Fundamental of Welding Science and Technology
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Lecture – 16
Physics of Welding

In last I was discussing about metal transfer and I have already completed in details about metal transfer. Today I will start the effect of different process parameter on metal transfer first, after that I will discuss about what are the different welding efficiency generally used in welding technology in details. So, first of all today I will discuss before going to discuss about the effect of different process parameter one metal transfer. First of all we should know what is melting rate how it occurs actually.

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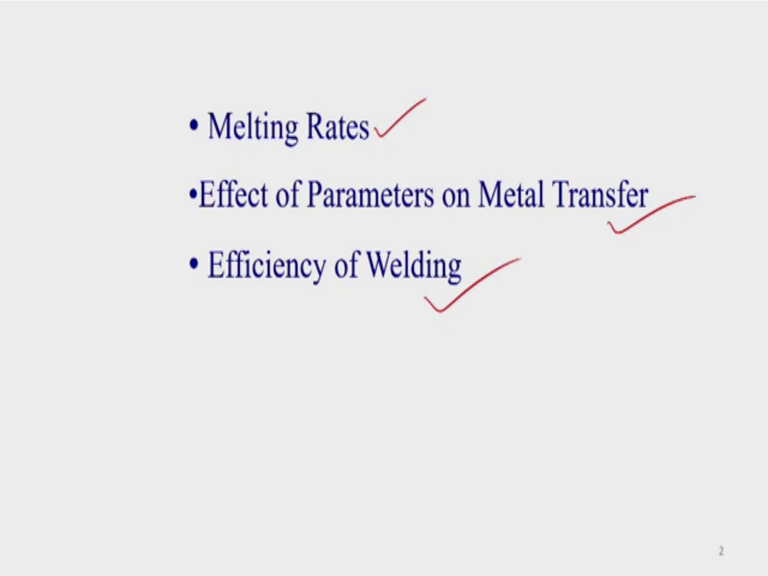

So, this is the today's topics content that is first I will discuss about melting rates why melting rate is required. Because melting rate means how much volume or how much mass of metal is transfer per unit time from electrode to workpiece actually, that melting rate also we should know in details. Then we will discuss about effect of different process parameter actually different parameters or we can say process parameters or we can say operating parameters one metal transfer. Then we will discuss efficiency of welding different types of efficiency of welding.

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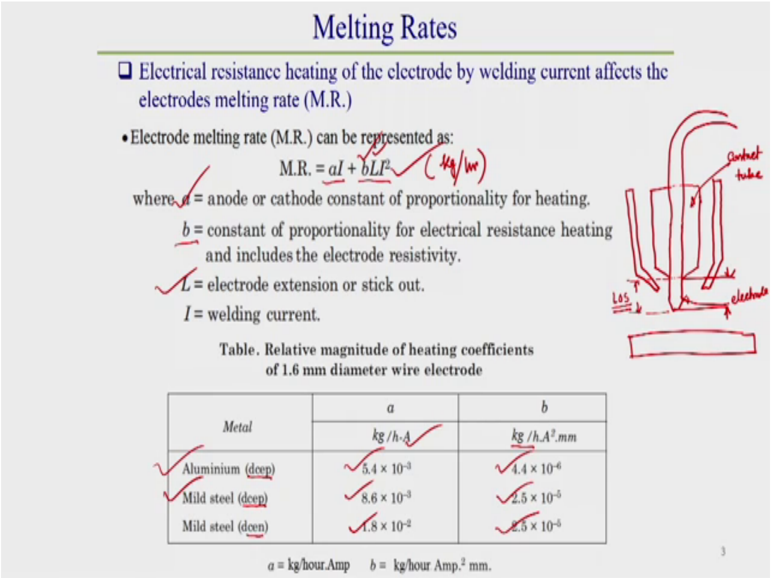

So, first of all we will discuss about melting rate; generally melting rate that what I have already told you; that means, melting rate means how much mass of metal transfer per unit time from electrode to workpiece. Generally, electrical resistance heating of the electrode by welding current affect this electrode melting rate L 1. So, here one things you keep it in mind that electrode melting rate is highly depends on mainly depends on or we can say mainly depends on welding current. Apart from this thing it also depend on length of its stick out and other parameter.

But that their effect is marginal that what means comparatively very less than welding current that is why here I am discussing; that means, how the melting rate dependent on welding current. Here melting rate can be represented we see is like that is melting rate means M dot R; that means, M for M stands for melting; R is stands for rate. So, melting rate is equal to a into I and b L into I square; that means, it depends on highly depends so; that means, here from here itself you can say it is a function of current and it is a function of current itself from here itself you can say; that means, a into I means I stand for current.

And a is generally anode or cathode constant of proportionality for heating. This a constant generally this a constant depends on electrode material type its type of polarity, then it is also depends on generally emissivity of the electrode. That means how much emissivity of the electrode are there; so this a is generally is a proportionality constant.

Similarly, this b is also a proportionality constant, but this proportionality constant for electrical resistance heating. And, it also include the electrode resistivity; that means, this proportionality constant b generally for electrical resistance heating and its include the electrode resistivity also.

Here L is called this L this melting rate is an another parameter dependent that is call length of a stick out, this is L is called length of a stick out. Here you should know what is length of a stick out length of a stick out means in case of MIG welding or we can say in case of MIG welding in case of MIG welding generally how the setup is look like little bit, I am just showing then it will be very clear to you. Because here generally we are discussing about consumable types of electrode related things; so in case of consumable types of electrode only there is occur melting rate means volume metal melted where we can say volume of molten metal transfer from electrode to work.

We generally in case of consumable types of electrode generally, here length of a stick out means generally this is call contact tube, contact tube contact tube. If this contact tube leads power source cable is connected through this contact tube current is flowing from power source to electrode and through electrode to arc and through arc to workpiece like this types of thing generally works. So, this is generally call contact tube and this is generally call consumable electrode consumable; this is actually electrode you know electrode you know. So, what is generally cause length of stick out? Length of stick out means from this tip of this contact tube how much electrode is extended out from this tip of the contact tube, generally that extended electrode portion is call length of a stick out.

That means how much is stick of electrode coming out from the tip of the contact tube that is; that means, this from here to here we can say; that means, from here to here this is generally call length of LOS; that means, Length of Stick out or you can say this is call electrode extension. So, here melting rate is depends on this length of a stick out L also this is this is here represented in terms of L. So, here one thing you see this melting rate generally depends on both current and length of a stick out. And, it is also depends on some coefficient; that means, proportionality constant which is a and b. What is this a and b? This a and b generally this proportionality constant a and b which is represented in this table.

Here you can see that for different different types of material its value is different, like for aluminium if we use this is if we as a polarity because this constant here a constant if a and b this proportionality constant depends on both polarity as well as its material type that I have already told you. So, generally in case of aluminium you see its value is value of proportionality constant a is 5.4 into 10 to the power minus 3 whereas, this b constant value is 4.4 10 to the power minus 6 actually kg per hour into ampere square into millimetre kg per hour per ampere square per millimetre actually.

Because, here from this things if you just multiple with this equation you will get the melting rate unit is kg per hour; that means, how much mass of electrode material melted per unit hour. That means, per hour how much electrode material is melted that is representing from this constant unit also you can get the idea from here. Because, here if you just is you see here b unit is kg per hour per metre square per mm. So, if you just multiple with this because here L length of a stick out unit is L and I I unit is ampere. So, ampere square and this length of a stick out millimetre will be cancel out.

Then what will be the remain part? So, remain part will be this kg per hour. So, what happens by this from here itself you can get that; that means, unit of what is the unit of a and b. So, unit of a and b is like this a unit is kg per hour per ampere, a is stands for ampere; a b unit is kg per hour per ampere square per millimetre. So, in case of mild steel also you see in case of mild steel also this a generally magnitude is like this and b magnitude is like this if it is dcep. Now, if the polarity is then because it depends so, is this depends on this a and b depends on polarity also.

If it is dcen if it is different; that means, electrode negative polarity then its magnitude you see is different than this is a generally; so, once we know this a constant and b constant value and so, we know the length of a stick out and current. Then we can easily we able to find out how much how much mass of means electrode material melted per unit time or unit hour from this equation itself you can get the idea about melting rate. Now, we will go what is the different parameter generally effect on the metal transfer.

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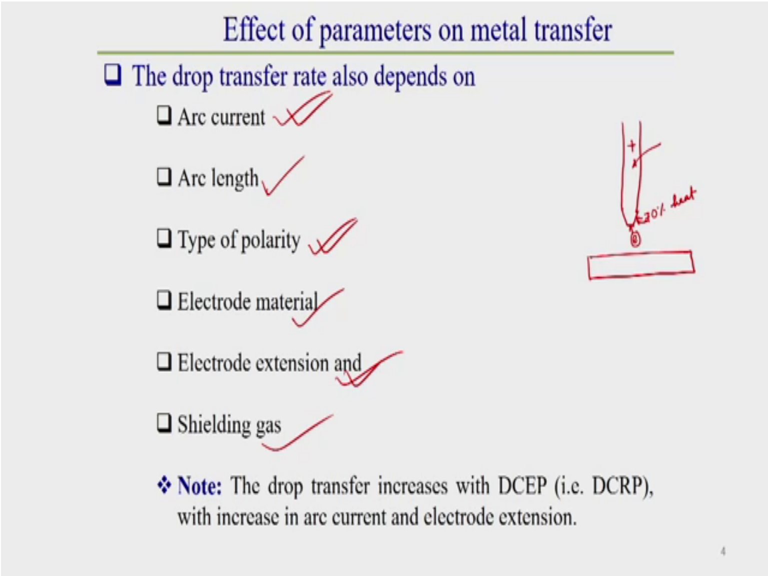

So, we got the idea about melting rate; that means, how the melting rate dependent. Now we will see this metal transfer and its type, what are the parameters generally affected this two; that means, type of metal transfer and a metal transfer rate how its affected by different operating parameters of welding process.

Generally, is this drop transfer depends on different different operating parameters here like its depends on arc current, it depends on arc length, it depends of type of polarity. It depends on electrode material type, it depends on electrode extension and its depends on shielding gases. So, one by one I will discuss in detail what is the effect of this different operating parameter or welding parameter 1 metal transfer rate that I will discuss. So, here one things you keep it in mind what I have already shown in last slides that mean melting rate is proportional to current.

So, which can say higher the current higher the melting rate and another things also we can say that with DCEP, DCEP means more melting rate is taking place definitely with DCEP. So, a DCEP means if it is positive then electron bombardment will be taken place on electrode; that means, here we can say that around 70 percent heat generally generated in case of electrode. So, more material will be melted so, more metal transfer rate; that means, state of metal transfer also will be increased. So, generally for compared to dc and with DCEP we get more metal transfer rate. And, apart from this thing it is also we have seen that metal melting rate also depends on length of a stick out. It is also you observe that melting rate generally is almost proportional to; that means, directly proportional to a length of a stick out L. So, would if the length of a stick out increases then melting rate also increases.

So, we got the idea what its call type of polarity, then electrode extension and current generally affect the melting rate or you can say metal transfer rate that idea will got from here.

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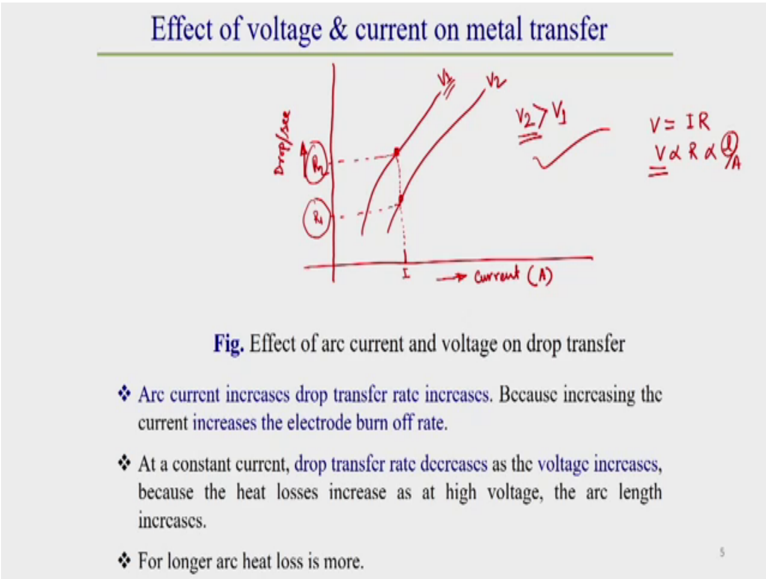

Then we will discuss about all other thing; that means, how the voltage, how the shielding gases, how the electrode material affect the melting rate that also I will discuss in detail in subsequence slides. So, first of all I will discuss about arc length and current with the change of current and voltage how the metal transfer rate changes that I will just discuss first here. One things you keep it in mind what I have told you; that means, with increase of current generally melting rate increase so, generally metal transfer rate also increase.

Why its increase? Generally with higher current turn of rate; that means, higher current more heat is generated and generally because, from Joule heating you know that idea that mean resistance heating from you know the idea, that more burn of material is taken place. And, apart from this due to high electromagnetic force for high current generally spins effect is more due to this spins effect means rapid drop transfer. That means, rapid drop transfer is occur; that means, drop transfer rate increases. So, generally what we can say if you just draw the relationship between this current versus drop transfer then you will get the very good idea from here.

Let this is current this is current in ampere and let this is drop transfer rate actually drop per second. We can say that drop transfer rate generally varying with increase of current, it has observed with increase of current generally drop transfer rate increases. Let us for a particular voltage V 1 we are getting drop transfer for a particular welding voltage, how the drop transfer per unit time varying that we can got with the varying with varying with the current that we can got from this curves. That means, it generally proportional if it generally with increase of current increase of drop transfer rate. Now, let us for another voltage if the voltage will change then generally if the voltage will change then this sets another voltage.

Also, if the voltage change then the what happens? This drop transfer rate also will change, how it is because what happens here one things you keep it in mind. So, for a particular current from this two curves itself we can get the idea for particular current for a particular current generally the rate of drop transfer the rate of drop transfer for a particular current, let us for particular current I the rate of drop transfer let us R 1 and R 2. And, one things you can easily observe for R n; that means, for particular current if the voltage changes then the drop transfer rate also changes. What happens here generally what will be the things here, here always keep it in mind here is V 2 generally greater than V 1.

Always keep it in mind V 2 greater than V 1, why it is generally with high voltage with higher voltage lower the melting rate metal transfer rate we generally lower voltage this is generally for lower voltage than this what is call V 1 that is lower voltage generally melting rate is higher. Why? Because, generally higher voltage means arc length is increases higher the arc length higher the voltage what we that I have already discuss. Again I am just little bit telling generally voltage is bigger from a Ohm’s law you know voltage is equal to V is equal to I into R; that mean voltage is directly proportional to R that R is generally proportional to length by cross sectional area of the R.

So, generally higher the length of arc higher the voltage that idea we are getting from Ohm’s law itself. So, generally higher the arc length if the length higher the arc length then heat loss is more. Due to this more heat loss generally what happens the drop transfer rate generally decreases. So, the rate of drop transfer rate is less because more heat is lossless for a particular current. General for so, more heat is losses for a particular current; so, that is why generally what happens thus, for higher voltage generally melting weight is less. So, if for less melting rate generally what happens heat loss is more due to this high arc length heat loss is more.

So, due to this lesser heating less melting of filler material will be taken place. So, less rate of a metal transfer will be taken place. So, from here what idea we got; that means, with increase of current drop transfer rate is increased, but with increase of voltage due to increase of voltage means higher arc length. So, higher due to this higher arc length as the heat loss is more due to that what happens; drop transfer rate also is less. So, for higher voltage generally drop transfer rate is less that idea we can get from here. So, generally drop transfer rate so, what are the parameter it depends. So, among these three about three parameter; I have already discussed.

That is length of a stick out, current and voltage among these generally current and length of a stick out directly proportional generally with drop transfer rate, whereas this voltage is inversely proportional with dot drop transfer rate. Now, we will discuss about another parameter; that means, polarity here always we should keep it in mind.

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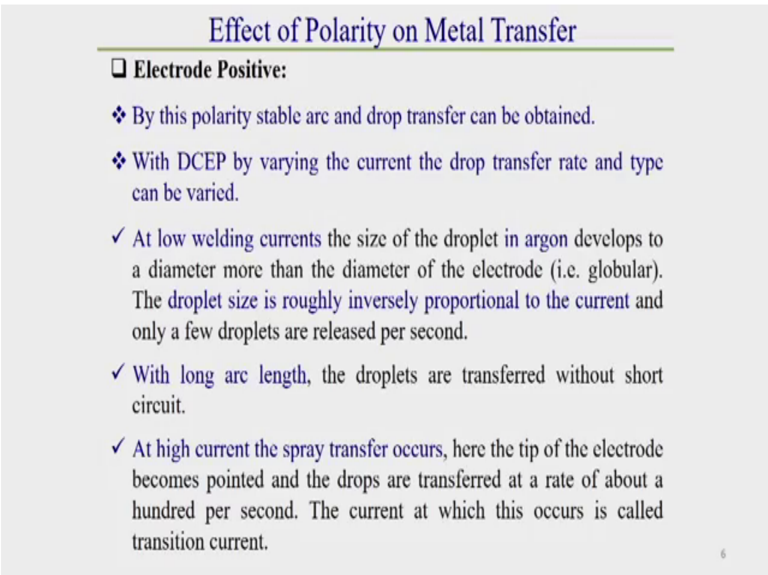

So, current higher current higher melting that we have seen now we will see what is the effect of polarity 1 metal transfer rate as well as type of metal transfer. Here one things we keep it in mind generally polarity have significant effect also in metal transfer type as well as its metal transfer rate.

What happens generally DCEP polarity generally is good for consumable types of electrode. Why it is good? That what I have already discussed in details because, in case of DCEP generally we can get a stable arc as well as stable metal transfer; why it is that I have already discussed. In case of DCEP with argon atmosphere generally, argon gas have a very good plasma property.

This argon gas plasma property gives better types of characteristics of metal transfer. Why? That is little bit I will discuss in subsequent slide in details. Type of metal transfer means generally by using DCEP you can get globular type of metal transfer, you can get spray types of metal transfer. How? Because generally for lower current trains if you use DCEP here generally you can you can create what its call globular types of metal transfer. If you just increase the current above the transition current what I have already discuss. So, above the transition current; that means, with increase of current above the transition current here you can get a spray types of metal transfer.

So, so this DCEP generally with argon atmosphere generally give stable arc and different types of mode of metal transfer as well as metal transfer rate different types of rate of metal transfer also by using DCEP. So, then DCEP is preferable for consumable types of electrode material metal transfer.

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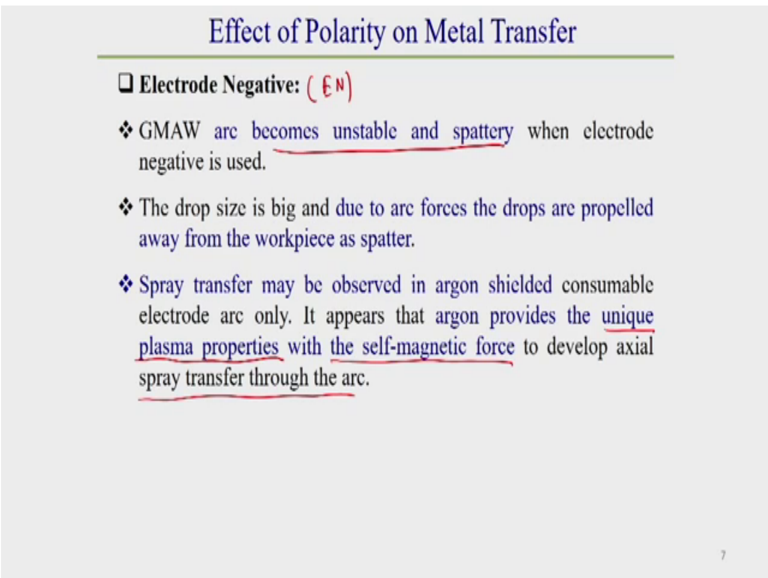

Now, we will see what is the effect of DCEN; always keep it in mind in case of a consumable types of electrode material like GMAW that is called MIG welding process. Generally, GMAW are becomes unstable and spattery generally if generally electronegative electrode negative polarity is used. Why? Because, what happens due to this electrode negative polarity here arc is what I have already discuss about this thing; in case of consumable electrode generally if we use DCEN sorry; that means, electrode negative generally then bombardment of the electron taken place to the workpiece whereas, bombardment of ion taken place on electrode.

Due to that generally ion have higher mass so, generally less impact energy than electron that; so, due to this less impact energy less heat is generated in what its call electrode if it is DC EN. So, what happens in this case generally 30 30 percent and 70 percent heat is generated generally in case of electrode and 70 percent heat is generally generated in workpiece if it is electrode negative. And, due to that reason and due to this flow of electron and ion generally what happens here in case of electrode negative case. Here generally what its call this arc become unstable and spattery in nature, generally if you use this DCEN as a electrode negative polarity.

Here generally due to this flow of electron and ion towards what its call workpiece and flow of ion towards electrode, due to this thing generally here the drops size become weak and due to arc forces the drop arc propelled away from the workpiece as spatter. That means, here generally due to this we can say repulsion force of the arc here in this case if it is electrode negative is there repulsion force of arc; here generally drop rippled away from its or you can say here generally drops are profiled away from the workpiece and it is generally transfer side orderly towards workpiece.

Due to that what happens a spattery types of metal transfer is taken place. But, one things you keep it in mind here generally in case of electrode negative drop transfer mostly globular in nature because, here due to this repulsion force of arc drop transfer rate is comparatively lesser than electrode positive with same current. But, here spray transfer also we can observe as spray transfer may be observed in case of argon shield with higher current range. So, in case argon atmosphere it appears that argon provides the unique this always you keep in mind; if we use argon as a shielding gas then generally its provide a unique plasma property with cell magnetic force to develop axial spray transfer to the arc.

Because, due to this unique property of argon plasma so, generally argon provide the unique plasma property with the shelf magnetic force which generally can develop axial types of metal transfer. But, this generally little bit higher types of current range, this types of spray transfer we can get with argon atmosphere. In this case compared to electrode positive polarity here metal transfer is spattery and more globularies nature than electrode positive type.

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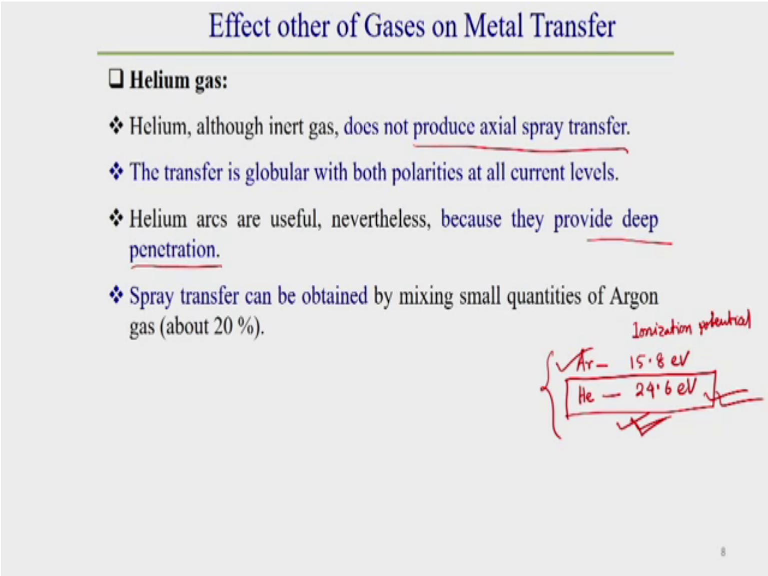

Now, we will discuss what is the effect of different gases on metal transfer. Here one things you keep it in mind generally what we observe that in case steel types steel types of metal transfer argon is very much preferable because, out of sense argon gives some unique plasma property. By which we can get generally stable types of arc can stable types of metal transfer. But, here one things you keep it in mind helium gas also generally sometimes helium also inert gas which is all like argon gas; helium also sometimes used as a inert gas for some cases. Here one things you keep it in mind helium generally although its inert gas it does not produce axial spray transfer.

Here generally if we use helium as a shielding gas generally it always produce globular types of metal transfer. Here both DCEP as well as in the case of DCEN with vary in current range generally in case of helium we get generally globular types of metal transfer. Then also helium is helium arc also useful nevertheless because they provide deep penetration. Why the deep penetration we are getting that I we will discuss. But, in case of helium gas also we can obtain spray types of metal transfer if you mix some percentage of argon gas with helium around 20 percent. That means, above 20 percent argon gas if we mixed with helium gas then this mixing can convert this globular types of metal transfer to spray types of metal.

Once helium alone cannot generate spray types of metal transfer, if we make some sort of argon gas with helium like about 20 percent then we can convert this globular transfer to what it is called spray typed of transfer. So, what we got from here that in case of helium generally its gives always globular types of metal transfer both DCEP as well as DCEN ok. Now here why, but the we why it has high penetration? Because, it has high generally this globular transfer rate depends on ionization potential. Generally why compared to argon helium drop size is more?

Because, this is happen because why drop transfer rate in case of helium is less that also little bit you should know. Generally, here one things keep it in mind this drop transfer rate also depends on ionization potential of the gases. It has observed that the argon has a ionization potential argon has a ionization potential potential; that means, argon gas to be ionized; that means, converted to positive ion and electron. Generally what happens here that ionization energy or kinetic energy that is ionization energy required is around 15.8 electron volt.

Whereas, in case of helium generally it is almost twice; that means, it is generally 24.6 electron volt. So, ionization potential of helium is much higher than argon that is why, generally in case of argon what happens transfer of material is stable and study in nature compared to these. Because, what happens due to this high ionization potential of helium here metal droplet transfer rate decreases, because we had high ionization potential is. That means, to be ionized of this helium gas it take more energy, it require more kinetic energy is required. Due to this more kinetic energy to ionize this helium gas here generally what happens here drop transfer rate decreases.

So, drop transfer rate in case of helium that is why drop transfer rate decreases means here size of the drop also increases. Due to this high size of the drop here generally drop transfer type is globular in nature then case then there is a then case of helium gas. But, what happens what I have told you due to this high ionization potential of helium gas generally it has a property that is called generally high penetration property. Because, it generally can provide deep penetration to the workpiece that is why helium arc also sometimes its useful due to its high penetration capability. So, we got the idea due to these different ionization potential generally in case of helium gas as its ionization potential is higher. So, due to this high ionization potential generally high energy is required to ionize the helium gas.

So, here generally more energy generally we can say losses or we can say more energy generally required for ionization; due to this more energy required to ionization here the less droplet transfer rate is occur compared to argon gas. In case of argon gas generally as its ionization potential is less; so what happens here generally more electron more ion can produce generally with less energy. So, due to that generally what happens more metal droplet because, if there will be more electron more ion so, more heat and other thing can generate than helium gases. Due to that in cases argon gas generally we can get more drop transfer rate compared to helium gases.

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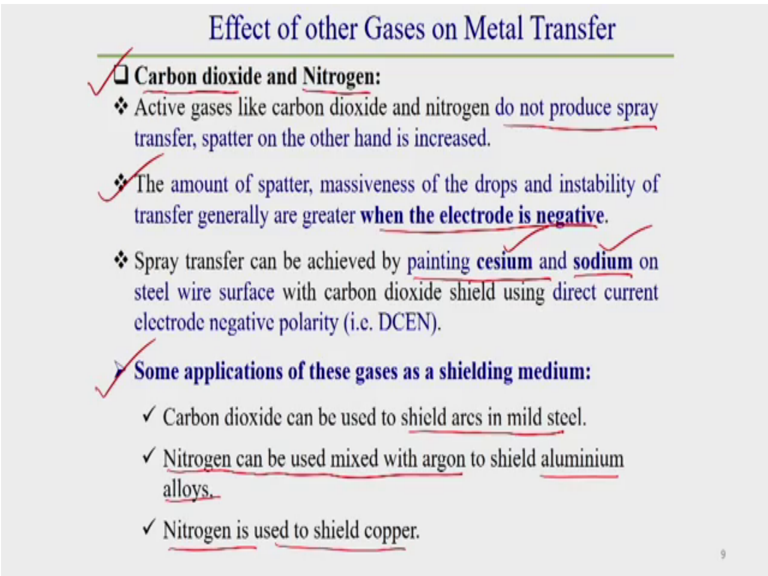

Now, we will discuss about the other gases also. So, generally argon and helium gas this two different inert gas generally used as shielding medium for generally CMAW process or MIG welding process or we can say most of the consumable as well as non-consumable types of electrode or electrode welding process. But, what happens sometimes some other gases also used as a shielding gas that gases generally is not inert in nature that gases is active in nature. These two different active gas we generally used as a shielding gas in case of welding.

What is this two different active gas? One is called carbon dioxide another one is called nitrogen nitrogen gas. So, this is the active gas which is also used as a what its called shielding gas or to protect the molten pool from atomic atmospheric contamination. Then you can think that why this active gas because, once we are use this active gas that is a chance of oxide formation and other thing that types of chances can be there. Yes definitely that types of things chances is there, but whatever the weld quality we can get by using this active gas that weld quality is good in nature and which is acceptable which is which is which is within a range of acceptable limit of industry.

So, that is why this types of gas also sometimes used to protect the molten pool from atmospheric contamination. So, always we keep it in mind these types of active gas once we use generally, it cannot produce spray transfer and spatter on the other hand is increasing once we use these types of active gas in case of welding. Then also is due to some economic or cost effective nature generally what happens this types of gases used as a shielding gas. Generally, these the amount of spatter and massiveness of the drop and instability of the transfer generally are greater once we use this spatter spatter in nature size of the molten droplets bigger size; if we use generally this and that means, if we use electrode negative polarity.

That means direct current if we use electrode negative as a polarity what I have already discussed that can; in case of electrode negative itself its produce generally a spatter a unstable types of work. So, if we use with active gas this types of decision we with this active gas this electrode negative polarity then what happens here also this spattering nature increase. And what happens size of the droplet also increase; that means, the massiveness of the drop size increases compared to only what it is called DCEN electrode polarity. So, so with active gas itself is producing generally what its call globular types of metal transfer.

With this its with this; that means, active gas if we again connect DCEN as polarity; that means, electrode negative polarity if we use then what happens here this massiveness and spattering nature further increases. Generally spray transfer then also in by using this what its call by using active gas a spray transfer. How? Generally by painting generally how we can get spray transfer? Generally, if we paint by using some material that is generally that two material that painting material is one is called cesium and sodium, on steel wire surface that mean in case of steel welding on a steel wire surface if we use this cesium and sodium or sodium metals.

Then what happens the with carbon dioxide shielding gas generally this with DCEN also we can get spray types of matter. What does it means? It means that spray transfer also we can achieved by using this active gas as a shielding medium and with electrode negative polarity. How? If we paint the electrode surface by using some material that material is called cesium and sodium material that; that means, by using cesium and sodium material over the surface of this consumable electrode we can get spray transfer in case of active gas shielding medium also.

Now, where is the application? Generally this active gas with some proper precautions we can use the when the following welding operation. Like this active gas we can use in case of mild steel this carbon dioxide gas used as a shielding medium through some extra precaution actually. If we use this active gas then with whatever the weld quality we can get that weld quality is good enough and which is acceptable range. Like in nitrogen gas also used as a active gas with mixed with argon gas in case of aluminium alloy welding operation.

Nitrogen also widely used as a shielding medium in case of copper. So, you see this carbon dioxide and nitrogen gas also have application as a shielding medium. But, what happens this gas is generally produced what its call globular types of metal transfer and which is generally more spatter in nature then also it is applied as a shielding medium. But, by this gaseous itself we can get spray types of material by using some extra metal painting over the electrode surface that is that metal is called generally cesium and sodium types of material; if we paint over the surface then we can get a spray types of metal transfer.

Now, we will go to efficiency of welding why this efficiency of welding is required that we should know.

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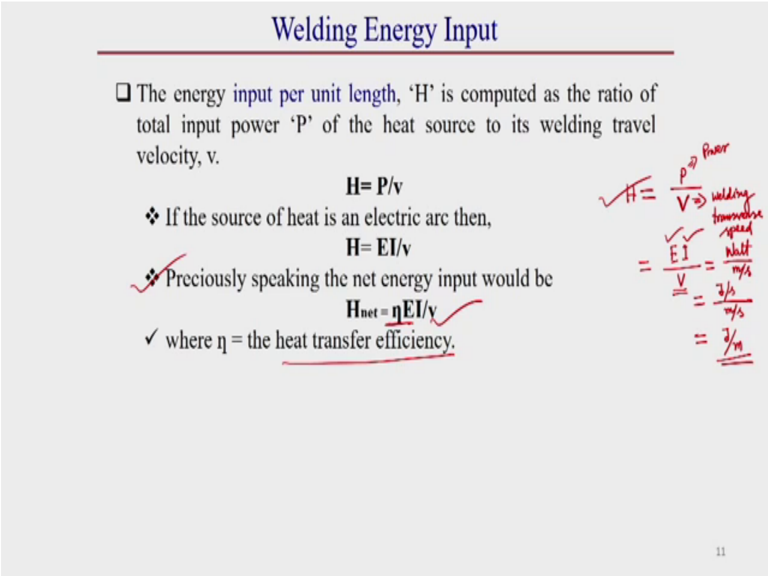

So, before efficiency of welding we should know some other term which is very frequently used in welding industry that is called welding energy input. Energy input per unit length have a wide application. This term generally very widely used in case of welding industry. What is energy input per unit length or you can say that heat input per unit length what does it means? Generally heat input per unit length or this is sometimes called as rate of heat input per unit length. So, here generally the energy input per unit length is represented by generally H which is generally represented by H which is generally power by welding speed.

Generally v is called welding speed or this is called power welding power and this is called generally welding traverse or transverse speed transverse speed welding transverse speed. How its look like this power generally we know voltage into current and welding; that means, voltage into current divided by welding speed is it. From here how the things you are getting generally voltage into current we know that is unit is generally Watt w Watt and this unit let us meter per second. So, what happens this from here generally Watt means Joule per second and this speed means meter per second.

So, from here now what we are getting this second will be cancel out Joule per meter or we can say Joule per millimetre whatever it is. So, this heat input; that means, once we divide this power with welding speed then we get generally Joule per millimetre. That means, heat input rate per unit length of weld; that means, how much heat is putting with unit length of weld from here we get. Generally, why this is very important because what happens its account both voltage current and welding speed. This three welding parameter generally is the main parameter we can say in case of welding operation.

Generally what happens so, it is generally account all these three and from here itself we got the idea higher the speed lower the heat input per length if lower the speed higher the heat input per length. That means, welding speed and from here also we got the idea; that means, what is the voltage and current this E is equal to voltage and I is generally current what is the effect of voltage; that means, higher the voltage higher the current generally higher the power will be. This is called heat input per unit length preciously speaking here we have not consider efficiency as a term. In case of welding also there is different losses taken place from heat source to weld metals on; there is different types of what its called losses is taken place.

So, to account this losses generally what happens this heat input per unit length generally there is coming a term efficiency which is generally represented in terms of eta; net input heat input required to do the welding generally we can represented as s net is equal to eta into this E I by velocity. This eta is called generally efficiency. This eta is which efficiency? This eta is called heat transfer efficiency. So, in case of welding generally there is two different types of efficiency we use: one is called heat source efficiency another one is called heat transfer efficiency.

To know; that means, to know heat transfer efficiency first of all we should know heat source efficiency. So, heat transfer efficiency it and heat source efficiency is two different efficiency. So, to know heat transfer efficiency generally we know first heat source efficiency.

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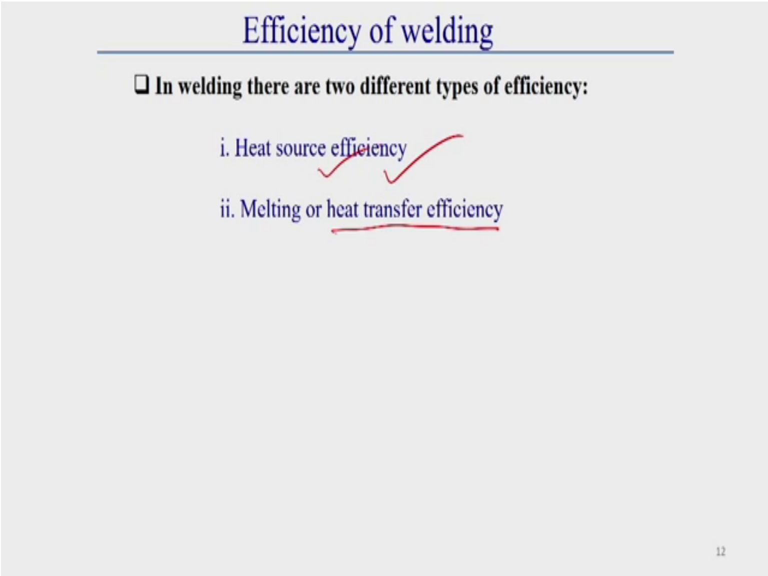

So, that is why generally in case of welding there is two different types of efficiencies used: one is called heat source efficiency another one is called melting or heat transfer efficiency. These heat transfer efficiency generally used in case of net heat transfer actually. So, to know this heat transfer efficiency first of all we should know heat source efficiency.

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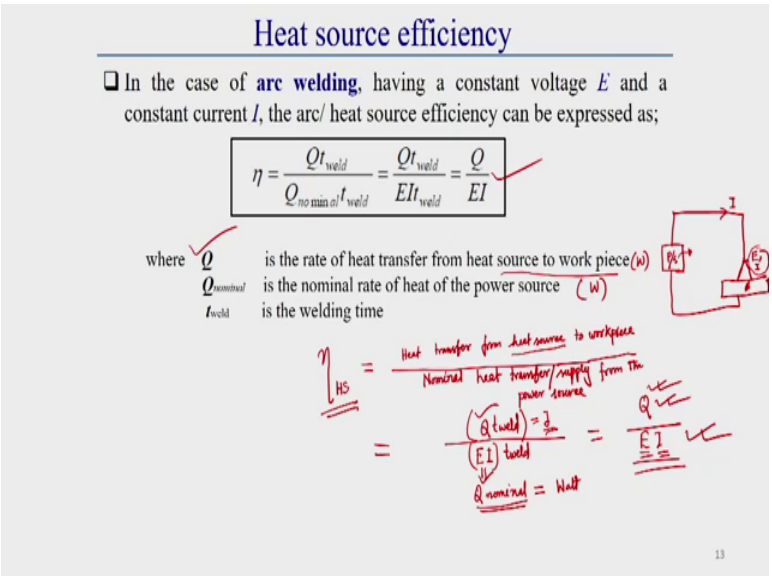

What is heat source efficiency? Heat source efficiency generally can be represented like this what is this that we should know. Generally, for a particular voltage and particular current we can say heat source efficiency this I am representing by it HS actually eta HS heat source efficiency. It is generally equal to we can write as heat transfer from heat source to workpiece and divided by nominal heat transfer heat transfer. Or, you can say nominal heat transfer or heat supply nominal heat transfer or heat supply from the power source from the power source.

That means; that means, heat transfer from heat source to workpiece divided by nominal actually this is nominal heat transfer or supply from power source to workpiece. So, what happens let this is a power source how the heat is transferring where there is arc and after that this is generally power source. So, this power source generally supply a voltage and current. So, that this power source generally supply a voltage and current. So, from here generally current its go; so, what happens we gets a welding voltage and welding current on the electrode.

So, from this power whatever the welding voltage and welding current we are getting due to this we get some power or we can we get some heat let us we get some heat here that heats does not deposited to the workpiece. Here generally some sort of heat loss is taken place. To account this heat losses; that means, whatever the heat supply from the heat source to workpiece in between generally there is occurs some heat losses. How this heat losses will occur? This heat losses is occur due to conduction, due to this resistance of the wire, due to this arc gap there can be conduction convection radiation. Due to these different different types of phenomena there is occurs some heat losses.

So, due to that what happens all the heat is not transfer from arc to workpiece. So, so some heat is losing in arc itself and rest of the heat generally supply to the workpiece. So, that that is that is why here this is even how much heat is depositing in workpiece divided by how much heat is supplying by the; what is called power source. This ratio is called heat source efficiency. It can be represented like this let us this can be heat transfer from heat source to workpiece. Generally this can be represented as let us Q Q into t weld why this Q into t weld we are writing what is Q that I will tell divided by we can say this voltage into current is the heat supplied by the heat source into t weld.

That means that for a particular welding time let us heat is supplying from heat source to workpiece, that is why t weld t weld I put. What is this Q represent? Q represent generally is called the rate of heat transfer from heat source to workpiece. This Q is called Q is the rate of heat transfer from heat source to workpiece, this we have to calculate. And, this nominal heat transfer this Q nominal, this E I generally called Q nominal. This is so, this Q nominal is the nominal - nominal rate of heat of power source; this is why it is called rate of heat of power source.

Actually this Q unit is what this Q unit is what, once we multiple this what with time generally then we get this. So, that the unit of this Q into t weld is Joule; similarly here E I into t weld gives Joule; that means, heat how much heat is transfer it that is why I have written here heat transfer. So, generally this t weld t weld is cancel out. So, we can say this Q by E I. So, heat transfer efficiency we can write as Q by E I here; that means, Q is the rate of heat transfer. Rate of heat transfer means; that means, how much power of is heat is transferring from workpiece; that means, electrode to workpiece. So, this Q unit is actually Watt once you multiply this Watt with time generally then this gives you joule.

So, finally, as the t weld t weld is cancel out. So finally, this heat source efficiency we can represent as Q by E I ok. Now, we will see how to how to calculate this heat source efficiency because, we know this E and I; that means, how much voltage and how much current is in arc that we can easily calculate by ammeter and voltmeter. Whatever the voltage and current we are getting in this arc region that we can easily get by using ammeter and voltmeter. But how we calculate this Q value, that is means how much heat is transferring from arc to workpiece; all the heat is not transferred what I have told you this we can calculate by using calorimeter.

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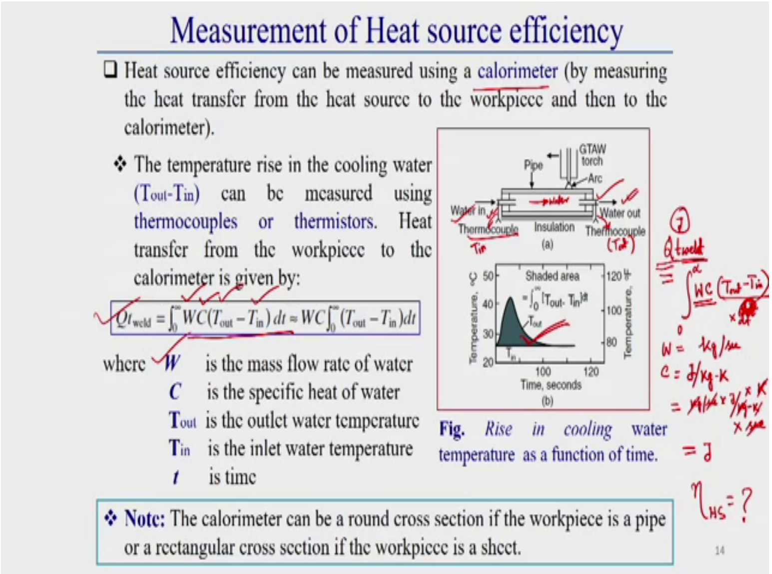

That means this Q value; that means, this how much heat is transferring from heat source to workpiece that we can calculate by calorimeter. How it is? We put some calorimeter below the surface of the workpiece generally so, whatever the heat is transferring from arc to workpiece. So, from workpiece to calorimeter so, how we are calculating the heat transfer here. First of all we are measuring the heat by using a calorimeter which is generally providing; here you see this is generally calorimeter. Calorimeter generally contain a which can be rectangular shape or pipe shape depending upon the shape of the what it is called our sample.

If the shape of the workpiece is circular what we can say pipe in nature then generally this calorimeter is circular in nature. If the shape of the workpiece is rectangular in nature then the calorimeter shape is generally rectangular In a calorimeter there is a continuous flow of cold water is there; that means, so what happens this cold water or this calorimeter generally provided below the surface of the workpiece. So, whatever the heat is coming from electrode to workpiece then that we can easily measure by using this flow of water through the calorimeter.

This flow of water through the calorimeter once is passing generally this cold water generally take the heat from workpiece. So, so what happens so, due to this taken heat from workpiece this cold water temperature increases. So, how much temperature is increasing; that means so, rise of temperature by this rise of temperature generally we can get the how much heat is transferring from electric arc to workpiece that we can easily calculate. For calculating this thing generally this is generally calorimeter we can say; here this calorimeter generally through this generally what it is called water is flowing this water cold water is flowing. So, this cold water have a inlet and there is a outlet.

So, in an inlet and outlet there is use generally two thermocouples. This is one thermocouple you see, this is one thermocouple and this is another thermocouple. So, by using this thermocouple generally we can get the what is the inlet temperature by using this water in. Here we can get by this thermocouple we can get t inlet temperature and due to this flow of water through this what its called pipe. Or, through the rectangular shape due to this arc temperature to workpiece it rise the temperature of this water; then what happens due to the rise of temperature once is coming out it has some outlet temperature. So, by this generally what we can get we can get what is the rise of temperature occur.

So, if we carry this operation for a particular time. So, then what happens we can say over a time how the total rise of temperature is occur that we can calculate. So, what happens this thing generally here I am showing that is means over a time how the temperature is rising; that means, after doing welding let us what happens after putting the arc or doing welding if we remove this. So, and if we just keep it for cooling; so what happens how much heat is generally dissipating; this generally once we start the welding during this time generally temperature is raised.

Once we cool the workpiece generally then temperature decreases. So, if we just do the welding for particular times after that if we just cool it then toward the heating and cooling how much heat is coming to the workpiece that we can calculate by using this rise of temperature over time. This generally you can get by using this formula generally Q into t weld; that means, total heat input Q into t weld; what is the unit of this thing t weld. This actually Q into t weld unit of this thing is Joule because, Q unit is Watt if we just multiply with welding time generally then we get the Joule only heat energy.

Those heat for once you multiply with t weld then what happens we get the heat energy this heat energy we can represent integration of 0 to infinity; that means, W C into T out minus T inlet dt over the time dt. For over this what is W? This W generally represent as mass flow rate, this W from here we can get this unit how the Joule unit is coming. W unit generally is mass flow rate; that means, kg per this is thus W means kg per second and C is the specific unit we know Joule per kg Kelvin. And so, if we just multiply with this thing what we get.

So, here generally kg per second into Joule per kg Kelvin into let us what happens this T weld T out and T inlet is generally what is the unit of this thing. This unit generally Kelvin and dt is also there this dt actually this dt here actually multiply multiply multiplication of dt is there into dt is there. So, into t means second is there. So, what is the unit of this things you are getting? From itself Kelvin Kelvin cancel out, second second cancel out, kg kg cancel out. So, this unit also you will get as Joule from this right side also you can get joule. So, by this generally if we know the mass flow rate also you can easily measure you know the specific heat; that means, this specific heat of the water you know.

You can easily measure this T out and T inlet by using this thermocouple. So, you can easily measure the how much heat is transferring from electrode to workpiece very easily easy way. So, by this generally what happens you can get the so, if you know this thing you from here itself you can easily get the Q value. So, if you know the Q value you know this voltage and current of arc that also you know. So, you can easily able to find out heat source efficiency. What will be the heat source efficiency you can easily find out.

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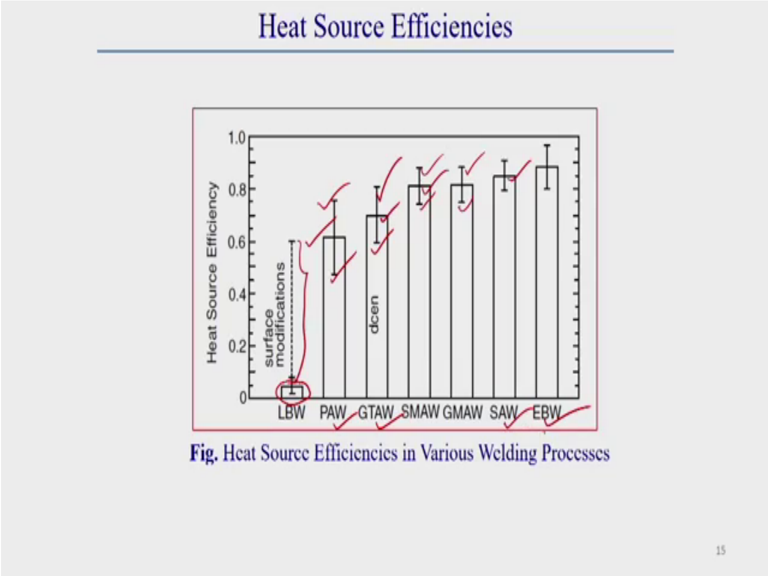

Fig. Heat Source Efficiencies in Various Welding Processes

So, just here I am showing some heat source efficiency of different types of welding process. Heat source efficiency depends on different types of welding process; that means, for all the welding process generally all the heat is not transferring from arc to workpiece. The different different welding process generally have different different efficiency of heat different different heat source efficiency. Like it has seen the whatever heat is supplying from the laser beam there generally what happens due to this reflection or radiation characteristics in case of laser generally here; generally what happens heat loss is very high.

That is why in case of laser beam generally heat source efficiency is lying now normal case generally what happens its lying within a range of around 10 percent efficiency. But, these efficiency we can increase by increase the absorptivity of the what it is called workpiece surface; that means, by some surface modification we can absorb more heat actually to the workpiece. Because, in case of laser beam generally or we use a light ray that we know. So, what happen due to this this light ray if it fall a reflected types of medium. So, what happens it will be reflected out and less it will be absorbed.

So, what happen that is why here the efficiency is very less, but by by by some painting black painting or some painting is there a special painting is there by this you can absorb more heat energy from this light ray. So, here by that you can increase your heat source efficiency and which can be around 60 percent. With you know; that means, from 10 percent to 60 percent this range of; that means, efficiency you can increase. In case of plasma arc welding generally here also this heat source efficiency is around 60 percent.

But this is varying from 50 to around 75 percent, why this thing once I will discuss about plasma arc welding there I will discuss why this efficiency is like this. In case of GTAW the heat source efficiency is around 70 percent, but it can varying from 60 percent to 80 percent. But, its original value generally within a range of 70 percent, this this this is the value. Similarly, in case of SMAW and GMAW process the heat source efficiency is around 80 percent; that means, around 80 percent.

But, these can varying from that means, 75 to 85 percent; whereas, in case of submerged arc welding this efficiency is within a range of 85 percent, but this can vary from 80 to 90 percent. But in case of electron beam welding generally efficiency is very high because, this electron beam welding generally its occurs in vacuum here heat lost we can say is negligible. So, this efficiency is around 90 percent, but this can varying go till around 99 percent within that range it can go. Now, why this heat source efficiency; that means, is varying for different different types of welding process; that I will discuss one I will discuss of different types of welding process.

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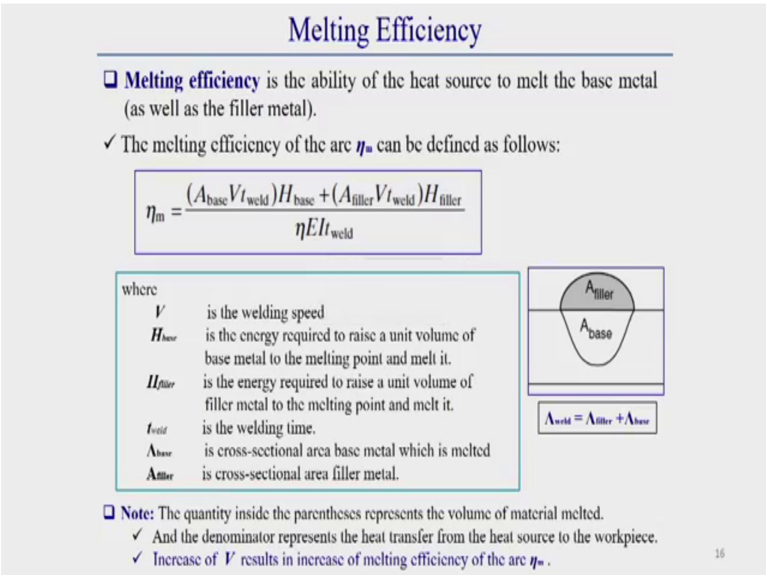

Next class actually I will discuss melting efficiency and subsequently, I will discuss about different types of operating parameters effects on weld quality, weld geometry in details.