Welding of Advanced High Strength Steels for Automotive Applications
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Lecture - 13
Principles of Gas Metal Arc Welding - Part - I

So you looked at the laser beam welding process to summarize what you have done so far in the laser beam welding.

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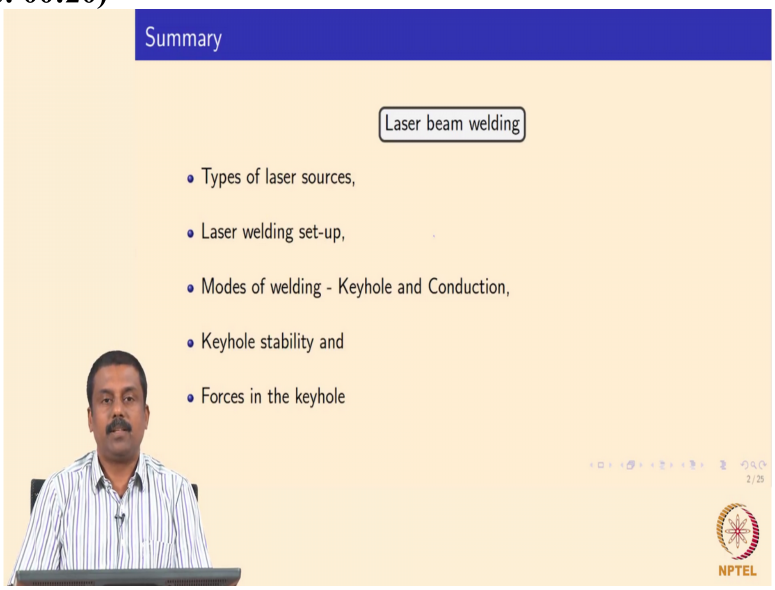

So we looked at type of laser sources, so various sources in solid state and gas as well as in fiber modes. We looked at it and then we looked at the typical laser beam setup and so the modes of welding. So what is keyhole welding, what is conduction mode welding and what is the importance of keyhole and the reasons why we should have a stable key goal in order to have an good austenitic weld and spatter free weld.

And we have too looked at the various forces that are actually affecting the keyhole stability, all right. So we looked at the effect of a vapor pressure in overlap joints. We saw some examples within galvanized steel with varying thicknesses of galvanized layer, how that the vaporization of the zinc effect, the keyhole stability in laser beam welding. And then, we looked at various welding parameters that generally be used for this beam welding processes.

So as we already explained in an automotive welding interface, the resistance spot welding and laser beam welding are the most commonly used welding processes. And apart from these two processes still the gas metal arc welding, the conventional GMAW is also used for very specific applications. So it is also good to look at the principles of gas metal arc welding especially we have made some advances in gas metal arc welding processes.

Conventional process we use in a constant current, for example, the amplitude of current is constant throughout the welding process. There are some disadvantages in terms of heat input the amount of heat you put it in the work piece as well as the transfer characteristic. So what do you mean by transfer characteristic? Now, how you transfer the molten droplets from the electrode to the work piece.

So in order to improve the transfer characteristic to our benefit as well as to reduce the heat input and we modified GMAW gas metal arc welding. And then these modified GMAW are you know, sometimes used in automotive industry to weld thicker sections. For example thick section advances high strength steels or even high strength steels that are used or in some applications where the material the weld strength is not really significant.

So we may also use the GMAW processes to do a brace joint. You can do bracing it is yeah different than the conventional GMAW of a welding process. And we were used a low matter of low metal low melting fillers to make a joints of advance high strength steels. So, these so in order to know understand all the welding processes, I also like to give you an overview of an GMAW because we in subsequent classes we will also be looking at GMAW bracing process as well which actually is very useful to join advanced high strength steels in some of the body parts okay.

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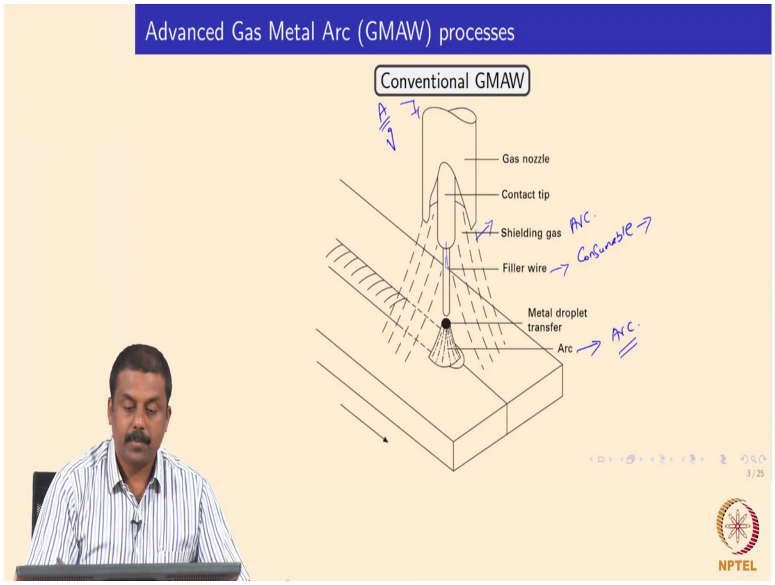

So we will move on to the GMAW process gas burn arc welding process and most of you familiar with the schematic of GMAW. See this is one of the oldest processes availing processes developed to weld conventional materials. So there are three important parts, you can see here. Now, the first important foremost important is the shielding gas and shielding gas is also known as arching gas because we strike an arc using this shielding gas and the filler wire.

So, in this case filler wire is a consumable electrode. Why it is called consumable? Because we melt and consume the electrode to fill the weld cavity and the third important aspect in terms of process is arc okay. So, arc is struck between the consumer electrode and the work piece using the shielding gas. So, I do not want to go into detail about the physics of arc and I will be covering in subsequent NPTEL courses and the physics of arc.

So, right now we are we can assume that so the arc is struck between the consumer electrode and the base plate by passing a current over the potential difference voltage generated across the circuit. So, current is passed through the electrode towards the work piece and then because of the ionization of the shielding gas we produce the electrons and ions. And then we strike an arc between the electrode as well the work piece.

And these various the components of a typical GMAW process is also shown over here and we have a gas nozzle and the contact tip. And contact tip actually feeds the electrode towards the work piece. The electrode is a filler wire, it is consumable. And this can be either similar or dissimilar consumable based on the various welding metallurgic principle microstructure what you are going to generate. And then upon passing a current a you form a molten droplet of the tip of the electrode which is transferred by various means towards the work piece.

So, we will see in detail what are the process parameters that can significantly affect the welding, welding process as well as the stability of the weld in subsequent slides, right now we can assume that in a gas metal arc welding process, so we use a shielding gas to strike an arc between the consumable electrode and the work piece. The gas is ionized and forming electrons and ions and based on your polarity and they can travel either from electrode to work piece or from work piece to electrode.

And the entire the heat is generated by passing an amperage towards the setup from a power source and the setup is maintained to a potential difference of volt of V.

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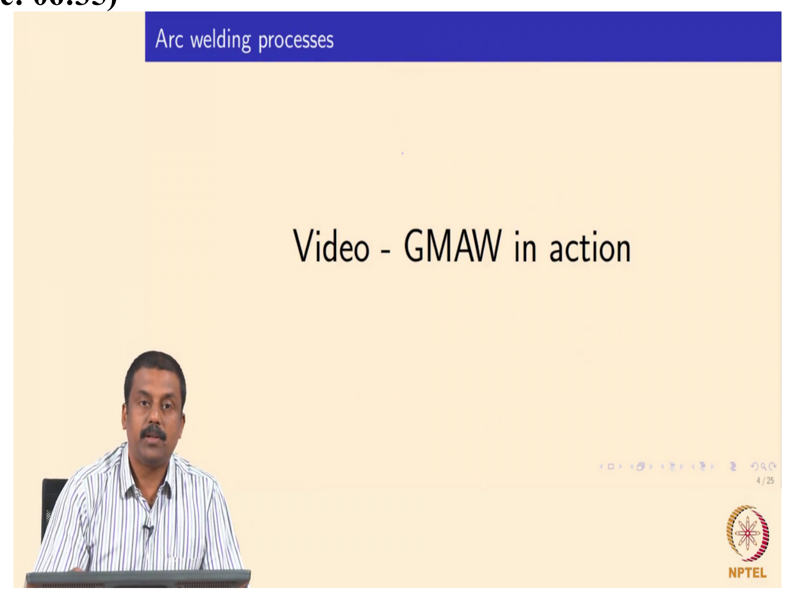

So I will show you in a small video about how the GMAW the gas metal arc welding in action. So it would be better clear for you.

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So, this video shows the consumable electrode the gas metal arc welding process in tandem. So, we have two electrodes attached to a power source and transferring molten droplet towards the weld pool. So what you see over here this is a one filler wire and another filler wire and we are passing varying amount of currents based on the current. And we may hear the transfer droplets in a spray mode or in this case as globules in a ripple mode.

So, these; the characteristic of metal transfer is very critical as we explained in laser welding and how the key hole is important for stability. In this case the transfer characteristic of the top layer is extremely important and you can already see here you know we have a sort of an molten droplets are sprayed towards the work piece and whereas in the other electrode and the droplet transfer is mostly by globules of a molten electro droplet.

And because of the change in transfer mode and this mode would also tend to spend a lot of spatter in towards the other direction than the work piece direction lead about forming a spattering. So the important characteristics of these process are controlled by the current, the amperage we sent, the shielding gas, what we use as well as the melting characteristic of the electrode which is also controlled by the current as well as the diameter and the stick out length, the distance between the contact in the work place.

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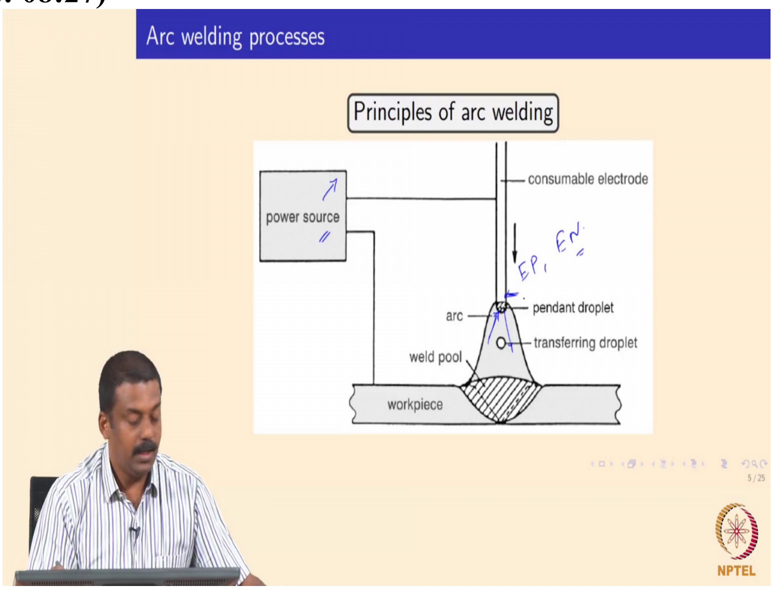

The other aspects of GMAW which you have to see, so again the schematic is shown in this slide, so this can be seen to understand the entire the transfer characteristics and the cross-section of the weld pool what you generate. So, we have the consumer electrode and the electrode and the work piece is connected to a power source. And these power source transfers the current it can be either alternating current or direct current.

And so even if it is alternating current we use a transformer, if it is direct current it is an inverter base power source and this, the power source is sending an amperage, towards the welding electrode and the work piece. And the electrode can be either positively connected or negatively connected. And if you have some DC source and this can be electrode positive or electro negative and based on the polarity you also change the heat transfer characteristics.

So, I do not want to go to detail about the physics but you can assume that when it is an electrode positive and then your the filler becomes an anode and if it is electro negative either filler becomes a cathode. And if it is electrode positive so you would be sending ions towards the work piece. The electrons will be attracted towards the filler if it is electro negative okay so it will be attracting the ions towards the electrode and you will be transferring the electrons towards your work piece.

Based on your current characteristics, you will also change the droplet shape as already explained now when you have an a current a low current mode you will be transferring the droplets in globular mode you know mode and by increasing current, diameter of the droplet which is transferred from the work piece decreases and you will end up transferring in a spray mode from the electrode tip to the work piece.

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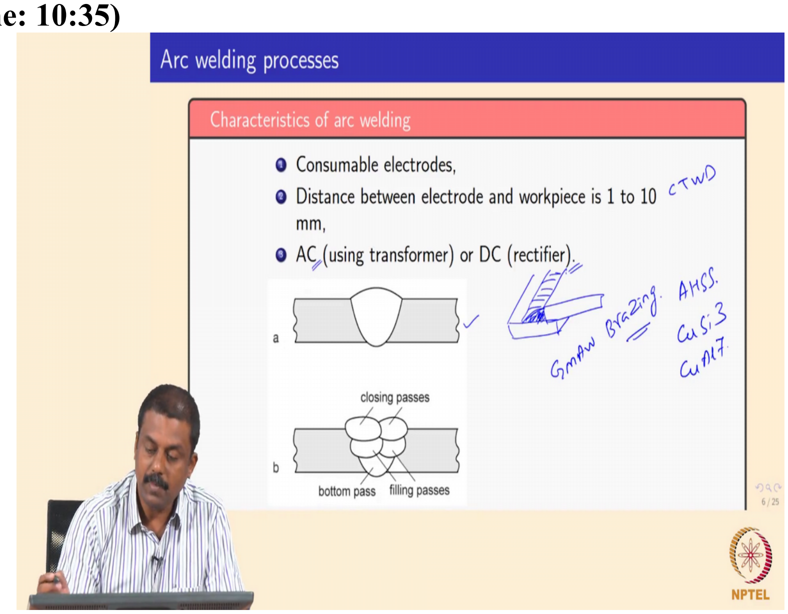

And if you look at the actual characteristic of the arc welding process so we use the consumer electrodes. Generally the distance between the electrode workpiece it is also known as CT WD. So it is contact ripped workplace distance. So contact tip is the electrode container which actually transfers the electrode towards the work piece. And the distance between the contact tip between and the work piece is very critical because that is going to determine the stick out length.

And the stick out length is one of the important parameter which determines the melting rate of the electrode. And we can either use in a; and alternating current or direct current and based on our need generally yeah we can choose between the direct current, alternating current. For example the welding of aluminium is generally done in alternating current. And use of DCs preferred in a welding of Steels because we can also change the, manipulate, the waveforms very easily within a direct current.

Either you can do it in a pulse current or you can also do it in with the same various modes of the waveforms. So, waveforms by meaning, wave forms what we mean is, the variation in the voltage and current in a given welding cycle. So, welding can be done either with a single pass so, if you have a very thin sheets that are going to be welded. You can also weld with a single pass or if you have thicker sections your welding is also carried out in multi passes by sequentially placing each pass on top of each other.

Generally in a welding of automotive steels, if you are doing using a GMAW and the most of the cases will be doing a single pass and some cases now we may also have to do in all of configuration. So, we will also be doing it in overlap configuration like in the lab joint in fillet mode. We will be doing and welding in overlap configuration and this is most preferred mode of welding especially if you are doing and GMAW bracing.

So, in this case the bracing is done using an low melting filler where say for example in advanced high strength steels so we use a copper base fillers cusi 3 or cul7 the copper base fillers and we melt and deposit the fillers to join to overlapping advanced high strength steels in by you doing and by carrying out a fill at weld.

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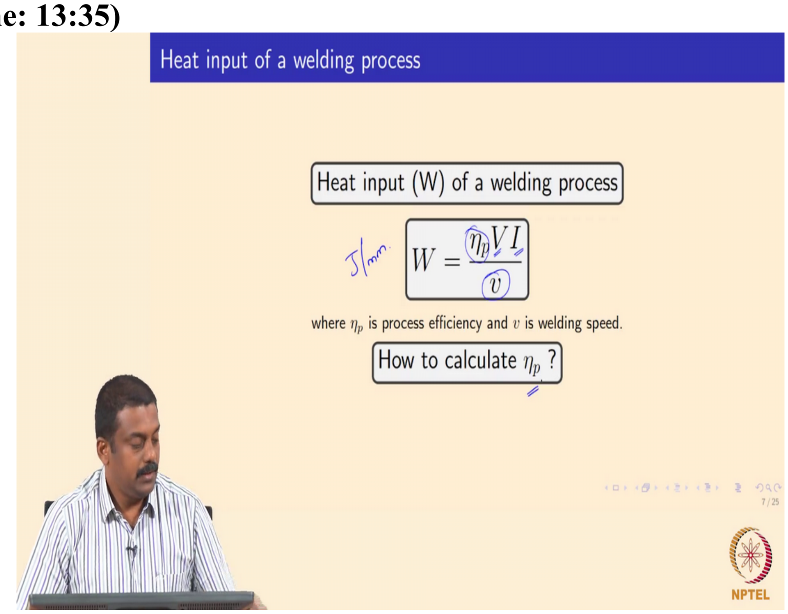

So, in this GMAW, the heat input is determined by a very simple equation. So, where we have the voltage and current which is actually passed to the, the current is passed to the system voltage V. So, the heat input which is calculated in joules per mm which is not is actually nothing but the np which is the process efficiency. Process efficiency determines how much heat which is generated in arc transferred to the work piece times the voltage of the circuit.

And I amperage of the current you send it into the system and here the V is the speed of welding. So the important parameter here is the efficiency. The efficiency of the process is determined by the various factors including a polarity of the source either you keep the electrode positive or negative. And your shielding gas characteristics as well as the process characteristics such as whether the arc is completely shielded, arc is completely protected from atmosphere whether the, all the heat that is generated in the arc is transferred and to the work piece are not.

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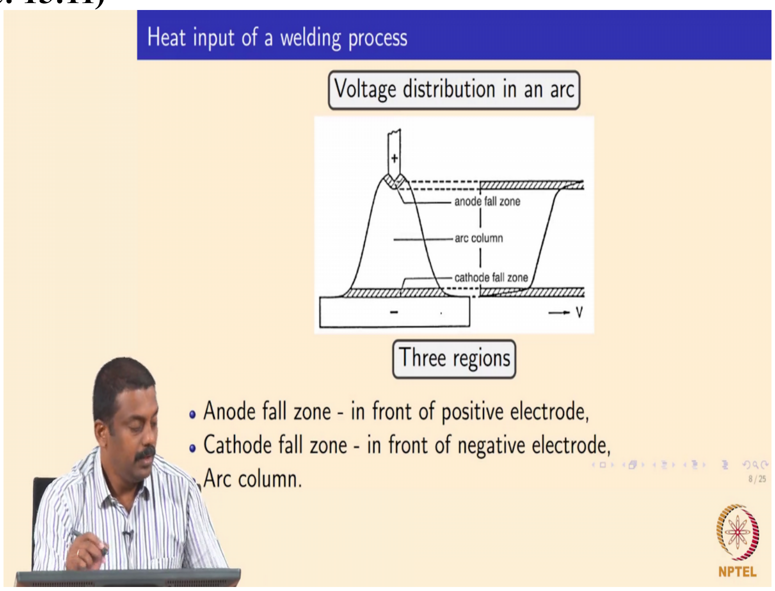

So generally the np can be calculated for a given composition of the filler wire and the configuration of the process. Generally the NP is calculated based on the polarity for example if you look at typical GMAW setup. So, we have three regions in the and the GMAW a schematic if you look at it and if your electrode is positive and you have an anode which is your filler wire and you create an anode fault zone and an arc column, surrounding the anode.

And if your electrode is positive obviously your work piece is negative then you have an cathode fall zone just above your work piece. So these three distinctive regions we always present in GMAW. So, in this case if you look at the voltage distribution and you have an more or less constant voltage along in the arc column and because of accumulation of electrons in the anode fault zone and because of the accumulation of ions positive ions in the cathode you have been in a steep voltage gradient in these two regions.

And based on your polarity, you may either transfer the electrons from the filler wire to the work piece. In this case, you will be transferring ions towards the work piece and if your, the work piece is negative obviously you would be transferring electrons and to the filler wire. So based on the polarity you will be transferring the electrons and ions. But in a GMAW process also you will also be melting on the electrodes and you will be transferring the droplets as well to the work piece.

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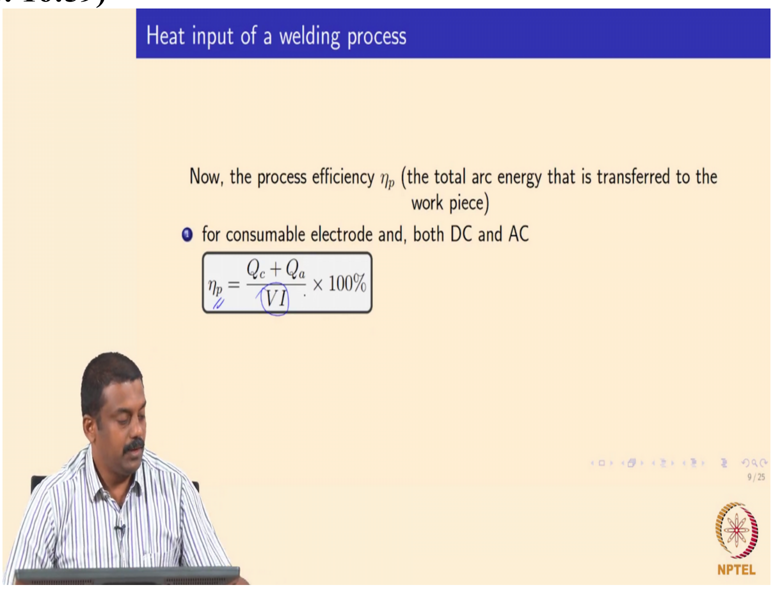

So then, the efficiency can be calculated very easily. This is the process efficiency is nothing but the total arc energy that is transferred the work piece right. So in this consumer electronics classes so you also melt the consumable and then transfer the droplet to the work piece so the total efficiency is the amount of heat generated in the cathode as well cathode fault zone plus the heat generated in the anode fault zone.

And because we are transferring the droplets from the electrode to the work piece the total heat generated is QC and plus QA and that the total heat transferred over the amount of the energy supplied to the system there is nothing but VI and times 100 that gives you the efficiency of the process. So, in GMAW, the Convention GMAW process the energy efficiency it is it is not that significant.

But it is much more than the laser welding process because the laser welding process we already looked at in the, the absorption of laser to the work piece is extremely small. So, whereas in this case, the, the heat transfer from the arc is until it remained by the, the atmosphere as well as the polarity so as I explained, whether you have a filler as an anode or cathode irrelevant because you will be transferring, you will be melting the, the filler and you will be transferring the entire heat that is there in your electrode towards the work piece.

So, if you have a non consumable welding process for example if we have a gas tungsten arc welding process, there you are not transferring the entire heat from the electrode because you are not melting the electrode, right. So then, based on your polarity you can be either Qc or Qa. So, that will be your efficiency of the gas tungsten arc welding process.

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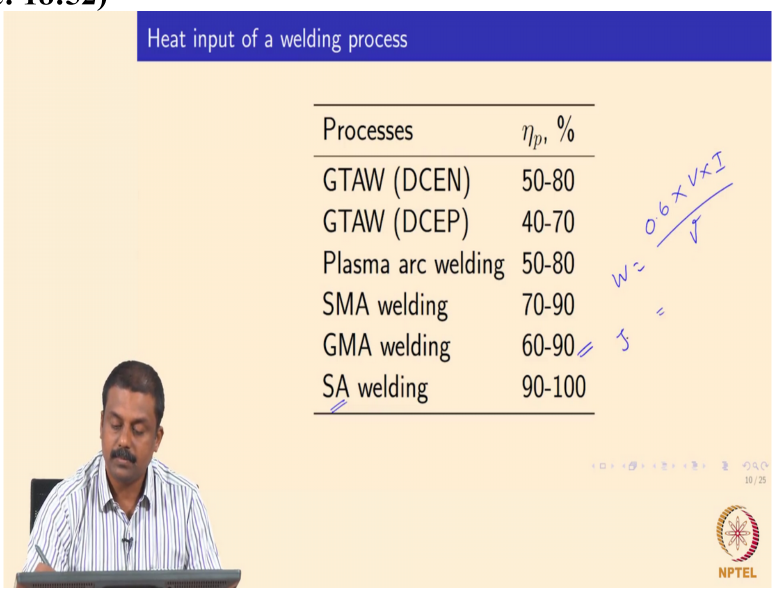

So, that is why generally in gas tungsten arc welding process the efficiency is quite low whereas in a GMAW welding process you can have the efficiency of the process going up to 60 to 90 %. And based on the heat transfer from the arc to the work piece and you also see I listed a various processes the other variant of GMAW is the submerged arc welding process which has an highest efficiency why because the arc envelop is completely covered by the flux in a submerged arc welding process.

So, whatever heat is that is generated it is entirely transferred towards the work piece so that determines the efficiency of the process. So, for a GMAW process we can see that I know the efficiency the amount of heat that is actually transferred from the arc to the work piece is somewhere between 60 to 90%. So, we can calculate the heat input from the efficiency for example if we assume, say 0.6% then you can use an a voltage and that can be instantaneous voltage or the mean voltage and then the current over the velocity. And that will give you the amount of heat generated in joules per mm okay.

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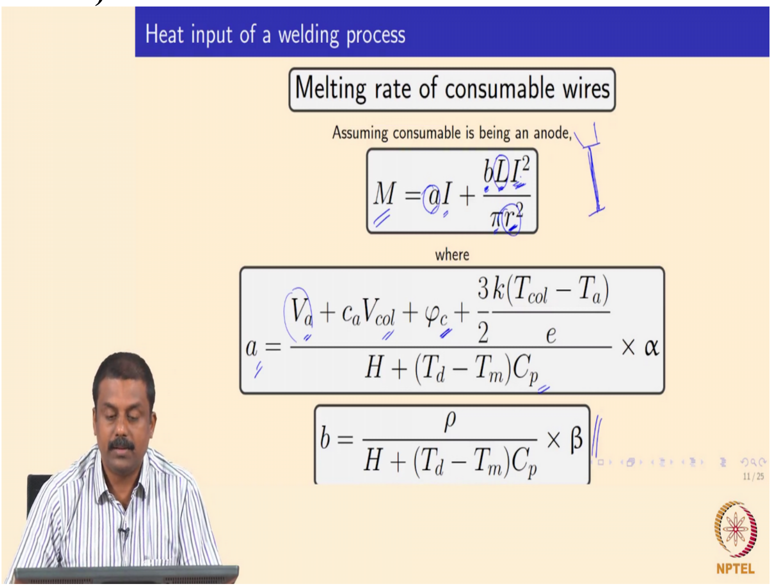

So, the other important parameter in consumable welding process is the melting rate of consumable. So, that is also very important to understand because that determines your well built geometry and your productivity. So, that is again is a function of the amount of heat that is transferred to the electrode whether it we are going to keep the electrode as a positive or negative. So, in this case, so if your electrode is anode.

So, you will have the amount of heat that is there in your electrode tip and the filler material parameter the energy needed to heat up with the electrode towards and the above melting point. And these two together you would have an equation ultimately will be leading to the melting point of an electrode which is nothing but a constant. And this constant is a function of the parameters which controls the characteristic of GMAW process.

For example the anode voltage and anode fall zone voltage and the voltage at the arc column and your; the cath in, cathode ionization potential and then the amount of heat needed to heat the your anode. So, to the excess the excitation temperature or ionization temperature and over the heat in need, required to melt the electrode and keep the electrode tip above your and the melting point.

So, with that now we can calculate the melting rate which is nothing but the constant over current. The current is zero at the welding current plus and another constant which is a function of material. And then L is a stick out length. The stick out length is nothing but the distance between the contact tip to the work piece which we already explained in a previous slide. And the stick out length is very important because that determines your, the resistance heating a part of the electrode.

And then again I is the welding current and PI as well the it is a universal constant and then r is your, the diameter, radius of your filler wire or electrode. So, using this so the a and b is a constant for a given material and for a given process conditions, whether it is a positive or negative. So, if you know a and b for a given stick out length and you fill away diameter we can calculate the melting rate for a given welding current.

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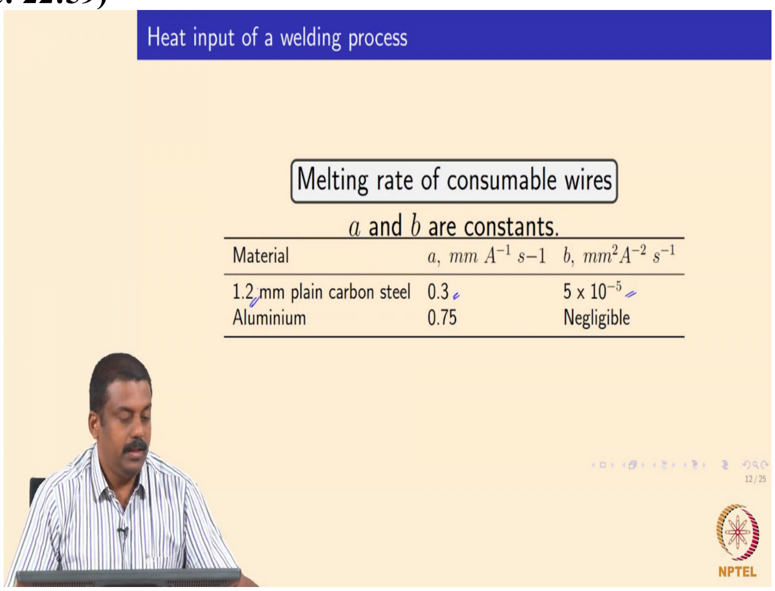

So, I have given some of the constants a and b, it is used for commonly common welding wires. For example, if you have a 1.2 millimeter a plain carbon steel as a filler. So, we can get an a and b calculated from the experiments. It is say or example, your, a vary from 0.3 and then b is 5 *10 power -5 and using this value if you know the stick out length the L as well as your welding current and your radius in this case diameter is 1.2 mm in diameter.

So, it will be 0.6 so, using that you can calculate the melting rate of the filler for a given current I. So, obviously if you look at these equations and if you have longer r they are the bigger R diameter is increasing; then, you are making lead decreases obviously. And if you stick out length increases you will also melt more. And of course if you have higher current you will also melt more.

So, the main important parameters for a given composition and given a wire diameter that means if you fix r as well as if you fix in the a and b the important parameters you can vary to change the melting rate is a stick out length L and they were welding current, right. So, that is very important to understand the important factor that can influence the melting rate for a given diameter of the wire as well as for a given process condition.

That means that in the foreign and if you use electrode positive and you fix the other process parameters for example, shielding gas, the important factors that can influence your melting rate is a stick out length and the welding current.

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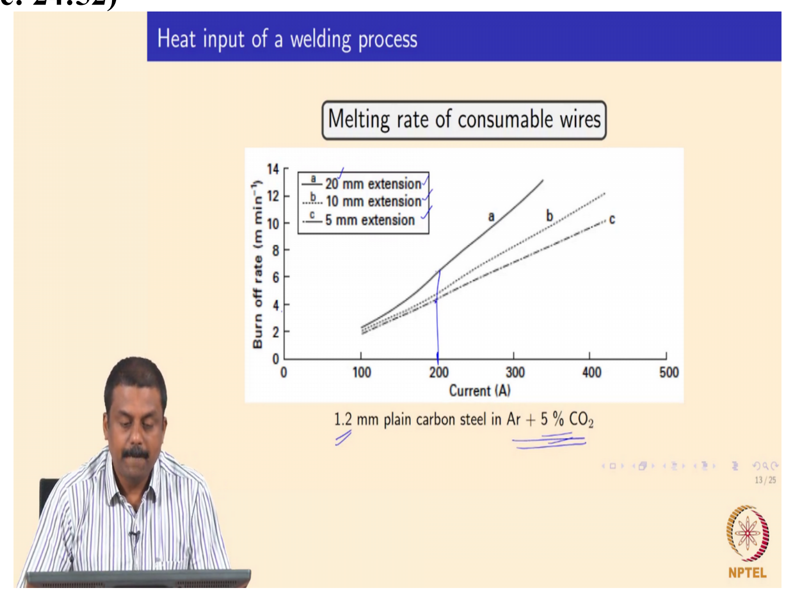

So, this graph this shows the effect of the stick out length on the burn rate or the melting rate of 1.2 mm plain carbon steel in argon + 5% CO2 atmosphere. And as already explained, we fix the diameter, your shielding gas is fixed and in this case these experiments were carried out in electrode positive conditions, if you look at the reference book. So with that conditions if you change this stick out length so, if you increase the stick out length what happens, your melting rate also increases.

So, for example if you have a 20 mm stick out length under 10 mm, 5 mm for a given base current given welding current so you would end up melting more and if you have a longer stick out length. That is how whereas if you have stick out length of 5 mm compared to 20 mm for a given current it will be melting less than when you have a stick out length of 20 mm.

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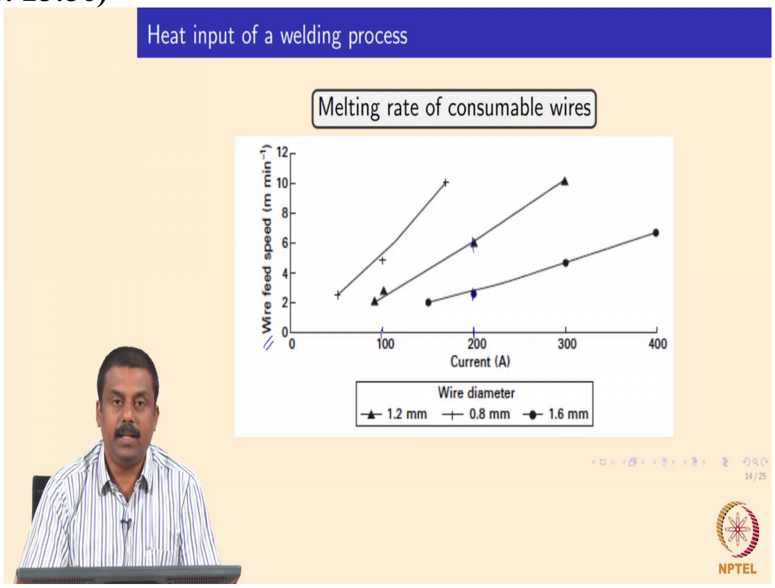

Similarly your right diameter also changes your melting rate as already explained. If you increase the wire diameter so obviously the melting rate decreases. So, if you want to keep your arc length constant so you always have to, have an wire feed rate also equal to your melting rate. So, in order to keep the arc length, the length between the tip of the electrode towards and the base metal, if you want to keep the arc length constant, so, you may have to feed the wire at the same rate you are melting okay.

So the when you want to keep the arc length constant so obviously your wire feed rates must be equal to the melting rate. And so once you have a constant arc length so your wire feed rate equals your melting rate and then yah as a function of wire diameter you keep stick out length constant. And if you change the wire diameter obviously increasing diameter you are melting less.

So, in this case if you have and the mean current of 200 amperes of filling current for a constant stick out length and for a given shielding gas, so larger diameter wire melts less than the smaller diameter wire. So, obviously if you reduce the diameter your melting rate increases for a given welding current. So, it is very important to understand this, the basic physics. I want to go into detail about the why the melting rate changes with function of current and the derivation of the equations of for the melting rate as well as the efficiency because I will be covering in detail in line with subsequent booked class of welding processes.

So, right now we, you have two equations as I showed you which are very important. How to calculate the heat input? Heat input is nothing but the efficiency time voltage current divided by welding speed. And the efficiency we calculate based on the polarity and for a giving and given the shielding gas and the arc enveloped transfer characteristics, we can calculate the heating rate.

Generally the efficiency for GMAW is calculated by an average of the current in cathode and anode. So we can assume that you know the total heat generated in anode cathode is transferred to the work piece. And then we can calculate the q heating the efficiency of the process as I had explained in the equations. And that is coming around 60 to 90 % deficiency process. Generally we assume a lower efficiency 60% to calculate the heat input of GMAW process.

So, once you know the efficiency we can also calculate heat input. And the heat input can be used to understand the heat input thermal cycles of GMAW process. So the other important factors is the melting rate of the equation and the filler wire and that is actually calculated as a function of welding current, stick out length and wire diameter. So if in case the welding current, obviously melt more and your melting rate increases.

And if you increase the stick out length again the resistance heating also increases and thereby melting rate also increases. And if you reduce the filler diameter you also melt more currently for welding and diameter increases even melting it also decreases. So with that we will move on to the metal transfer characteristic of the droplets, okay. Thank you.