Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 14
Principles of Gas Metal Arc Welding - Part - II

So, we will move on to the metal transfer characteristics of a droplet from the electrode towards the work piece. So, as we look at in keyhole a keyhole stability is also determined by the various force balances. The metal transfer characteristic GMAW also is determined by the balancing of forces bit that opposes the droplet and detachment and those forces promote the droplet detachment.

Based on the forceful balance, the shape of the droplet that is transferred from the electrode tip the work piece changes. And we looked at in some of the videos in the earlier slides, spray transfer and globular transfer. The mode of transfer is entirely determined by the balance of forces that I displayed in this slide.

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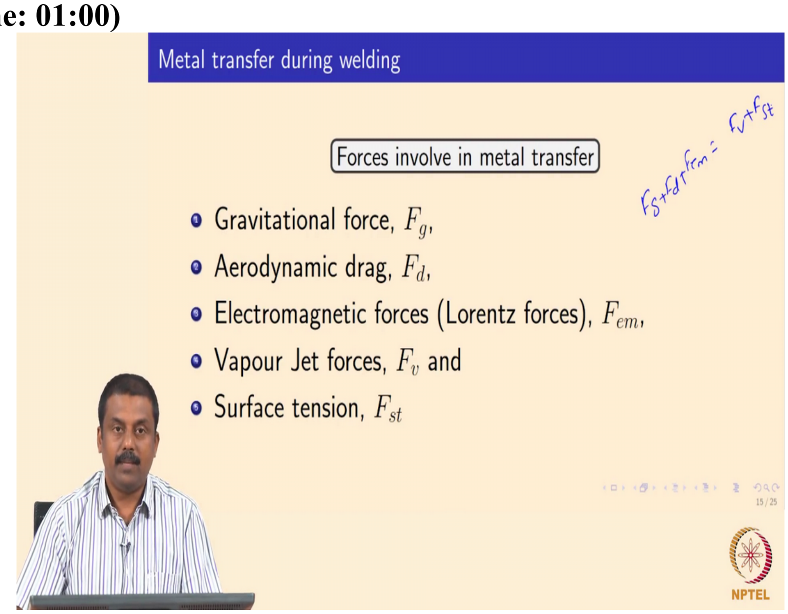

So, there are 5 forces that dictate the transfer characteristics. The first one is a gravitational forces and the gravity when you are doing in a down hand welding that the welding is done when it is then down hand. The gravity always aids interplay detachment because gravity pulls the droplet towards your work piece. And then, the, the plasma drag forces or economic drag forces that is actually nothing but the force, the plasma, the force generated by the plasma jet of, of an arc.

So, the arc is not really plasma so but therefore in the arc welding processes we say it is an aerodynamic drag given by the, the force of the arc and the shielding gas that always aids the droplet detachment as well. And then, the third one is the Lorentz forces, Lorentz forces which is actually determined by the converging and diverging the electrons and ions and the basic particles in the in an electric circuit.

And the Lorentz force also always aids the total detachment. And then the two forces that oppose the droplet detachment are the Vapour jet forces. Vapour jet forces are generated because of the vapourisation of your base material. And these vapors are generated and then sent towards the electrode which always opposed the detachment of droplet. And of course surface tension off the droplet molten droplet aids it always opposed the detachment of the droplet from the electrode tip.

So, obviously see the force balance is nothing but so in this case the Fg + Fd + Fem and if that equals the vapour forces and the surface tension, then, you will have a stagnant in the droplet because detaching forces are equaling the opposing forces. So, your droplet will be in equilibrium but if any one of the forces exceeds, obviously, you will have either detachment or opposing detachment.

For example, if a droplet grows in size big enough, so obviously, Fg in the gravity would pull the droplet down because the gravitational force increases significantly and Fd again it is Fd's determined by your the shielding gas velocities for example, or you have plasma characteristics if you are doing plasma welding or if we also have an arc force that will also determine your Aerodynamic drag force. And then Lorentz force is obviously the, another important factor that determines the metal transfer.

And then the droplets characteristics and the Lorentz force. Generally it is a tabular transfer and if you increase the current so you also increase Lorentz force. So obviously you can then detach the droplets in much more smaller size where Lorentz force supersedes your gravity effect. And so at lower currents you can imagine and that in the main important is the force that detach it droplet from the electrode tip is the gravity because the Lorentz force is minimal.

So once a the electrode the molten droplet and against enough mass so it can be pulled by the gravity so that it determines the detachment characteristics. And if in case the current obviously the Lorentz force supersedes the gravity, then, the droplet can be detached with a smaller diameter or with a low mass, so of course, if you have in a very high amount of vapour jet forces that will also determine your shape of the droplet to be detached, from the electrode tip.

For example if you have a very low current and your droplet is growing in size, in diameter then the vapour jet force can also change the shape of the droplet into globular ripple into the globular and because of the vapour jet force, vapour jet coming from the work piece. And of course surface tension is also a function of your droplet liquid droplet composition so that will also either that will also resist to the droplet detachment. Again that can be controlled by changing your changing the composition of the electrode.

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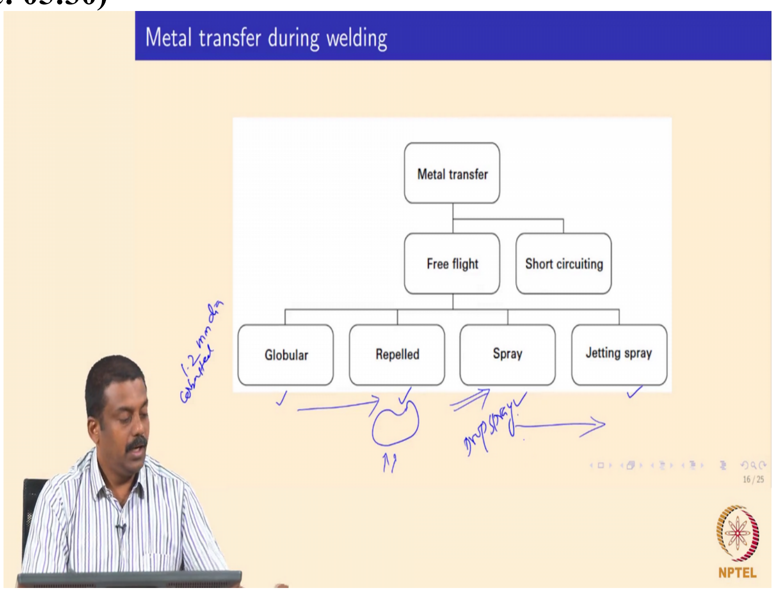

So, based on the force balance I said it explained which force is actually promoting the droplet transfer and we can classify the transfer in majority in four mode. So if you look at a free flight transfer, the free flight means droplet is transferred, transferring from the tip to the work piece in a smooth, without any contact between the tip and the work piece. So, in the free flight mode and so there are 4 types of transfer generally observed: The globular, rippled, spray and jetting spray.

So, the goal globular transfer it happens it in I mean for a given diameter of the electrode. For example, a 1.2 mm which is commonly used to diameter electrode in common steel. For example globular transfer happens; globular transfer happens at lower currents and because I already explained when the current is lower, Lorentz force is very minimal so the main force that actually aids the droplet transfer is the gravitational force.

So you need to have a mass created the moment you have the moment the droplet is grown in size obviously the gravitational force can pull the droplet in a globular format. So, if you increase the current slightly so you also generate some Lorentz force as well as because of increasing current you may also tend to vaporize. So both increasing a lot Lorentz force and lead to a generation of local magnetic field which can repel the shape of the droplet from complete globular to shape often like a shoe of a buffoon in the in circus, so something like this.

So this happens because of the increasing in the vapor pressure from the work piece which actually acts opposing and acts against the detachment of the droplet as well as the increasing current can lead to a change in Lorentz force locally a magnetic field can change the shape from the globular to and repel the globular. So upon attaining the mass obviously the gravity can pull the droplet down and which is known as a ripple to transfer.

And if you increase the current so obviously the droplet transferred more changes to spray mode and in spray mode you transfer the droplet and continuously where the diameter of the droplet is much smaller than what you see in globular and rippled mode. And so this happens by increasing the current significantly where were your droplet can be transferred with a very low diameter compared to the globular and ripple.

And this transfer is possible by increasing Lorentz enforces. Lorentz enforces aids it operates detachment significantly wherein the important droplet can be transferred in much smaller diameter. And the generally, diameter in the spray mode is considered better for a good stability and even you were doing in as transfer in spray mode, if the droplet diameter is similar to your wire diameter. And spray mode is generally acceptable mode if you have a very stable spray transfer.

And you also have a more volume of material transferred per unit time as well as the stability of the process can be controlled much more easily as I showed you in the video. And if you have a continuous spray of a droplet with a diameter similar or smaller to a wire diameter, you can transfer the droplets to the work piece uniformly without any spatter. And of course because of the transfer rate increasing transfer rate and you will also have a very good productivity.

So, if you increase the current even further and obviously you also increase the melting rate of the electrode and you will end up melting more and then you would also reduce the droplet diameter significantly, you will end up having a spray velocity increase, compared to the conventional spray mode. And you will start having in a stream of molten droplets continuously transferring and in this smaller it is not generally advisable because and because of increasing Lorenz in process you may also have a local disturbance in the transfer.

And so we may end up having an spatter and because of this increasing Lorenz reinforces. So this kind of jetting spray can be used for some applications in the in a coating. For example like if you are doing a cladding surface cladding applications where you need to have when a very high productivity. So we can have jetting spray induced by increasing the current significantly.

But for welding applications the most of the cases the most preferred the transfer mode is in a spray mode just above the transition between the repelled to the pro spray so that we can the; we can transfer the droplet similar to the diameter similar to the electrode fill wire continuously and that transfer is most preferred. This also known as drop spray where you will have a single drops of droplet continuously transferred or sprayed to be work piece when the current is just above a critical value and that critical value is known as the spray transition current.

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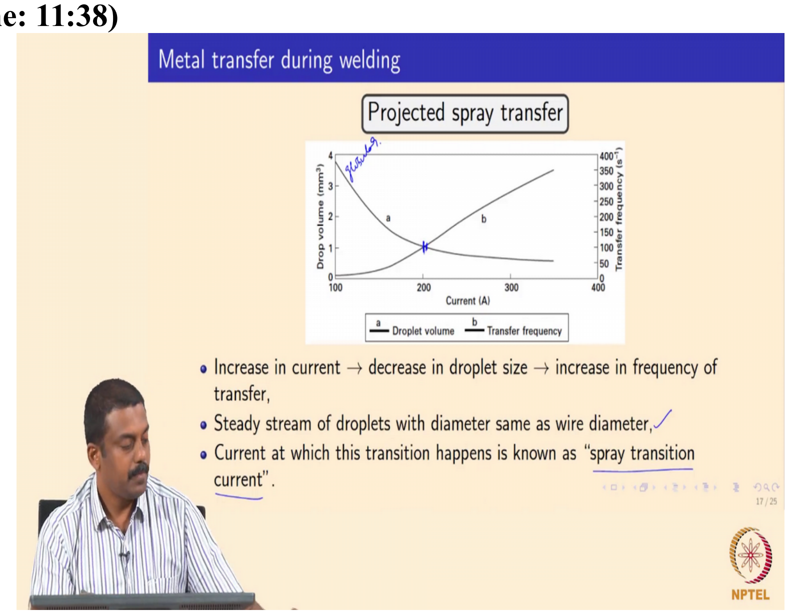

So, this graph already showed, it shows the influence of the welding current, on the droplet diameter as well as a droplet frequency. It is for a given current, you can see that and now in the A drop volume is nothing but a diameter you can say, as function of diameter and the other graph B is the transfer characteristic or transfer frequency. So, obviously a slide explains to know at the lower current and the most significant transfer more is a globular transfer, where the gravity gravitational force is a major force that detaches the droplet.

So, in order to and it has a droplet obviously you need to increase the size of the droplet significantly so that the gravity gravitational force can pull the droplet down to the work piece. And if you increase the current obviously you can also transfer with a lower diameter because of the influence of Lorentz field forces. So at a given current and where you see and the transfer mode the changes from the globular or ripple globular to these spray mode and that is current the critical current is actually known as a spray transition current.

So, this is an important parameter and GMAW where in order to get good aesthetics of the weld as well as the spatter free stable welding. We generally operate in and around the spray transition current where we can transfer droplets within a diameter equal to the fill wire to the work piece continuously in a spray mode. So, if you further increase the current obviously you also increase the melting rate that will lead to the jetting spray mode.

Of course, your productivity will increase, but your process stability can be affected significantly, okay. So the ideal situation of the transfer is the event is the steady stream of droplets with the diameter same as the welding diameter transfers from the electrode tip to the work piece. So that is the stable conditions we always aim for. And that happens generally just above spray transition current.

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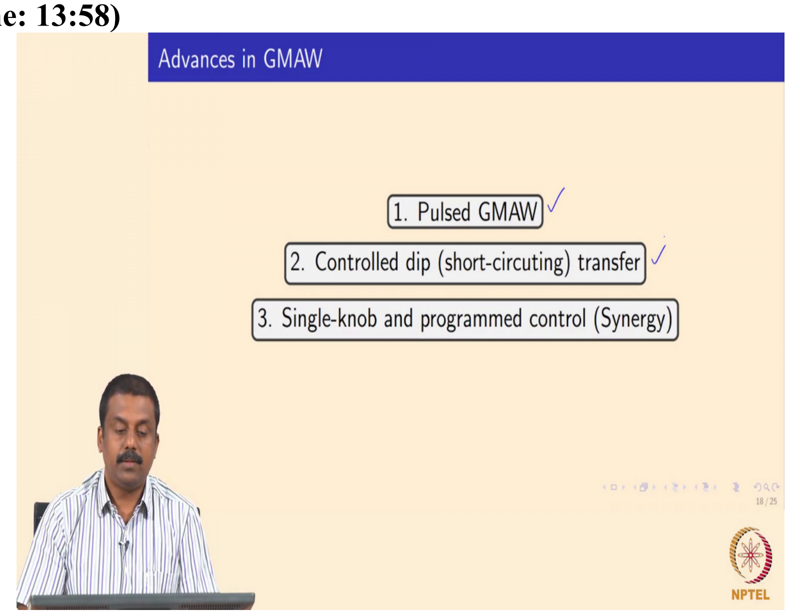

So, far we looked at the conventional GMAW process. But there are some disadvantages of using a conventional GMAW process. For example, if you use an a constant current often a given amperage like in previous graph we showed 200 amperes is the mean current already the transition current but we apply a constant amperage of 200 amperes so then you may also increase the heat input significantly okay.

So, but so we like to apply that ampere H in order to get this spray transition to get an stable transfer characteristics but we may also get similar transfer characteristic by instead of using a constant current and by using a pulsing. So, we can introduce in pulsing in current waveforms or voltage waveforms to promote the spray transition. So, in we can do a pulsing. By doing pulsing, we can also reduce the mean current significantly.

So, by using pulsing we can achieve a spray transition in a much less mean current than otherwise if you use the constant current. So, the pulse GMAW is also one of the most attractive processes to reduce the heat input considerably but still achieving a spare transition. So, for the automotive applications, this also used as a favorable process because we reduce the heat input significantly by reducing the mean current.

So, obviously but even if you use the mean current because of the pulsing of the current or voltage we may still get the spray transition achieved at the work piece even to transfer the droplet in a spray transition mode. And the other development we have made in GMAW is the control dip transfer process where we transfer the droplets in a surface heading mode during this surface heading mode we also significantly reduce the heat input by reducing the current or a voltage close to zero. So, that when the droplet is transferred, it will be transferred transparent in cold conditions compared to the conventional GMAW or even pulse GMAW.

Therefore the heat input of the process decreases significantly and this process is nowadays is used very widely in automotive industries especially in order to do an bracing of a low melting filler and to join advanced high strength steels or even to weld aluminum alloys; aluminium and steel joints, where we can significantly reduce the inter metallic formation by reducing the heat input significantly. So, we look at these two processes and then third process obviously the development made in the process control side where we can control all the parameters what I explained in voltage current wire feed rate and the melting characteristics just by turning a single knob and using an programmed, programmable power source.

So, we can vary yeah we can control the entire process and stability in case significantly. We touch upon all the aspects of the single knob program controlled the power sources with known as a synergy. Synergy via process and then we lined up the welding processes as we move on to the welding metallurgy case.

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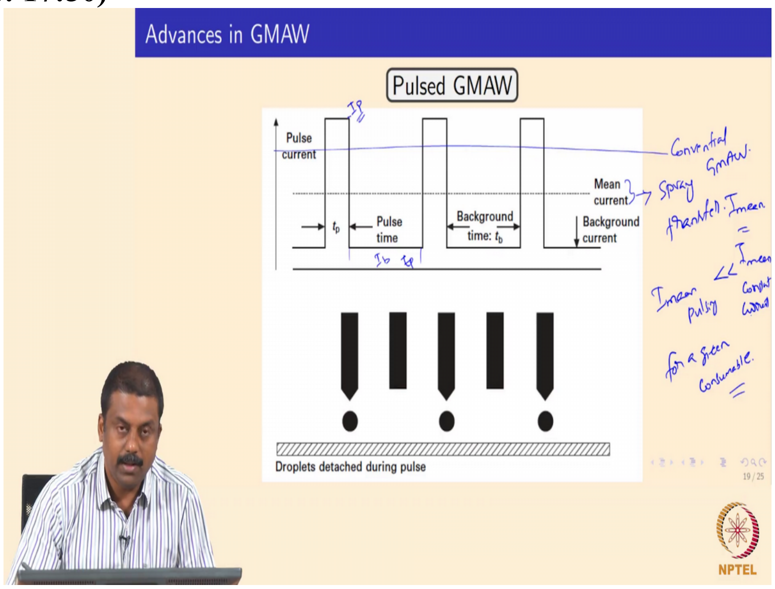

Now first I said explained the pulse GMAW the pulse GMAW process is very widely used in order to reduce the mean current of the process so that we can also reduce the and the heat input. So, the main advantage of using pulse GMAW as already explained, so we can attain the spray transition at much more mean current lower than the, if you use a constant current.

So, in a pulsing current what we do is so instead of having in a continuous current in a conventional GMAW, so we have a current pulsing, so where we have a pulse in current is given for example two and a pulse current which is much higher than the conventional mean current and then we vary the pulsing period which is tp and then the background current Ib and then we also have a background time which is tp.

So, by carrying out such a current pulsing and because of the increasing the current during pulsing in Ip, so you form you melt electrode tip and the transfer the droplet at this pulsing period and then your background period either you maintain the arc or you can also extinguish the arc and then subsequently when you have in second cycle, second pulse is happening you may again strike an arc and then melt the droplet and then transfer the droplet at each pulsing period.

And so because of the nature of the pulsing the mean current what you achieve in this the pulsing is sufficient to get a spray transfer and this Imean what you get in a pulsing process will be much, much Imean of pulsing is much lower than what Imean in a conventional process in constant where you have constant current without pulsing for a given consumable. So, if you have a 1.2 mm say carbon steel consumable if your Imean is in 200 amperes when you have a current pulsing where your, the IP the pulse current and can go up to 320 and 350 amperes.

But your Imean will be decreased significantly into the range of 150 amperes. So, in this case again we can also control the heat input because your Imean decreases significantly and therefore you can also reduce the damage you are done in the for example heat affected zone of the microstructure, width of the heat effected zone. And of course you can also reduce the dilution as well as if you are being an dissembler welding of aluminium steel you may also already use the inter metallic formation by reducing the heat input.

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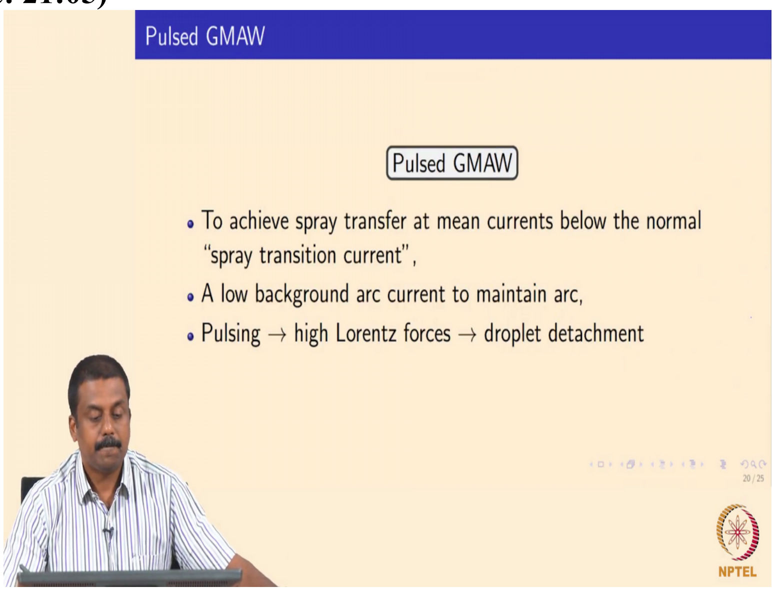

But again compared to the conventional welding process so pulsed GMAW's we use it to achieve the spray transfer as mean currents much below than the normal spray transition when you use the constant current. So, we maintain a low background sometimes to strikes to keep the arc all the time on because if you the background current reduce it to much lower than your arc may be extinguished.

And then doing the ignition you may also affect this stability of the weld pool. So, as already explained, because of the pulsing and the Ip, the peak current induces high Lorentz force which means the droplet detachment. When IP is given the peak current is given which promotes the droplet transfer in spray mode. So I will show you in one video.

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So this process again I, we have done it with the tandem two electrodes. So if you see each electrode is actually given with a pulse current whenever there is an pulse you melt an electrode tip and then a droplet is transferred per pulse. And these properties attached in a drop spray mode where the droplet diameter is similar to the electrode diameter. In this case, because we do not maintain the current I have done mean current in conventional GMAW process.

So, we increase the current only during pulsing period and then during background period we maintain a very small background arc. You may see in this video. So, because of the use of both mean current and both pulse current and the background current so we have a most stable process where we detach the droplet per one droplet and per pulse. And then by changing the frequency of the pulsing, we may also hang change the droplet transfer frequencies.

So, the main advantage of this process pulse GMAW is we achieved the spray transfer it much more mean, lower mean current than a conventional GMAW and because of that we reduce the heat input significantly.

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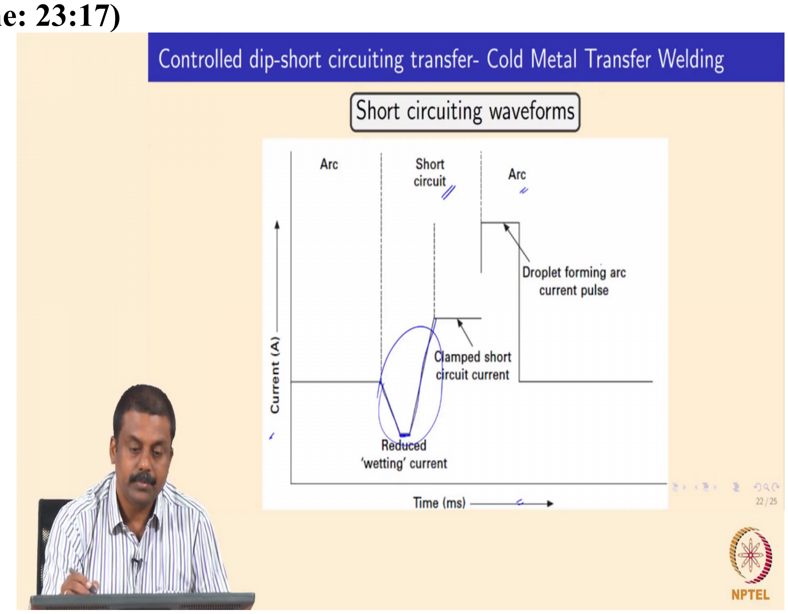

See other developments we have done in control in the heat input especially in order to minimize the damage in terms of the materials to minimize the heat input. And therefore we can also improve the mechanical properties of the weld by controlling the microstructure. So one of the developments recent days which is actually coming up in a very widely in automotive industries is the control the dip short circuiting transfer cold metal transfer welding processes.

So, one such process is commercialized by a very famous welding company and the trade name is known as the cold metal transfer welding CMT. You must have heard about it. And the CMT, then the process which is technically known as controlled dip short-circuiting metal transfer process where we have a metal transferred by short circuiting process primarily. During the short circuiting, we completely reduce the current or voltage to an a very low level so that when the droplet transfers from the tip to the work piece it transfers the without the influence of the arc.

So, the heat input of this process decreases very significantly compared to the conventional GMAW or even with the pulse GMAW and the waveform is slightly complex. And this transfer this process is achieved both by controlling the waveforms as shown in this graph where we have a current and then time. For example, when you have a control current short circuiting where we have when we have the arcing current, which actually forms an arc and the moment you have the droplet actually formed at the tip.

Then, the, welding electrode is actually moved towards the work piece and during this process the moment the short circuiting is established the current reduces significantly. And then it maintains at a very low current which is known as a wetting current and which actually we used to perform a pendant neck of the electrode of the droplet. And then when your current becomes extremely low and your arc also extinguishes, and then because of that process your heat input decreases significantly.

And subsequently upon such a coating and your, the electrode is retracted back to its original position and during this process we also increase the current significantly so that you know you form an Neck as well as the surface tension driven detachment happens. Then the droplet is transferred when the wire reads detracted from the pool and simultaneously slightly increase in the current so that you form a neck and the droplet is detached to the work piece.

And subsequently when the electrode is completely attracted obviously your, current is increased to maximum levels to strike an arc and then the cycle continues to the next cycle. So, the trick over here is to reduce the current once the short-circuiting is happened and upon decreasing current so you extinguish the arc and then droplet is transferred when the wire is retracted towards their contact tip.

And during this process in the current is slightly increased so that you form the neck by the increasing Lorentz force and the surface tension would lead that is of the molten pool will detach the electrode and the molten droplet onto the work piece. And doing this process because of the absence of arc your droplet is transferred with extremely low heat input compared to when you have a transfer either by pulse or by conventional GMAW.

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So I will just show you one video of this process where you can appreciate the process characteristics. So, what you see over here is, so this is your lurking pace where we have a high current and then you have an short-circuiting following that arcing and then moments of short circuiting happens your arc extinguishes. And then a moment your arc short circuiting happens your current becomes close to zero.

And then droplet is transferred by the forces by slightly increasing the current as well as the surface tension when the droplet is retracted from the pool towards the contact tip. So if you look at it very carefully here when the droplet is actually transferred to the work piece, the arc is completely extinguished and then properties transferred by the surface tension of the pool as well as the slight increase in current driven by the wave form.

And because the droplet is transferred with a very low heat input and this process is known as Cold Metal transfer because when you were transferring droplet the droplet is transferred without the presence of the arc. So therefore the superheating off the pool is avoided by the continuous and because of when you have a continuous arc extreme present then you may also superheat the pool. But in this case and because of the absence of the high current and the arc current and you transfer the droplet with much more lower heat input than the conventional GMAW or pulsed GMAW.

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So, this process is now very attractive for automotive applications because the heat input of this process decreases significantly. And we also have control over transfer characteristics. We can also change the short circuiting frequencies as well as you may also introduce a pulsing between these short circuiting events so that you know we can also change the transfer characteristics and the productivity of the process.

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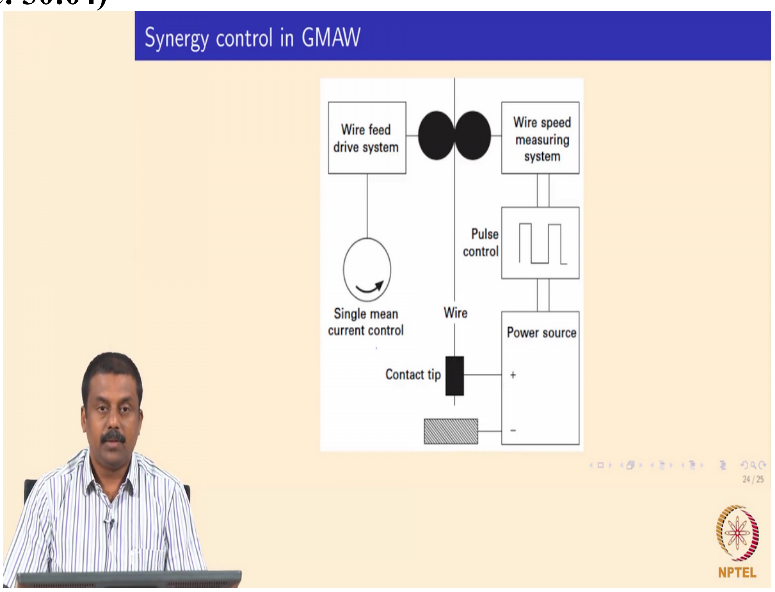

So, these kind of the complex mechanism, complex process parameters variations can only be controlled nowadays by the invention of synergy power sources, where the because of the control over the input current and the voltage as well as the wire feed rate and using a micro processes based on the power sources so we can independently control the wire feed systems, the current voltage, we can measure the waveform simultaneously.

And then say for example if you look at the CMT process, Cold Metal transfer process, see the wire feed rate, the voltage current and the arcs will be synchronized in such a way that whenever this short circuiting happens in the voltage, all systems will be measured. And then the moment we measure the voltage, close to zero then, we identify the subsequent event and then simultaneously current has to be minimized and then the wire is subsequently tracked.

So, in order to control all these important force parameters and the micro processor of nowadays are very widely used and which can give a synergy in the process parameter by controlling the all the parameters independently using an input output module so that you know, for a given current, we can achieve short circuiting. When we can achieve short circuiting, we can be calculated by the melting rate as well as by varying these wire feed rate and the current.

So, we may also control the short circuiting event and subsequently when you know short circuiting we may also independently increase the current to such a way that we form an pendant neck of the droplet and then we can also retract once you have a known amount of current given and then we can retract it and then and it has it droplet to the work piece and subsequently this cycle can be continued.

So, the development in the GMAW, if look at in this synergy process, where we can independently vary the parameters and we can also get the parameters measured institute so that we can develop the much more robust and then processors which can be used to release a heat input significantly without affecting the welding parameters. So with that we will summarize this chapter.

So, we looked at the GMAW in detail. So we did not look at the physics of the processes we just looked at the important characteristic of GMAW process. And we looked at the transfer characteristics changing from the mode of transfer from globular to repulse spray to jetting and how the current changes the transfer characteristics, importance of various forces balances, determining the shape of the droplets, how increasing current can change droplet diameter from larger to smaller.

And subsequently we looked at some of the advances made in GMAW process especially in two important variants like pulse GMAW and then controlled dip and short circuiting process in a GMAW process which are very widely nowadays used to weld dissimilar steels as well as dissimilar materials.