the metal transfer is completed the arc is reignite. So, reignite the arc, arc is created, because there is some gap at this point and at the same time reignite at the same time the wire is moved soon forward. Because, initially the there is some backward retracted back to the particular position the same amount, the wire is some forward motion has given to the wire.

And, once again and then reflow of the current starts and there is a again the droplet creation of the droplet and (Refer Time: 40:34) on the droplet. Then, once you touches to the work piece material then wire is retracted back, such that the droplet will transfer to the work piece.

So, this is the repeatedly this process is normally followed and this followed over a particular frequency in this cold metal transfer mechanism. So, that is why these are the typical features of the cold metal transfer, and which is different from the metal transfer in as compared in, as compared to the gas metal arc welding process.

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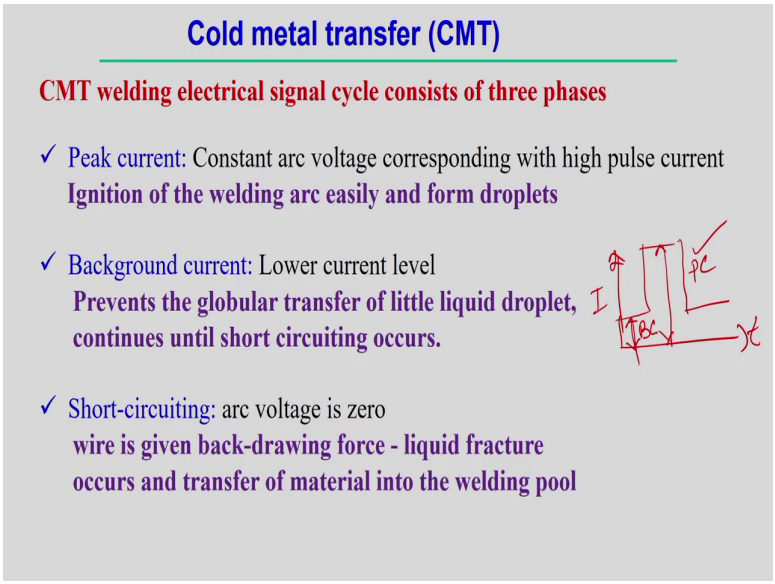

Now, in depth the CMT welding looking into this thing; how the metal transfer is as a CMT welding processes. The in CMT welding the electrical signal cycle consists of the basically the three phases. First phase is that the peak current is very important the peak current, in this case the constant arc voltage corresponding with a high pulse current.

So, we definitely (Refer Time: 41:26) the CMT also normally use the pulse mode of current. But, pulse is modulated different way to cater all this kind of metal transfer here. So, one peak current is follow we know then in specific pulse if we define one particular pulse the

peak current is followed. Constant arc voltage with the high pulse current is follow; this actually helps to ignition of the welding arc.

So, initially if we apply the very high pulse current, so high current is basically ignition of the welding arc becomes more easily. And, the creation of the droplets will be more easily at the very high peak current. So, that is the one part, the peak current is normally followed, but it is normally happens the constant or voltage. Second part is the background current.

So, background current is the very lower current level is followed in case of the background current in a particular pulse. So, in a particular pulse we you can say that suppose this is the pulse current. So, this is the background current, so this for example, this is the current and this is the time.

So, pulse this is the background current and this is the, this amount is the peak current. So, background current is low and peak current becomes normally high this is a typical characteristic of the pulse associate with the CMT process. Now, background current lower current level, so how it works?

The if lower current levels prevents the globular transfer, because current level is low, it actually prevents the metal transfer in the form of the globular kind of the form, rather than we can create the particular size of the droplet depending upon the parameters chosen. So, therefore, it is avoids the globular metal transfer if background current is becomes low.

And, up little liquid droplets, so basically the with the application of the pulse current when the droplet forms. Then, we can control the in such a way that the droplet, but would not sufficient time to grow in the bigger size of the droplet. Once a particular size droplet is reaches and that that is basically, accelerated by the by following the lower level of the background current.

So, prevents the globular transfer of the liquid droplet and continues until the short circuiting occur. So, background current happens then until the short circuit occurs means that, it is lower level background current is followed. Until or unless short circuit means, that when the

whatever droplet has been created with the application of the high peak current that droplet will try to touch through the work piece material.

So once touch the work piece material then the short circuiting happens. So, therefore, until and unless the short circuit happens it is maintains the low background current. Now, once the short circuiting happens in this cases, one the again the short circuit happens, then the we follow the detachment of the retracting back of the wire such that this; whatever size of the droplet it will transfer to the work piece material.

So, once the short circuit happens then the arc voltage is almost, definitely we know that if there is a short circuit current arc voltage is very low. So, there may, because there is no arc gap is it is basically not necessary to maintain the arc or to maintain the arc gap. So, in that case the voltage becomes very low and thus short circuit happens immediately the wire is retracting back giving the back drawing forces such that the liquid fracture happens between electrode and the droplet.

And, the droplet becomes part of the molten pool; that means droplet transfer to the molten pool. So, it becomes transferred to the molten welding pool. So, these are consists of the three different phases associated with the CMT process. Again, I am repeating this thing first is the peak current is the one phase then, background current is a one phase and what is the role of the background current also we can see. And, then short circuit we can use the another phase.

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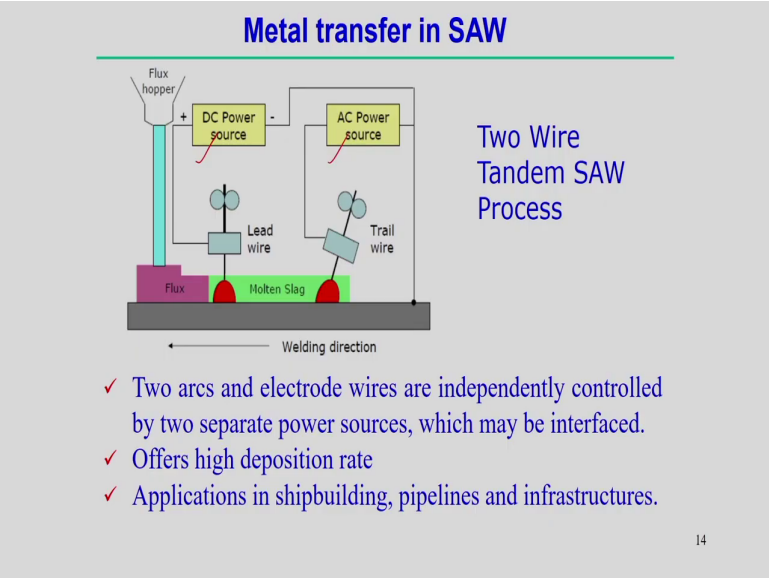

So, apart from this metal transfer and the CMT and gas metal arc welding process, we can see the metal transfer in the submerged arc welding process. But, submerged arc welding process; the we know the submerged arc welding process the everything happens this arc is over the slack or below the flux. The arc is created below the flux, this is covered with the flux arc is created and there is the metal transfer from the droplet.

But, submerged arc welding process is mainly applicable when there is a need to join the very high thickness material. So, in that cases the submerged arc welding is the most suitable. But, the development of the submerged arc welding in terms of the metal transfer is normally happens in the what. For example, in this case we can see that two wire tandem submerge arc welding process.

So, two wire; so, metal transfer happens from the two different wire. So, that two different wire, where the metal transfer can be controlled independently. So, this kind of development is normally happens in case of the submerged arc welding process, as associated with a metal transfer.

Now, here you can see that the two arcs and the electrode wires are independently controlled. We can see this thick tandem, two wire tandems submerged arc welding process. So, AC power maybe we can see one wire the lead wire it is can be in the DC power source and the trail wire can be the AC power source, such that metal transfer can be controlled. And deposition; normally, the metal deposition rate is very high in case of the arc this tandem submerged arc welding process.

So, two arcs and the electrode wires are impudently control is possible by two different kind of the power sources, which may be interfaced and maybe interface in these cases also. But, this very high when there is a requirement of the very high deposition rate then in that particular case, we can follow this kind of the metal transfer mechanism.

So, application in the ship building very big structure we want to make and the pipelines infrastructure in that cases, we can use the metal transfer using the submerged arc welding process. But, so far there is no use of the this metal transfer mechanism associated with the submerged welding process for the development of the any kind of the additive manufacturing process.

So, for that kind of development is not, because there is some instinct difficulties is always there in metal transfer and submerged welding process or even this particular welding process, such that it is very difficult to make the automated system, which can be applicable in case of the additive manufacturing process. So, that is why not much detail explanation or information may not be required associated with the metal transfer in the submerged arc welding process.

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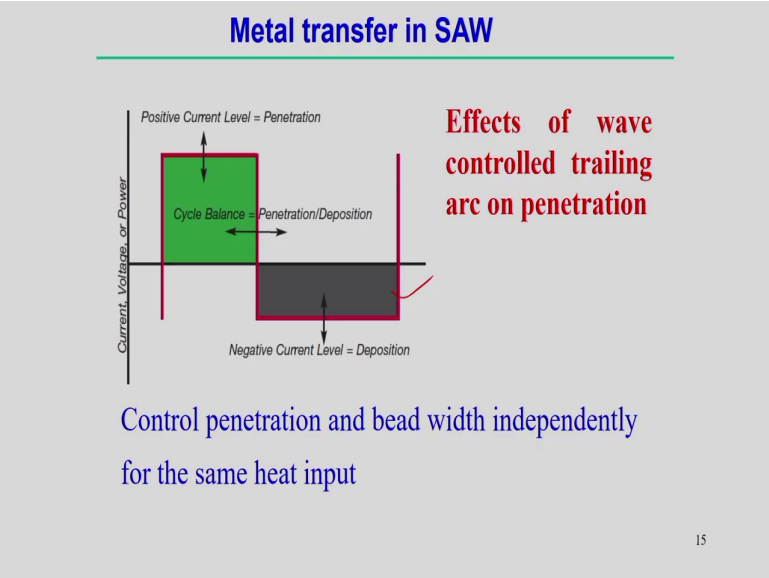

Even we can see that the metal transfer submerged arc welding process, that there is a effects of the wave control trailing arc on penetration. So, basically we can see the what we can control the penetration also in arc welding process, by simply changing this thing. So, positive current level, the current balance positive current level if it is a positive current level that actually enhance the penetration.

And, this thing that this negative current level is basically control the deposition. So, negative current level, basically control the deposition, and positive current level is basically enhance the penetration depth of penetration it can enhance in this cases. So, looking into these two aspects maybe, it is possible to modulate the metal transfer at the same time or maybe to modular the deposition in a controlled way.

The deposition can be; deposition can be controlled at the same time the penetration can also be controlled using this particular wavy nature of the power supply in this case. So, that is one the power source can be designed in such a way to take this advantage of this particular positive current level and the negative current level. So, that actually control penetration and the bead width independently, for the same heat input it is possible to using the submerged arc welding process.

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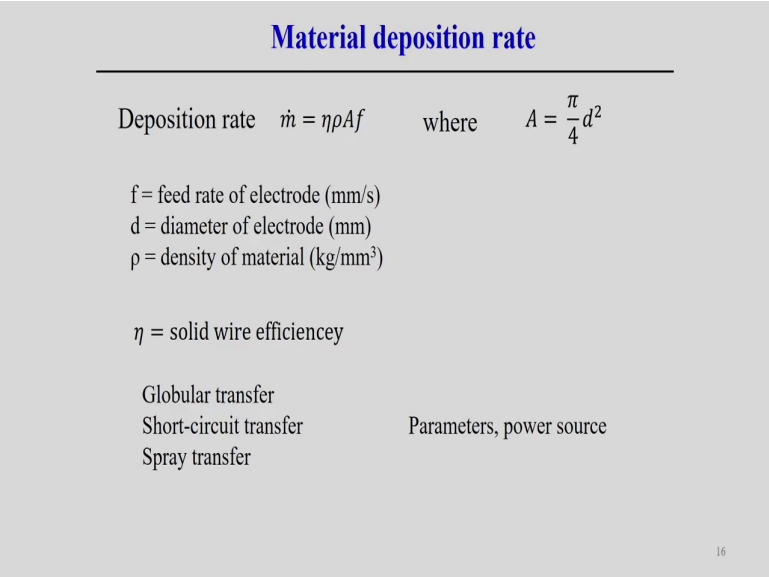

Now, I think we have discussed that the what are the different kinds of the metal transfer and that associated with the gas metal arc welding process. Basically, we are talking about the mode of the metal transport in the gas metal arc welding process but, apart from that we have discussed only on the CMT process and we can see that how the CMT process is the

advantageous in terms of the metal transfer mechanism, as compared to the gas metal arc welding process.

Even we have discussed about the submerged arc welding process and basically associated with the metal transfer and what were even in submerged arc welding process there is a possibility to control, to design the particular power source such that the metal transfer or deposition rate can also be controlled.

So, these all are useful to understand the basic mechanism of the metal transfer associated with the; associated with the arc welding processes, which process normally use the consumable electrode. So, thank you very much for your kind attention for this particular module. And now, next class we will try to discuss about the; what are the different modeling approach or maybe sample calculation associated with the metal transfer in arc welding process. So, thank you very much.