Welding Processes
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Physics of droplet transfer in consumable welding

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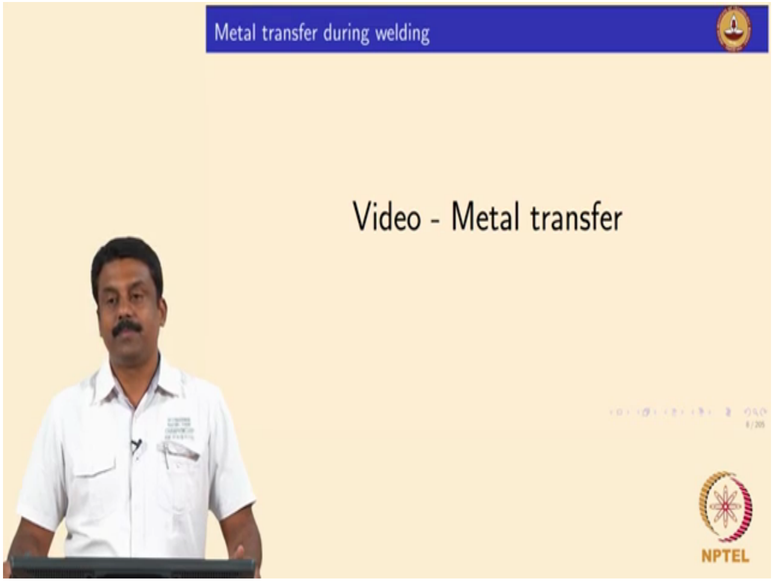

So we will move on to the other interesting physics in consumable welding process which is metal transfer. I showed you a video in earlier classes. So in a GMAW you melt droplets getting transferred to the work piece, how does the droplet get detached and then transferred to work piece? Why should we do?

Student is answering: Gravity.

Professor: Gravity, only gravity?

Student is answering: EMF.

Professor: EMF, okay so first we will take gravity. How would gravity assist the droplet transfer? Would it always assist the transfer droplet detachment or it can also resist detached? Is always assist all the cases? Yeah it based on the welding position, if it is down hand welding it always assist, if I am doing up hand welding gravity will not assist the droplet transfer, is it depending on the position of the welding? Is it clear?

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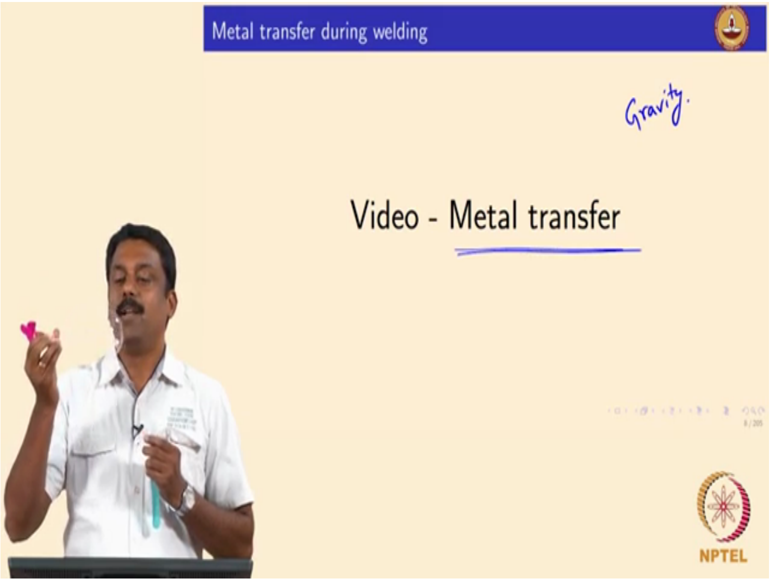

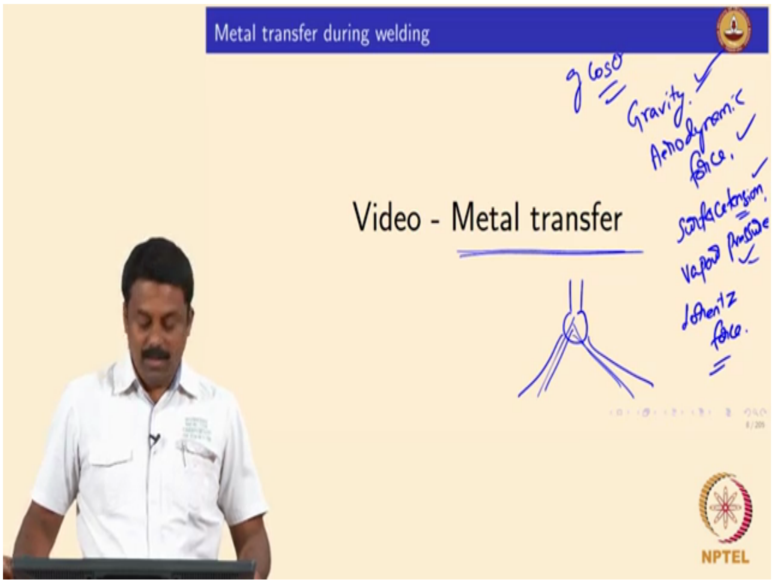

I will show you a video and then we will come back to that, so previously we saw one video. So in this case I showed you a video of two cases this wire and the other wire, this wire droplet transfer is much different, so when it is getting transferred it is transferred into on a field like opening a tap, whereas in this case it is transferred as globe, as a ball, why would they change? Depending on the current, only the current is going to change the transfer? So what are the other forces which can influence?

So I have an analogy here bubble, so let us I hope all of you have played with bubble, so I am going to blow a bubble now if you want to transfer detach this bubble from this tip what are the forces that are involved in this detachment and the droplet is detached from this bubble? Which force would assist, which force would resist (())(3:06) detachment? Is a gravity, how does gravity influence?

Suppose (())(3:11) doing it here, if I do it like this already changed the diameter of the bubble. By doing some way some trick in first case the diameter was bigger, in the other case diameter was smaller, why would that? Which force? Say first gravity you said right so gravity now is promoting the detachment. Suppose if I am doing it like this it is still getting detached even though gravity is opposing detachment, so something else is playing around. The one force is the blow I do.

So you can call that blow what do you call that blow? Aerodynamic force, okay some force that is there. So the blow I do it always assist the detachment because the faster I blow the bubble can separate from this the air the point of generation much faster and smaller diameter, what are other forces you can think about? Surface tension, okay. How does surface tension help? Will it help in detachment or it resist? What happens to surface tension? Will it assist the detachment?

It will always resist because that is the role of surface tension, it has reduced the surface area. So it will never allow the droplet to detach, if it detaches then surface area increases. The surface tension would always oppose the detachment. What are other forces you can think about? Lorentz force, it is there independent of Lorentz force, no current here I am not blowing anything, unless I have like a X man or so I can sense on the electrons whenever I blow, then I will be very rich.

Suppose I am blowing against wind, now imagine there is air, air pressure is there, suppose there is a fan I am blowing against a fan what force you would generate? So when the bubble is going out of this mouth to outside there is also something which is resisting, yeah air pressure. So the air pressure would always push because you are working against the air pressure that means there the air pressure we can also say that suppose I am blowing against an air conditioner, so that always push the droplet to be in its position.

So you can say it is a vapour pressure, so now we have gravity, aerodynamic force so aerodynamic force is my blow and then surface tension it is the bubble the composition material and then vapour pressure it is the atmosphere. So in welding case of course we also have current so you will also have a Lorentz force, so Lorentz force so this force gravity based on the location whether you are doing a down hand welding or up hand welding so the g is a function of theta Cos theta.

So g Cos theta with respect to the work piece if it is 90 degree g is maximum, if it is 0 it would resist, the aerodynamic force is a blow force. In welding case aerodynamic force is a plasma jet, plasma jet force, plasma jet velocity so that is what is blowing the droplet so like I did it in my bubble, the faster or the heavier I blow droplet can be attached with smaller diameter same with the plasma jet as well, to always assist the droplet attachment so the plasma jet would also assist the droplet detachment that is aerodynamic or plasma jet force.

Then surface tension again it is material specific, (())(8:50) always resist the detachment. The vapour pressure where do we vapour pressure? During welding, so during welding we also create metal vapours it would be going up the melt pool vaporizers it goes up, it will always push the droplet to be in its position. Same in the bubble, suppose I am blowing here so if you have wind is coming, the droplet would be attached.

So the vapour pressure which is coming from the melt pool would always resist the detachment and then we also have a Lorentz force, Lorentz force is slightly complicated that is based on the shape of the arc, so if arc is very wide. Suppose if you have a tip like this and you have a droplet formed and the arc is like this, the electrons would be diverging and they are travelling. If this is a case so then droplet detachment is promoted because the electrons would diverge by pushing the droplet out.

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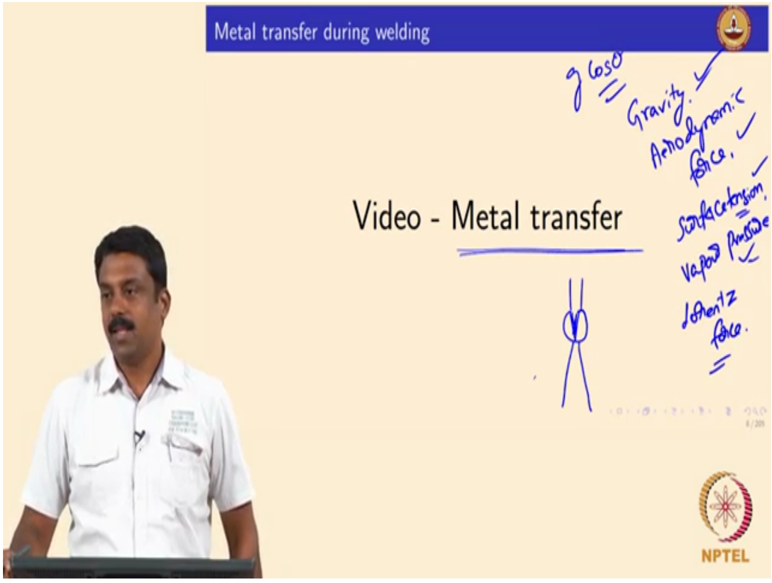

So imagine now the arc is very narrow okay so arc is narrow in this case your droplet diameter is already larger than your weld the electrode as well as your arc is in very narrow, in this case the electrons will converge because obviously electrons would travel via arc (()) (10:51) discharge, recall. If arc envelope is very narrow you have a convergence of the tiny particles, the Lorentz force would be converging in this case these particles or this Lorentz force would resist the detachment. If it is diverging it can take the droplet, it is diverging, but they are converging that means that the force would be keeping droplet in its place.

So the balancing these 5 forces would determine the transfer kinetics as well as the shape of the droplet, is it clear? So these 5 forces how it is balanced? The forces which are going to assist the droplet transfer, the forces which are going to resist the droplet transfer, if they are perfectly balanced system is in equilibrium. In order the droplet to be transferred one of the forces which assist should be maximized, either gravity or vapour jet vapour jet means the plasma jet, the aerodynamic force or Lorentz force one of them will be maximized to overcome the resisting forces.

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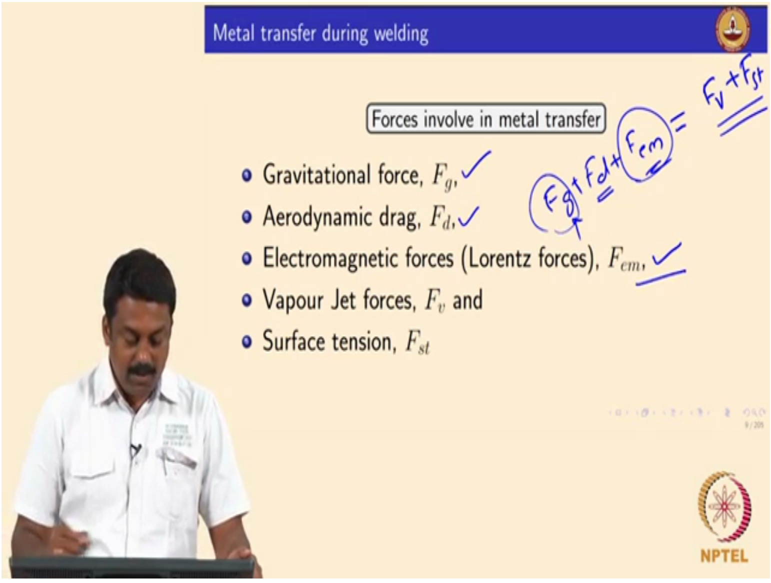

So we will see the force balance and that would determine the shape as well as the transfer kinetics number of droplet transferred per unit time, is it clear? So that is what we said forces in metal transfer they are gravitational force, gravitational force determined by the angle Cos theta whether you are doing a down hand welding or up hand welding, if you are doing a down hand it always assist the droplet transfer and then you have a plasma jet aerodynamic drag F d and then electromagnetic forces, most of the cases Lorentz force always assist because creating a narrow arc is very difficult. So you always have a droplet diameter much much smaller than the arc envelope diameter.

So you always see that Lorentz force aid Lorentz force aids the double detachment, alright so these three forces F d plus F em F g if it is equal to the vapour jet plus surface tension is equilibrium situation. So if the droplet should be detached either g must be the force gravitational force must be higher and this is fixed that is the process parameter. And the Lorentz force it is function of current, so what current are you operating.

So in this case suppose if you want to detach the droplet either your gravity should assist or Lorentz force would assist to overcome the forces that are resisting the droplet detachment which are vapour jet force and surface tension force, is it clear?

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So how does the gravity works? So this is the force balance I was talking about, so (())(14:52) have a droplet, the vapour jet force is coming from the vapour F v so they will always come from the work piece towards the droplet so the force would always resist, the surface tension would keep the droplet in its position so it would not allow droplet to detach because they are creating new surface area. So these two forces would always oppose.

And then gravity if it is down hand welding would act to assist the droplet detachment. Similarly plasma drag force which is the my blow in arc it is a plasma jet would always assist the double detachment and then you have Lorentz force, if the Lorentz force is always diverging it will always assist the detachment, is it clear? So if this equation, so this is material parameter, this is in a way material parameter the vapour generation and this is (()) (16:14) parameter.

So now the two things we can independently change is gravity which cannot be changed, but the force can be manipulated by changing the mass, so mg or you can change the current. So we will look at independently now each equation then we can understand how the droplet shape can be changed as a function of this parameter, current as well as the droplet size.

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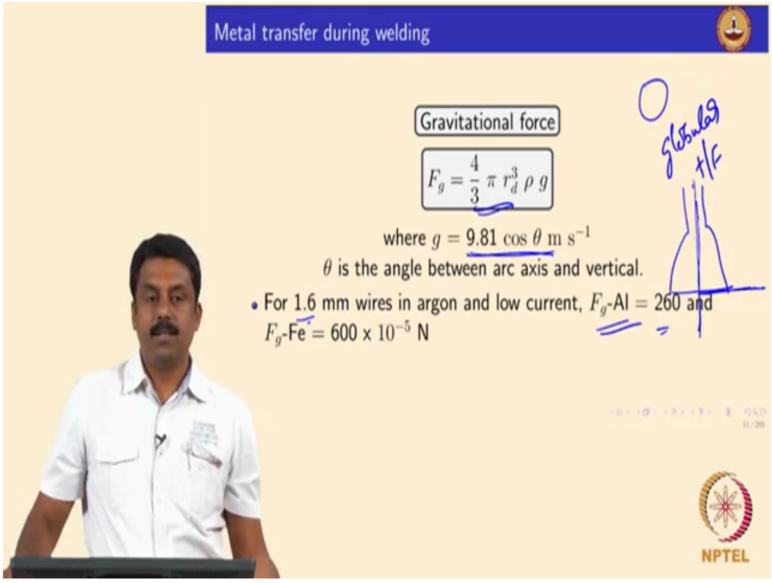

So gravity, so this is what 4 by 3 Pi r cube volume times density is mass. Suppose if you are operating very low current extremely low current there is no influence of Lorentz force, so then if you want to detach a droplet you need to maximize the mass so that droplet can detach. So now you already see the video, I showed you two videos, one your one of the wires it was transferring as a globes individual globes, so why are they doing it?

Because that case we intensely kept current extremely low so that droplet detachment is seen as a globes which is assisted by the gravity. So the moment the droplet reaches the critical mass if Lorentz force is very low the current is very low, the droplet can be detached by the gravitational force that is why when you are welding at very low currents you always see global transfer, the transfer happens as the globes that is because the main force which assist the droplet transfer is gravity, so that is why (())(18:34) known as global transfer we will see in subsequent slides very clearly.

So when at the low current when the Lorentz force is not maximized the maximum force that influence the droplet detachment is a gravity, gravity is influenced by mass. So in order to achieve the droplet transfer the droplet should reach critical mass then it can be transferred, is it clear? So the term here is Cos theta so this is very significant force when you are doing it in low current, so for 1.6 mm wire meter in argon, low current so it can be say 260 to 600 10 power minus 5 newton the force, is it clear?

So 1.6 mm it is coming around 600 times 10 power minus 5 newton, so when a Lorentz force is very very small at lower currents the gravity is the main force which would detach the droplet that is why at lower currents you see global transfer where the droplet has to grow in size to attain the critical mass and then it can drop, is it clear?

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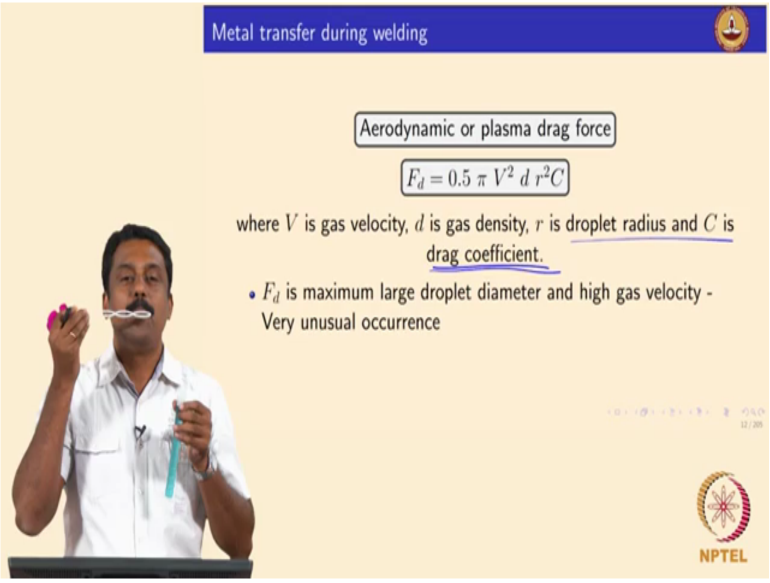

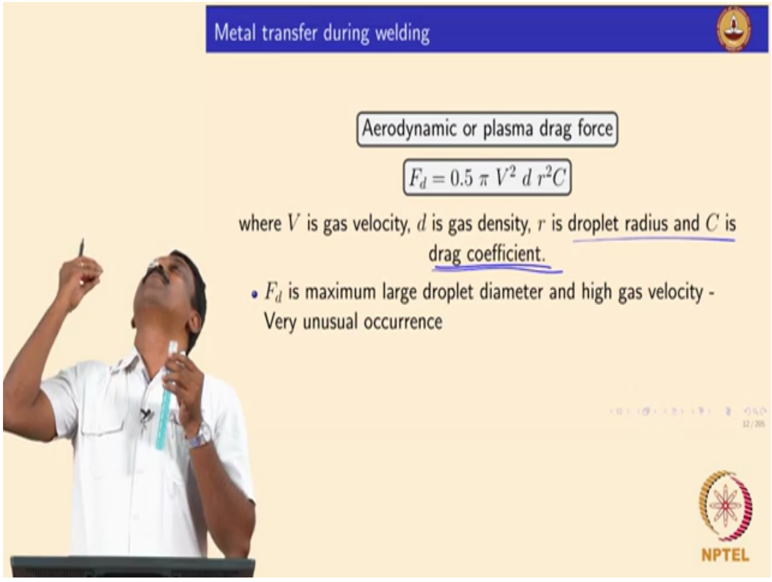

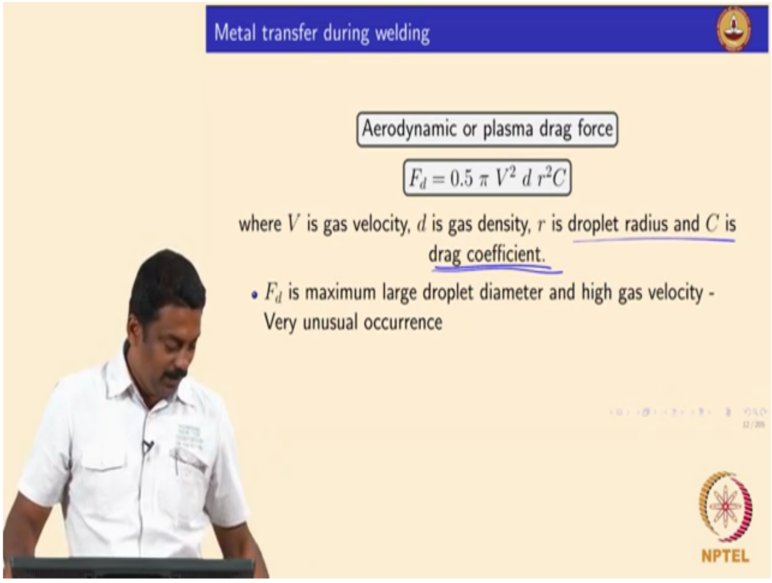

So now the other force the aerodynamic force or plasma drag force, it is depending on the gas velocity and density of the gas and of course the drag coefficients. So when you are using convective gas for example so you can have a very high plasma jet velocity creator that means that in that case the droplet diameter will be much smaller when it is detached, okay. So in that case the process, the shielding gas can also influence your droplet detachment for example for a same current, same the material chemistry if you change the shielding gas your plasma jet velocity can also change. If that is the case then F d can also influence the droplet detachment, is it clear? Yes or no?

So plasma jet force for a given process, given shielding condition is fixed it cannot change because it is a function of a shielding gas the velocity as well as the density of the gas, is it clear? And if you keep all the parameters constant if you change the shielding gas then you will see the effect of the shielding gas on the droplet transfer because the drag force will change, yes clear? Yes, okay good.

And this force like it is a blow force like I did it when I was detaching droplet if I blow faster I would detach the smaller droplets, if I blow slowly the force is getting balanced so droplets can grow, so now the angle is 45 degree if you are doing like this, if you are doing different so now the angle is 45, so Cos 45, so gravity influence is negligible so my drag force the aerodynamic force would it has to overcome the surface tension.

So if surface tension is maximized droplet cannot be detached, it will grow if I am doing very slowly the surface tension is keeping the droplet in its position so my drag force is not overcoming surface tension force so droplet is not detached. So droplet is growing in size suddenly if I tilt my head you may see droplet detachment because gravity would assist, you want to try?

Okay but then force balancing will be very tricky. I will have to make sure when I am blowing like that and doing like this the drag force should be same, it is very tricky let us see. So I need to overcome the surface tension (no) so drag force is now overcoming the surface tension, see already droplet diameter is decreasing. So if you want to make a bigger bubble you need to blow like this okay it is already there I am (())(23:39) out of breath, so my drag force is decreasing so you can play around so based on the gravity the drag force the balancing force is surface tension, so I need to overcome the surface tension to get the bubbles to detach from the whatever instrument, is it clear?

The same thing over here also the plasma drag force if I am blowing really fast the bubbles can be detached much faster, is it clear? So then the drag force overcomes that becomes the rate controlling, then gravity, is it clear? Good.

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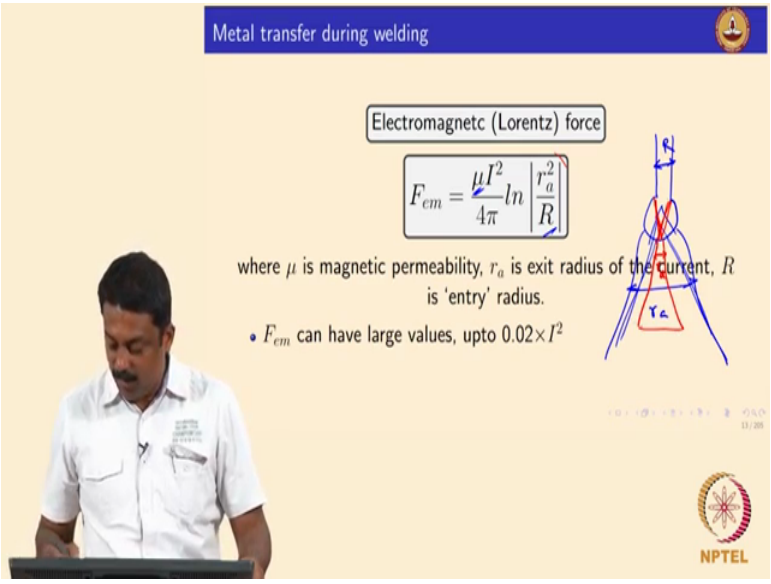

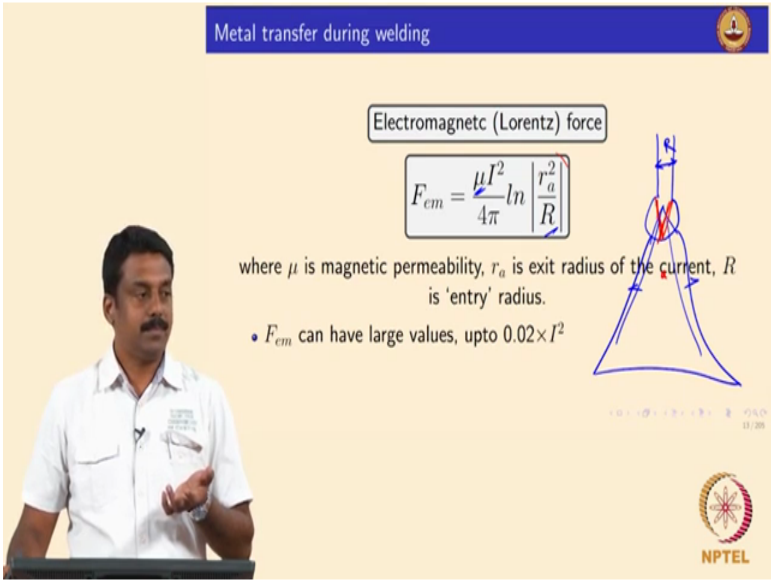

So the third force which assist the Lorentz force so again you can use the equation to calculate its magnetic permeability and this is the exit and the entry radius. So R is entry radius for example so this is wire and then we have a droplet formed and something like this is arc, the ratio between the radius between this radius. So if ra is bigger than R the Lorentz force would assist the droplet detachment.

Because then the (())(25:12) what is Lorentz force? Lorentz force is for generated between the basic particles of electrons (())(25:18). So when you keep it closer than each other then you create enormous amount Lorentz force and then how the particle would travel? If they are diverging for example this case so obviously the electrons are which are generated would diverge in the arc column that means that while diverging they can assist the droplet to detach from the tip.

So suppose if ra is different, now ra is smaller than your R, so now this case ra. So if ra is smaller than R then these electron particles would try to converge. So this term becomes smaller so obviously then what will happen? If they are trying to converge they would not assist the droplet transfer. So they would try to shrink the droplet, so they would try to because it is a bubble is there, the force is pulling droplet so they will not resist the droplet transfer.

So in most of the welding case our arc diameter, our arc envelope diameter will be much much larger than the droplet diameter. So you always have a situation where the arc will be much larger than your filler wire. So in that case Lorentz force would always assist the detachment and this become very significant when you increase the current, okay. So when the current is increased Lorentz force becomes highly significant that droplet can be detached with smaller mass because plasma drag force is a function of your shielding gas your gas velocity for a given process condition it is fixed.

So suppose if you want to minimize the droplet diameter what we do? High current, so Lorentz force can detach droplet with much (())(28:02) diameter. So in the video I showed you two conditions same wire everything is fixed, so this wire the welding is done with low current, in this wire welding is done with high current, you see already influence. In low current case droplets detached after achieving a critical mass, whereas in this case the droplet diameter is much smaller, it is like a spray the droplets are transferred and continuous drops, so they drops overlapped it becomes stream or spray we call it.

So in this transfer we call it globular transfer, whereas in here we call it spray transfer because the drops are all accumulated and becomes continuous spray, is it clear? So these reforces would always assist gravity again assume that we always do down hand welding, is it clear?

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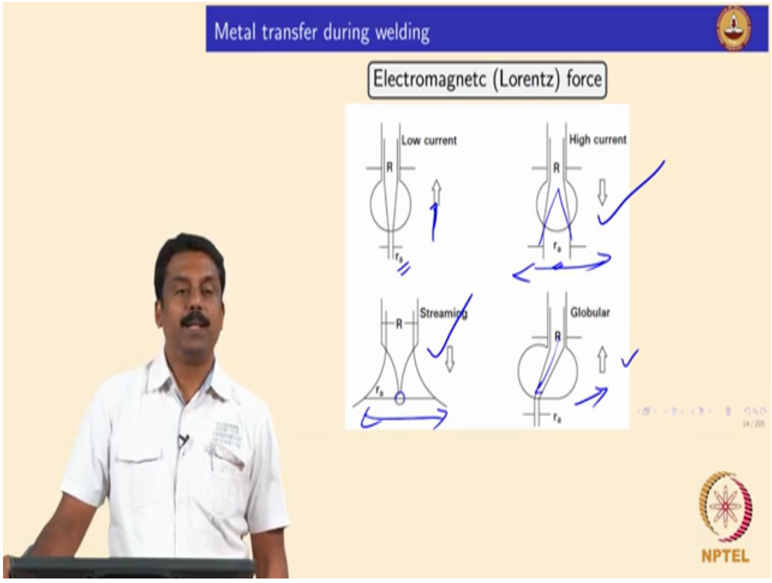

So the Lorentz force that was explained so if your exit radius is smaller than entry radius it would always resist that means that arc is very narrow, the electrons would converge they will not diverge. So in this case the exit radius ra is larger than the entry radius that means it will diverge, okay. If in case the current further so you also increase the arc envelope that means that the droplet can be detached with very small diameter, your maximum divergence.

And this situation will can also happen, so when you are increasing the mass significantly then you also have a diverging path even if arc or converging path even if (arc diameter) is arc envelope is larger so we will see in the subsequent transfer (())(30:17) happen. So in most of the cases in a welding case based on the nature of the Lorentz force convergence divergence so if your arc envelope is very narrow and if the exit path is narrow than your entry path then the Lorentz force would resist that is highly unlikely in arc welding case. In most of the arc welding case this is the situation and in case the current is becomes like that, is it clear? Good, any question so far? No? Good.

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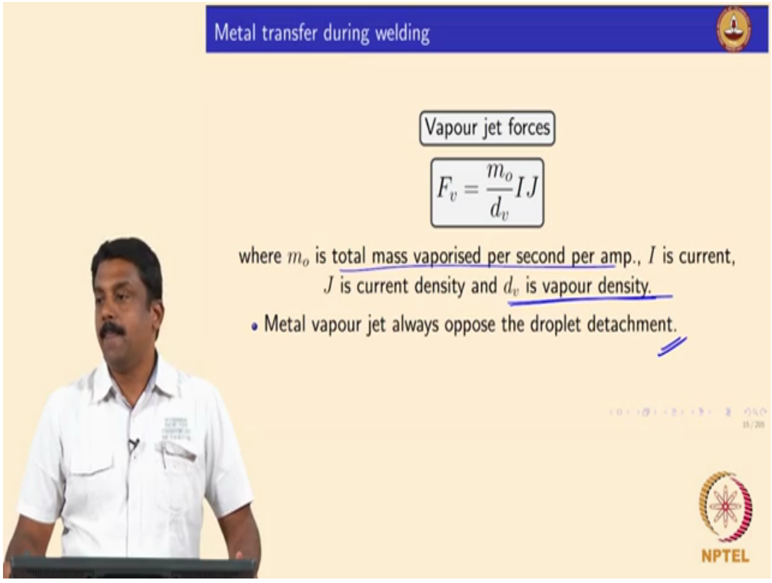

Again two forces would oppose and these two forces should always be overcome if you want to do welding otherwise there is no GMAW, droplet will not transfer, the two forces would resist the droplet transfer or vapour jet force and surface tension and if you are not overcoming then you cannot weld. So the vapour jet force is coming from the vaporization of the metal, okay so the total the mass vaporised per second for a given current and the current density and vapour density. So vapour jet force would always oppose the droplet detachment and we can calculate.

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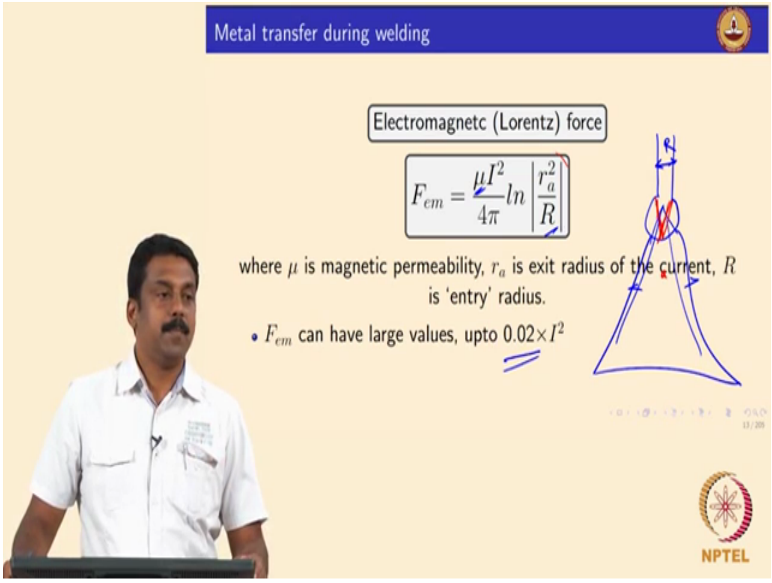

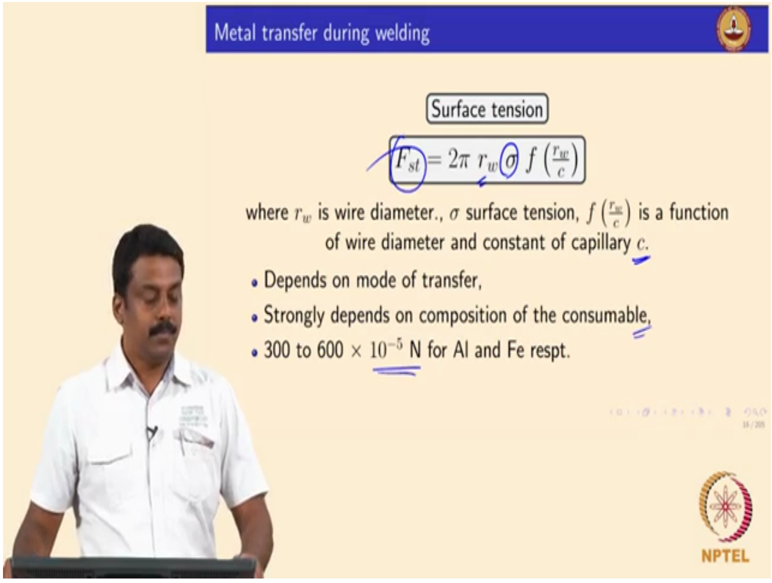

And then the last force surface tension, surface tension again the function of composition, so diameter you can calculate the surface tension of the moulted droplet from the droplet diameter and this function this is the coefficient of surface tension and then you have capillary actions that is (())(32:16) the surface tension, it is totally depends on composition because if you change the composition surface tension also change.

So suppose if you want to drop or transfer droplet with lower surface tension then you need to add some elements. So you can enable or you can assist the droplet transfer by adding fluxes. So in MMAW or flux cored arc welding we had fluxes so that we can play around the surface tension, the droplet and droplet can detach at low current okay so that is (())(32:57) flux to play around the surface tension.

If you look at all the values it will be same, except the Lorentz force, Lorentz force value can be very tricky I do not know the (())(33:08) value yeah see that 0.02 times I square. So when the current is increased Lorentz force increase exponentially, where the other forces will remain (())(33:25) 10 power minus 5 newton, is it clear? Good.