Welding Processes
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Introduction to consumable welding processes

We will move onto the consumable welding process, the second, third unit, right okay. So in a GTAW, in a gas tungsten arc welding it is non-consumable welding process where the electrode is intact at least it does not melt, okay. So in a consumable welding process the electrode melts and then the molten droplet is transferred to the base material and then we form the weld bead by melting the work piece or the base material plus mixing the droplet from the electrode and the molten fully solidifies we form the weld bead.

So in the consumable welding process there lot of advantages compare to GTAW because now we can weld much lower the cross section in a single go because you add more material, the other disadvantage main disadvantage we saw in GTAW process efficiency, is not it because the heat if it the electrode is electrode negative the heat is absorbed by cathode it is lost. Whereas in this case in a consumable welding process that is again transferred back to the weld pool, is not it.

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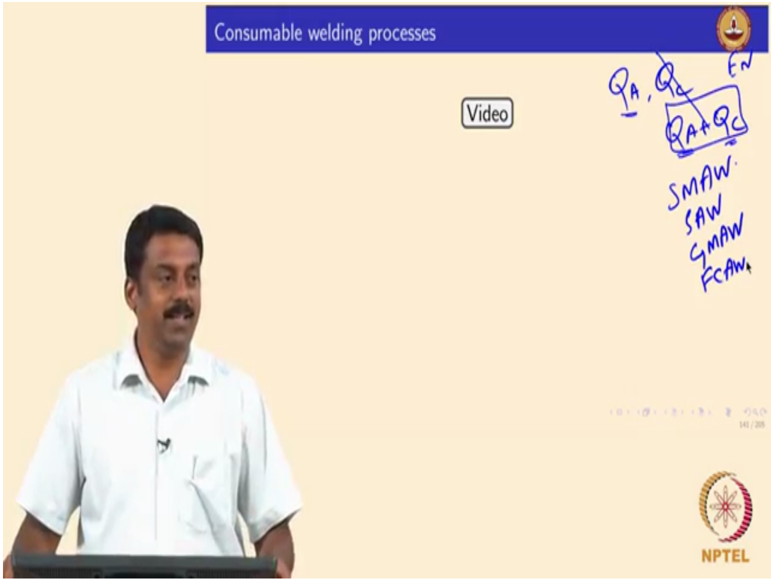

Suppose if you Q A is a heat in the anode and Q C that is a heat absorbed by the cathode in a GTAW this is lost completely in electrode negative conditions, is not it? So only whatever heat is available in anode it is what it is actually used, right. So ultimately we if we make conditions such a way that Q A plus Q C is transferred to the work piece that mean is that efficiency increases, is not it.

So in the consumable welding process this is possible because even if you have an electrode negative situation and the electrode is observing the heat or the generated heat at the cathode is transferred back to the work piece and of course well we have also Q A anode heat generated and both are combine so that the efficiency of the process can be improved, ok. So that is also in a practical terminology the g m a w is much more efficient than GTAW because they both anode and cathode heats are transferred arc to the work piece, ok.

So we will see in physics, so bust first we will see a now video so we get used to the process then we will go to the physics, how many of you are seen GMAW? So what is GMAW first? Gas metal arc welding, ok. So what are the variants of consumable welding process can you name some? Submerged arc welding, very good and then this two.

Student is answering: Flux cored arc welding.

Flux cored arc welding, very good and then another famous very commonly used low cost process yeah SMAW, what is SMAW?

Student is answering: Shield metal arc welding.

Shield metal arc welding or manual metal arc welding or stick welding, ok. So this four are we most commonly used the consumable welding process SMAW, SAW what is SAW?

Student is answering: Submerged arc welding.

Submerged arc welding, GMAW gas metal arc welding and then flux cored arc welding, ok. So we are going to the look at each processes this four processes but not just processes as I always said that we will look at a physics of this processes, ok so the lot of science in this processes which control the stability as well as the arc stability metal transfer, force balances so that we can change the process characteristic, efficiency, heat input, arc energy and so on so forth and we also look at in a flux code plus big processes that are all affected, ok how are they going to affect the process stability and whenever thing.

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So since most of you are seen not seen the GMAW process I will show you a video, ok so what we are actually doing it, so what see over here is so we I see two electrodes in this case I use to electrodes to make this video and we strike an arc between the electrode over here and the base material, so the arc is struck in this case I am doing a pulsing, ok and during this process the electrode also melts by observing heat from the arc and then the molten electrode droplets are transferred to the work piece, ok.

So and the nature of droplet how we transfer that determines the bit geometry as well as the process characteristic for example so in this case it is like a spray is not it, it is coming like an opening a tap spray whereas here the droplets are transferred individual globules, ok and the characteristic of this transfer determines the stability of the pool, for assuming this case you may have a hire productive process the melting but if you increase a current even further than the you may also change the spray into some sort of an jet.

So in this case a globular transfer can also be made into a ripple globular by changing the current as well as the other forces and you may end up creating a lot of spatter for example in this case you see this spatter formation is not it. So when the globules exploded once it enters the arc say in some cases you see this spatter is flying away is not it, see again. So these are all some instable (ins) the unstable conditions.

So in this unit we are going to look at the all the physical forces that are present during the GMAW like we saw in GTAW and we will also calculate how we can melt and what are the parameters that are controlling the melting characteristic of these electrodes, right. So again so we look at all the physics behind the process.

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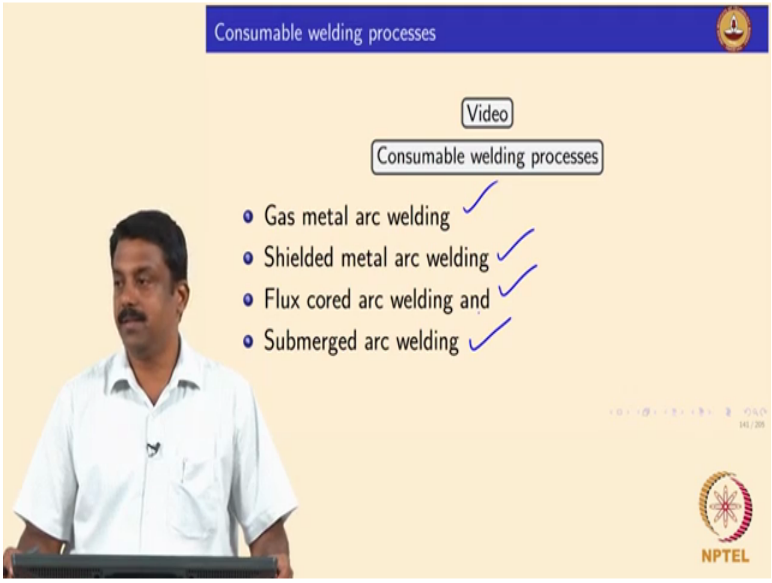

First, so the four important processes gas metal arc welding, shielded metal arc welding, flux cored arc welding and submerged arc welding. So we will go in this sequence because gas metal arc welding is the most widely used the welding process for engineering applications, ok and the shielded metal arc welding it is also used for low end applications but with large production and needs and flux cored arc welding also it is widely used if you want to melt more and you will have to deposit more volumes per unit time and submerged arc welding is widely used for welding thicker sections because the efficiency is so high so you can achieve a good amount of penetration because arc is completely shielded, ok. So the radiation and the convective heat transfer is minimized by completely shielding the arc, ok so we will see one by one.

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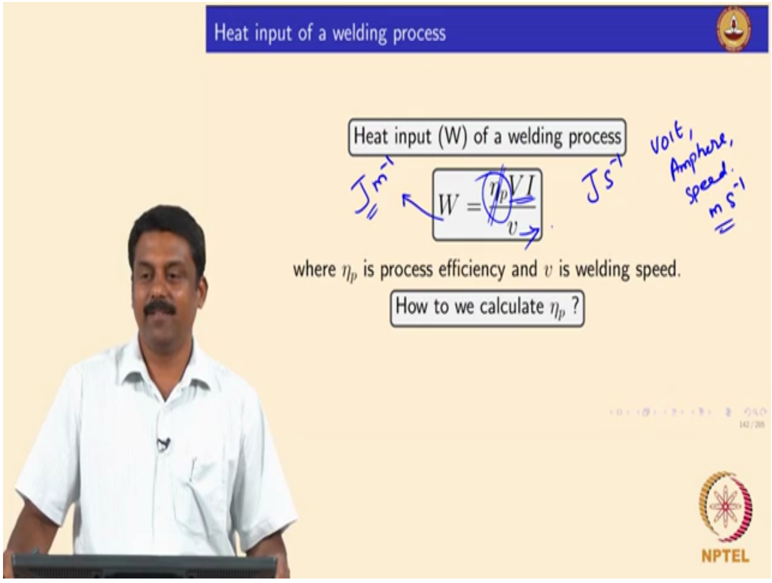

The first is the basic equation, heat input and this is valid for any arc welding process, ok. Let us look at this equation in detail, the first question will always arise so what is the unit in either side? Yes so how do you define so these equations? So what is unit of V?

Student is answering: Volt.

Volt, what is unit of current I?

Student is answering: Ampere.

Ampere, what is that ampere? So you will have to recall my first lecture and what is v? Which is speed is not it, right? So then what is in left hand side L H S? What is that? What is unit of heat?

Student is answering: Joule.

Joules per…

Student is answering: Meter.

Meter, good because here we define is meter per second, SI unit. So LHS is joules per meter and RHS is, there is no joule in RHS, where does joule come from?

Student is answering: V I.

So how does V I becomes joule?

Student is answering: (())(09:52).

Power is….

Student is answering: Joules per second.

Joules per second again where does joules come from then?

Student is answering: From the work it carries.

From the work exactly, so that come from the basic definition of voltage and current, ok. So electron volt e v, ok so the energy gain by the electrons while moving over a unit distance that is what the electrons gain the energy joule, so that is a basic definition of voltage and the current, right is not it? So I taught you in first class when you define the amperage, is 1 ampere is when 1 clove of electrons travels in 1 meter if they gain 1 or if they spend 1 joule of energy that is 1 volt, right.

Or if they release 1 joule of energy when they are traveling from one point to other point which is kept at 1 meter interval so then it is 1 volt, so that is the basic definition of the voltage and current, 1 volt and the current, ok that is a work done by the electrons while traveling over a potential difference, right because they are lot to work so that is define, so joules come from the work done by the electrons while traveling over a potential difference, so that is joules per second and here we have a meter per second the seconds cancel out and then unit becomes joules per meter.

So we always supply a heat input and you define joules per meter and there is another guy here, so why we put this guy?

Student is answering: Efficiency.

Efficiency I already mentioned here, is not it?

Student is answering: Supply the (())(11:58).

Yeah, so that determines how much amount of heat is transferred from the arc to the work piece is not it, I just explain in previous slide Q A and Q C. In a GTAW if it is electrode negative Q C is consumed, it is not transferred to the work piece is not it, the whatever heat is consumed by cathode it is gone, so that is why the efficiency is quite low, is not it? So if in the cathode also transfers whatever heat is consumed to the work piece then the efficiency increases, is not it?

So if you want to calculate the efficiency we need to look at again the heat generation in the arc, so by looking at that we can accurately calculate the efficiency, right. So we will do that because that is important so the without that they cannot calculate how much heat you are actually inputting to the work piece per unit length, right. So if we do not use an efficiency and this is your arc energy the energy is there in the arc but all the energy is not transported to the work piece, it is some of them lost because of the inefficient method we use to transfer the heat, right.

So how do we calculate the efficiency? There are must some method, right is not it is as just some number as some people always say that point 6, point 7, point 8, 60 percent, 70 percent but as a welding engineers and the welding scientists now we should give some physics physical background for this efficiency, ok. Let us calculate efficiency from the basics, ok like we did it in a when you look at the energy transfer in the arc, it is very simple.

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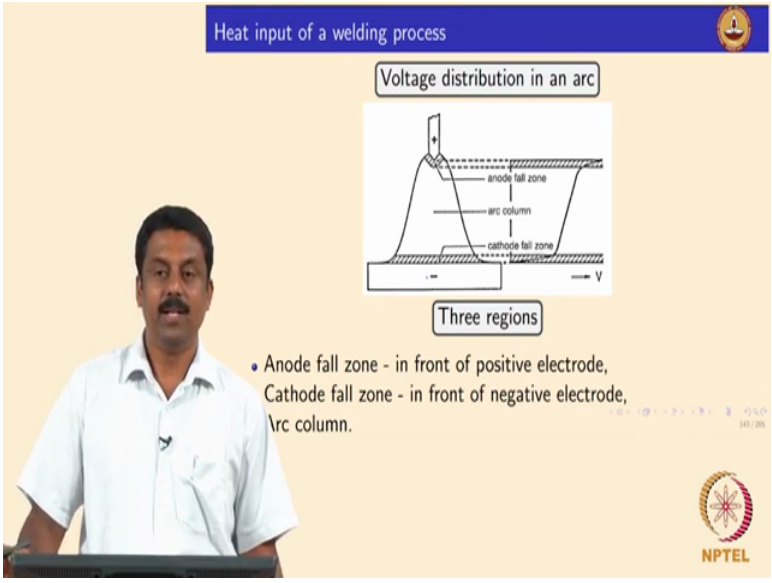

So what we will need to understand is again the go back to the basics, so in the basics what happens here so we have an arc column and the cathode fall zone and anode fall zone. The voltages are not linear is not it except in arc column in a cathode fall zone and anode fall zone you have a gradient in voltage, so the this the basic for heat generation we are talking about, right because of this gradient in voltage we have accumulation of charges, okay.

So the accumulation transfers the heat is not it, in this case if it is in the electrode is anode, ok the electrons are transported to the anode and that transfers the heat similarly if it make is in a the electrode negative the electrons are transferred to the work piece and that transfers the heat by looking at this fundamental mechanism we can calculate the efficiency so how do you calculate the efficiency then so we always know that we have a three regions, ok.

The one region is the anode fall zone and the other region is arc column and then the third region is cathode fall zone, suppose if you know the heat generated in each three regions we can then using an a simple heat transfer to calculate the efficiency, ok.

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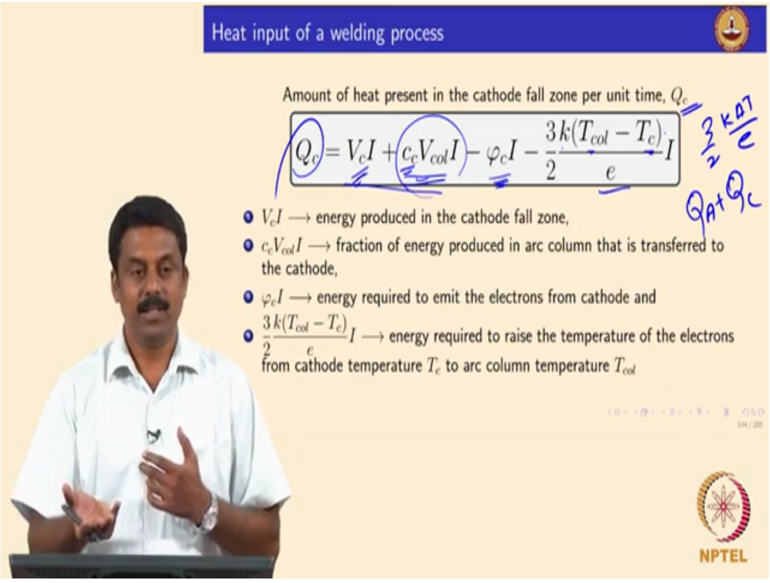

So we can assume that imagine now your the consumable electrode or the electrode is a cathode, ok at the cathode what happens at the cathode when we look at what is a main function of cathode?

Student is answering: To emit electrons.

To emit electrons, is not it. So to emit electrons it also observe heat work function is not it, the work function that mean is that it asked to consume heat to emit an electrons is not it, and the moment the electrons emitted and the electrons are send to arc column, is not it. So when the electrons are at the cathode the temperature of the electron is the cathode temperature is not it, the ones the electrons are coming out of the cathode then they also consume heat otherwise the electrons will be at low temperature.

So once they go into arc column and they will have to attend the temperature of arc column, right. So they also consume heat is not it, so if you look at the amount of heat present in the cathode or cathode fall zone is the heat generated at the cathode because cathode also as a current and the voltage which is V I is not it, that is the energy produce in the cathode and then cathode also get the energy from arc is not it, the arc column also sends the energy to cathode the total energy in the arc is V arc column times the current I but not all the heat in the (cath) arc column is not transfer to the cathode, right only fraction is not it.

So we have the fraction of heat energy transferred from the arc column to the cathode and this two are the energy gain in the cathode is not it, energy produced at the cathode fall zone plus energy occurred from the arc column this two are very connect, the energy connect but this energy connect spend by two ways, the one way is electron emission which is negative term, right the second term is to heat the electron to the arc column temperature when the electrons are there in the cathode the electron temperature is the cathode temperature, the moment electrons comes out then they also consume heat because they will have to be heated up, ok.

So the heat balance at the cathode fall zone is the heat energy generated in the cathode, energy acquired from the arc column minus energy consume to produce an electron minus energy consume to heat the electron which is produce to the arc column temperature and that is the 3 by 2 k the Boltzmann superstar, ok that is the electron temperature and this is column temperature the delta T, ok.

So this is 3 by 2 k delta T divided by e, so that is the equation to calculate the amount of energy needed to heat an particle to a temperature, right. So we assume that so electrons consume the heat in two ways because the work function consume the heat and then when the electrons heated up and then the electrons will be heated up to the arc column temperature that is also consuming heat, ok to this four terms made the energy balance at the cathode fall zone, ok.

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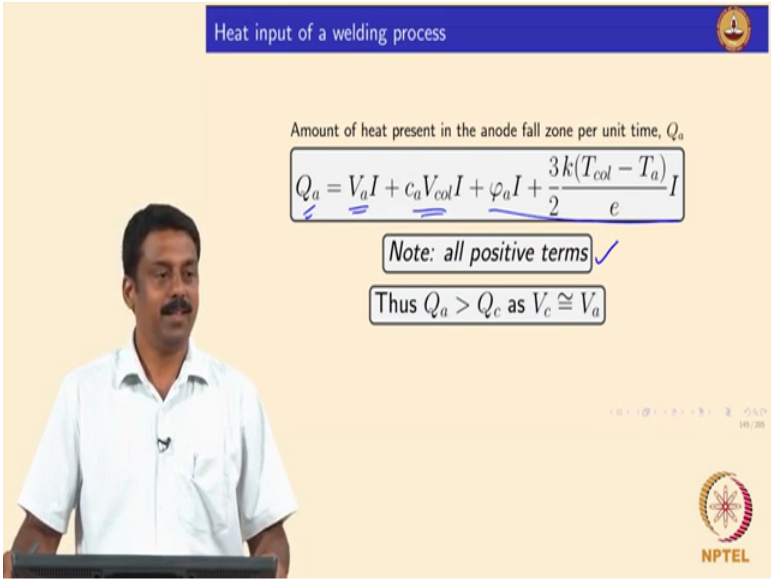

And the now energy balance in the anode fall zone would be plus terms, ok because the electrons ultimately reach the anode, is not it. So now we have similar equation for the anode fall zone or the anode that means that heat is generated in the anode and then the amount of heat transferred to the arc column to the anode, right and then again from the electrons, is not it?

The electrons ultimately reach the anode, so whatever heat is consumed by the electrons will be gained in the anode, is not it so your question is answered, so whatever is consumed by the electrons would reach the anode, right it is clear? So we already see where the temperature will be high, where temperature will be high?

Student is answering: In electrons.

In anode is not it, so that is why when you keep the electron negative, ok so anode will be work piece, so the work piece will always been in higher temperature than the cathode is not it because of this balance, so that is what when you doing a GTAW if you are keeping electrode positive the cathode temperature the your electrode temperature will be higher than the work piece, so that is not good for the stability of the electrode is not it because according to the equation when the electrons reach the anode they also carry heat, so whatever they gain in the cathode is transferred to the anode, it is clear.

So it is so that is why so when you are welding so you always we always tried to make sure that a work piece is anode so that is a efficient process, so that we can attract the electrons,

electrons bring the heat from the cathode in the arc column to the anode, yes it is clear. So now the efficiency say efficiency is now based on the polarity, is not it.

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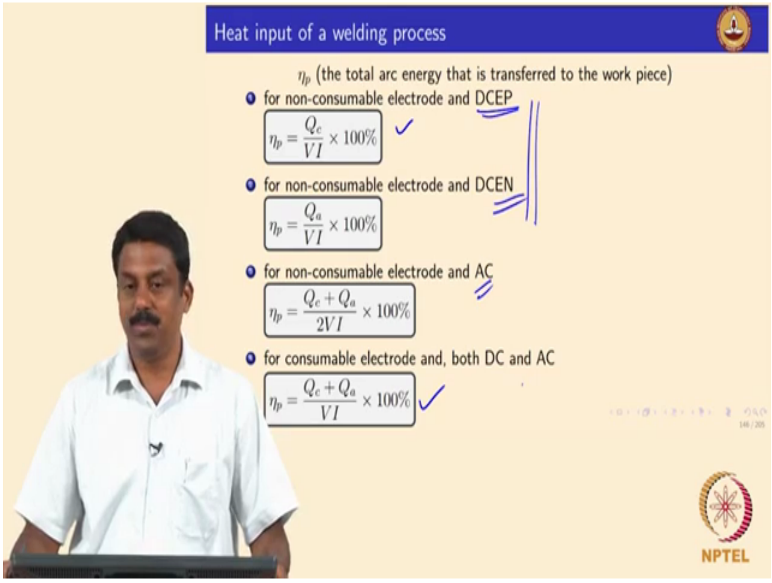

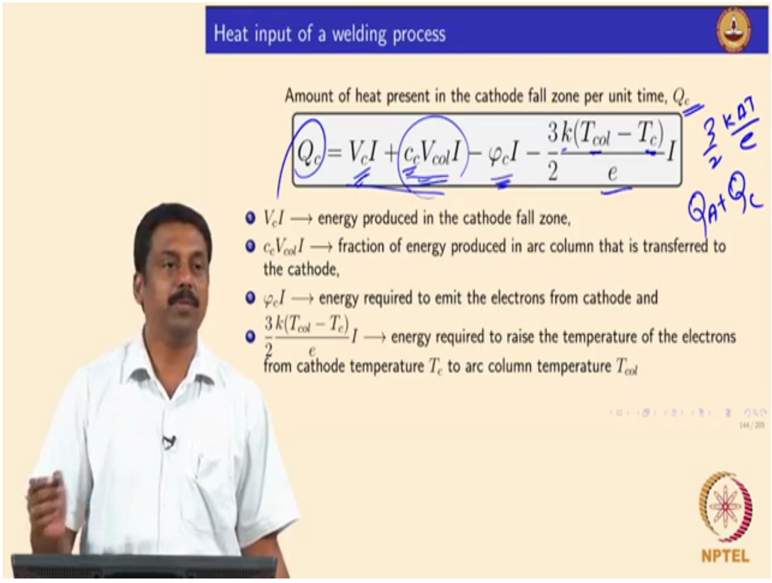

How do we calculate for the non-consumable electrode when the electrode is positive, so electrode positive means the work piece is negative that means that work piece is cathode is not it, so that means that from the anode nothing is coming. So only the heat whatever is available is Q c is not it, so efficiency is nothing but the Q c over V I, so V I is the overall your I and then voltage, so Q c by V I times 100 percent V I is the total energy available in the system over the Q c times 100 is the efficiency is not it, it is not efficient process is not it Q c cathode is always at lower temperature, so if you make work piece negative in a cathode that is not efficient because you are losing heat somewhere electrons are not reaching, right.

So if you use a DC straight polarity or electron negative your work piece is Q a that mean is that the heat energy will be maximum because all the positive terms the electrons would also whatever the work fiction function it gained whatever temperature gained in the arc column would be reaching the anode the efficiency will be higher, right it is clear right. And then we can calculate Q a and Q c by using these terms.

So if you know the arc cathode fall zone voltage and the I is the actual e, ok and that similarly the arc column voltage work function we know what is the arc column temperature, electron temperature you know and we can calculate now the efficiency very accurately, right. And for AC alternating current is an average because you are changing the polarity every cycle, yes it is clear.

And the consumable welding process, ok in both DC and AC does not matter because in this case whatever Q c is generated is transferred back to the work piece together it is a electrode negative or positive so whatever (cag) the fit the consumable is electron negative you melt and again you are return in sending back to the anode, so the efficiency is Q c plus Q c together is not it, it is clear.

And V I is the overall the energy, ok it is clear and this is how we calculate the efficiency of the process when you are doing an a heat input calculations, right it is clear. So now according to this equation which is a most efficient process?

Student is answering: Consumable welding process.

Consumable welding process, is not it. Which is a least efficient process? So when you have a non-consumable with reverse polarity where you make your electrode positive, right it is clear. So in the both the cases you know this is not efficient GTAW because in any one of the cases you the electrode is not transferring heat what is consumes it is not efficient, is not it.

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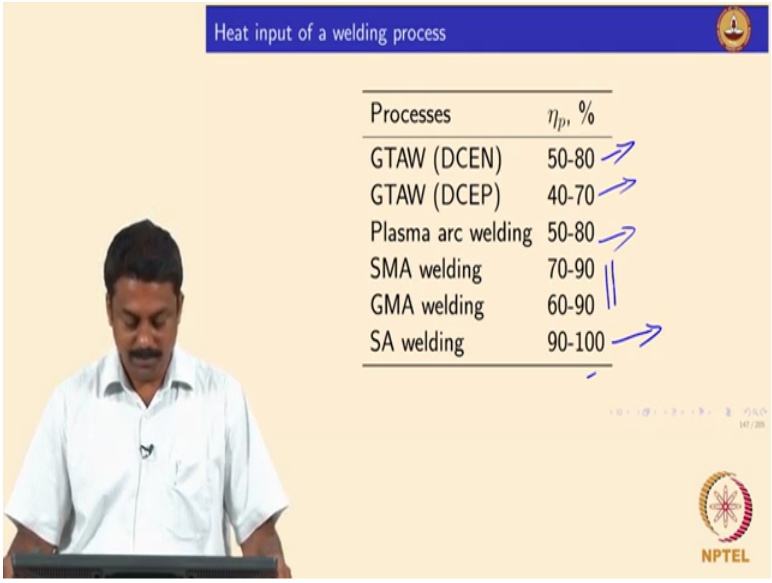

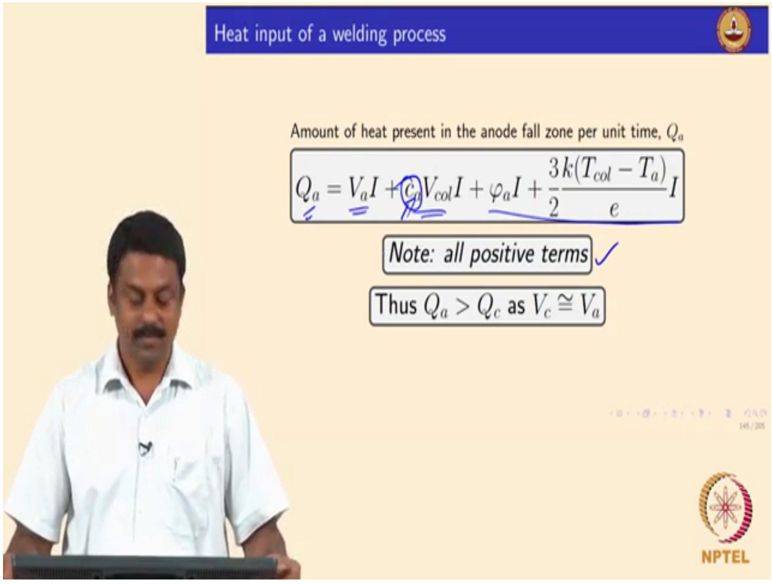

So that is why when we calculate the efficiency GTAW in electrode positive case we have a least efficient efficiency, the maximum efficiency comes from submerged arc welding process why? Because this factor becomes close to 1 is not it, look at this factor gives the fraction of heat transfer from the arc column to the anode or cathode is not it, so this factor if it becomes 1 the entire heat generator in the arc column is transferred to the either anode or cathode is not it, so that term takes care of the heat transfer from the arc, yes it is clear.

If this close to 1 that mean is that whatever arc column heat is there it is transferred to the anode and cathode in submerged arc welding the arc is closed, so the fraction of heat is transferred from the arc column to the cathode and anode is the maximum, so this term the C a and C becomes close to 1 so the efficiency increases to very high amount, so if it becomes close to 1 it will become 100 percent efficiency because this is a consumable welding process so you need to add both Q c and Q a in that the fraction of heat transferred from the arc to the anode cathode also maximum, so that is why it is very efficient process, yes it is clear.

So we calculate we can calculate the C terms by using a spectroscope, spectrometer and we can identify the efficiency of the each processes. So you see the in plasma welding also we also enhance the as a (fra) factor terms by constructing the arc we maximize the heat transfer from the electrode to the work piece not the other direction because plasma jet transfers the maximum heat to the work piece, yes.

And the shielded metal arc welding and GMAW will have equal the heat transfer, in the shielded metal arc welding it is slightly higher because the fluxes also generate insulating vapor layer, so they that protect the arc from radiation, ok so the efficiency increases because that factor terms increases yes clear and it costing so far. So it is a simple heat balance how do you calculate the efficiency? So it is not a simple like a term you use 50, 60 so there is a physics behind it, so when you are using a heat input equations, yes it is clear good.

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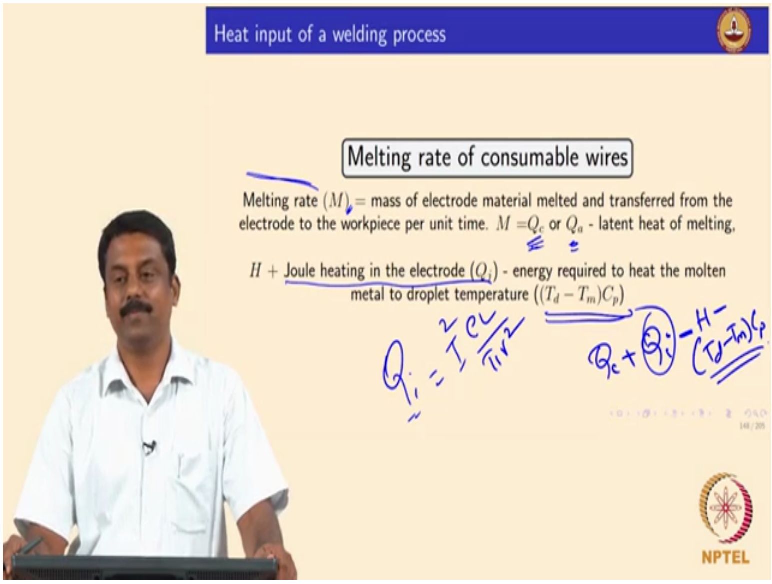

We will move on further, ok so quickly will go and then we calculate in a consumable welding process using the same principle we can also calculate melting rate because that is all determine by the heat balance. So melting rate of a consumable so how do you calculate? So what is a melting rate? The mass of electrode material melted and transferred from the electrode to the work piece per unit time.

We use to we looked at video, right. So how do you make sure that you know you have the enough droplet transfer per unit time, so you can play around voltage and current and then calculate is not it but there is an a fundamental way of calculating that from the heat balance just as I taught you in Q c and Q a, right let us do it and then we look at in detail the equations.

So melting rate we define as a mass of electrode material melted and transferred from the electrode to the work piece per unit time, if you want to calculate the melting rate of wire you need this two parameters, first parameter is latent heat of melting of the wire second term is the energy required to increase a temperature of the wire the droplet which is already formed to the droplet temperature to wire temperature to the droplet temperature, is not it.

So heat of the heat is needed to rise a temperature from the wire temperature to the droplet temperature, so these two would be consumed is not it, so what is available? Which heat is available?

Student is answering: Latent heat.

Latent heat is available, ok. So latent heat and the these are all consumed where is energy supply coming from? Where does heat come from? Arc, right ok so that is either Q c or Q a, is not it, that takes care of cathode heating, ok the amount of heats coming from the arc to the cathode, right and then work function and then temperature consumed by the electrons. So that is the heat is available either Q c or Q a and the additional another heat is also generated in this case if it is wire, so that is joule heating, is not it.

So the melting rate is nothing but this positive terms Q c plus joule heating, right minus latent heat of melting, ok so that you can say H minus and then the energy required to heat the molten metal to the droplet temperature, so which is nothing but d T minus T m times C p, right if you know this we can calculate the melting rate, right and what is Q i, Q i is.

Student is answering: Joule heating.

How do we calculate Joule heating? Is it.

Student is answering: I square r.

I square r, exactly. What is r?

Student is answering: Resistance.

Ok, how do you calculate resistance?

Rho L by is not it, right it is clear. So we have now a equation for Q c and Q a, we have a equation for Q i, we know H, we know this if you know specific capacity, if you know all this four we can calculate the melting rate is not it, yes so simple.

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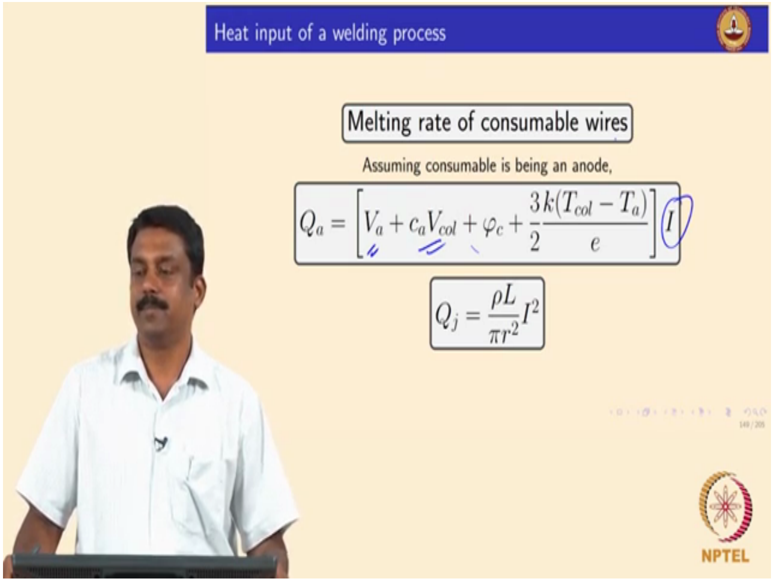

Q a is suppose assume where consumable is anode, what is Q a? So we can take I out because I is common, right the current is not it, so it becomes now the voltage in anode the amount of heat transferred from the arc column to the anode and then this guy the work function energy gained by the work function with the electrons and then the energy gained by the electrons by the heating up from the cathode temperature to the arc column temperature and that is I and this is joule heating and these terms added minus latent heat of melting minus your C p specific heat term that will give us the melting rate, is not it.

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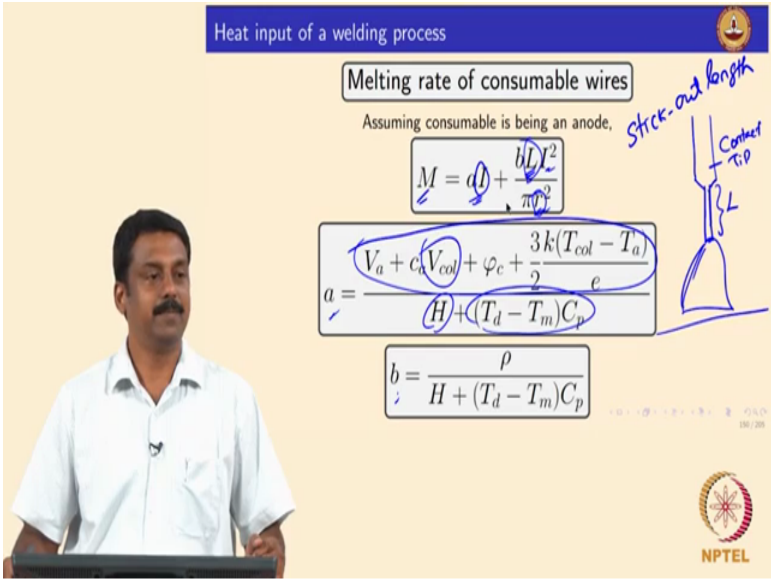

So melting rate we can get the relationship now and M, so if you add all four and balance the equation so you will get the item, item comes from the Q c and Q a and then other term we get that is from the joule heating, so L I square by pi r square and a and b is now it is a constant for example this entire term is fixed for a given process suppose if you fix your electrode polarity you make the electrode in anode, right given a shielding gas the efficiency is determined already, ok for a given process condition and this is fixed, it is clear yes or no because I is we already taken out I because I is a variable, is not it and this is material constant, material specific constant this is again material specific constant.

So now if you look at this equation what is the important variables? Is current and then L and then r, a remaining else is constant for a given process and given material composition, is not it. So there melting rate of a consumed is determine by the welding current, if you send the welding current melting rate changes and the other two important parameters the r which is electrode diameter if you increase electrode diameter melting rate decreases, the other parameter is L what is L here?

Student is answering: Length of the wire.

Length of the wire, in welding case we call that length as a stick out length. What is stick out length? Suppose if you have an a your c t w d or the electrode the length of the wire which is sticking out from the contact tip so this is known as a contact tip, ok and then you form a arc here and this is a work piece and this length L is known as stick out length. So if you increase a stick out length what will happen?

Student is answering: Melting rate.

Melting rage rate increases, so for a given process condition so if you fixed a shielding gas, ok then you fixed this is not it, if you fix a shielding gas the heat generated in the arc column is fixed, right and if you fixed the material composition then H is fixed, C p is fixed, this term is fixed, right. And if you fixed this the seat the electrode composition the work function is also fixed is not.

So for a material given material composition and given shielding gas and a and b are fixed, so then the variables which can be control to change the melting rate or welding current stick out length and then the consumable diameter, ok and if you fixed the diameter also that mean is that this also goes away, so there are only two parameters can be change independently they are stick out length and then welding current, yes it is clear.

So if you fixed all other things shielding gas is fixed therefore the arc column heat is fixed between the composition is fixed therefore H is fixed, C p is fixed is not it and then now you fix also fixed the welding electrode diameter so r is fixed. So what are the two parameters can be changed to change the melting rate? The welding current, stick out length, right and in practical cases we play around these two parameters to get good sound well bit characteristics, we change the stick out length and welding current for a given electrode diameter compositions.

So when you buy an electrode diameter to you are planned to weld at 3 mm thick and as say as 69 steel and you have a equal similar pillar and you are established the process parameter, ok and then you need to now calculate the melting rate, so your composition is fixed you are buying an a 1 point 2 mm diameter welding wire, it diameters fixed, I am going to use organ as a shielding gas, so all are the parameters are fixed.

Suppose if you want to establish the welding procedure two things you can vary is current and there stick out length, yes it is clear it is good. So with this we will finish this class.