Joining Technologies of Commercial Importance
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Lecture - 09
Shielded Metal Arc Welding

I welcome you all in this ninth presentation on the subject Joining Technology for metal and in the last lecture, we have seen the technical aspects related to the shielded metal arc welding process and in this presentation, I will talk about first a few basic fundamentals related to the arc welding processes and thereafter I will go into the gas Tungsten arc welding process and submerged arc welding process.

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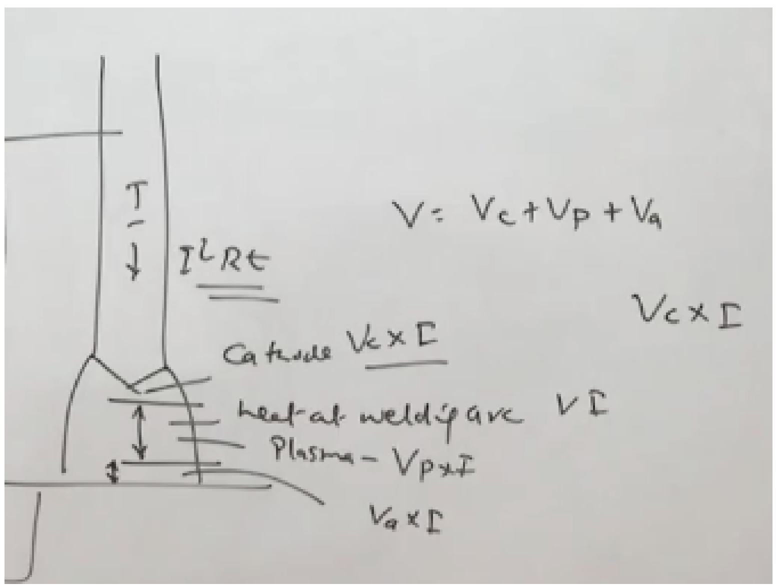

The fundamental aspects, which I want to take up first, they are related with the factors governing the melting rate in case of the arc welding process and for this purpose, what we have to see, the one empirical equation, which have been developed like aI + bl I square, where there are two terms, which in combination determine the melting rate and what these two terms are all about.

Like say, this is electrode, this is the work piece and arc is generated. So due to the flow of current through the electrode I square RT heating of the electrode core wire takes place in case of the consumable arc welding processes and at the same time heat generated at the welding arc, which is given by VI comprises basically the three constituents. One is heat generated in the cathode drop zone, which is obtained from the VC, voltage drop in the cathode drop zone.

And the welding current I, the voltage drop in the plasma zone that is VP into I and anode drop zone, VA into I, the voltage drop in the anode drop zone. So basically, this voltage drop is sum of the VC, that is voltage drop in the cathode drop zone, VP and VA, voltage drop in plasma and anode drop zone. So if we are talking about the melting rate of the electrode, then the VC into I plays a big role in melting of the electrode.

Because the heat being generated in the plasma zone and in the anode drop zone is affecting much the melting of the electrode. They are away from the electrode tip and these heats are like, the anode drop zone heat is mainly used for melting of the work piece and plasma heat either part of the heat is used for melting of the base metal or the heat carried by the molten metal drops, which are being transferred through the plasma.

But most of the melting is in the cathode drop zone, is attributed to the heat being generated in the cathode drop zone. The melting of the electrode is primarily governed by the heat generated in the cathode drop zone. So there are 2 constituents, which are related with the heat generation and heat generation will be affecting the melting rate of the electrode. So one heat generation, which is coming from the cathode drop zone or anode drop zone, as per the polarity of the polarity being used.

If the electrode is connected to the positive terminal, then the anode heat will be considered for the melting of the electrode and the heat being generated in the cathode drop zone will be attributed to the melting of the base metal. So heat being generated due to the electrical reactions in the anode drop zone or cathode drop zone, as per the case, this aI factor accounts for the anode or cathode drop zone heat.

And I square RT is due to the flow of current through the electrode. So these 2 factors are clubbed together. Here the first factor accounts for the melting rate due to the heat being generated in anode or cathode drop zone and the second one is due to the electrical assistance heating, that is I square RT, which is in simplified form written as like bl I square as an empirical equation. So here what is a, b, l and I.

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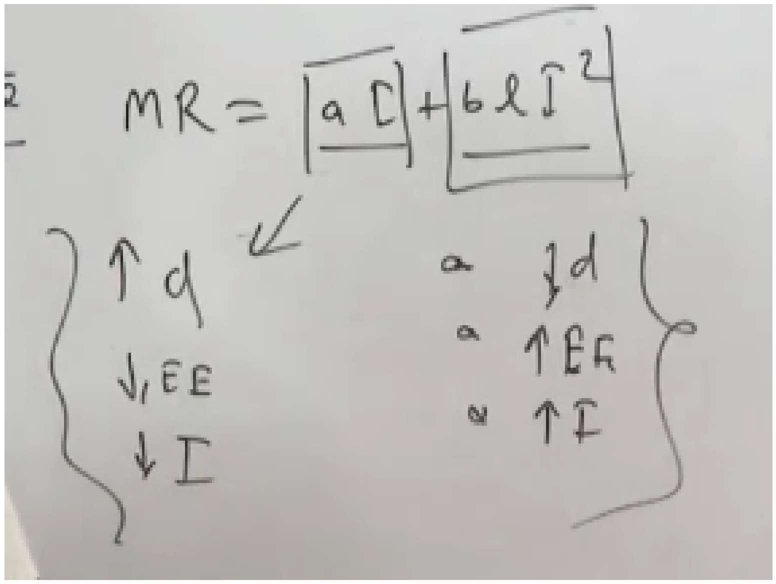

That is what we will try to talk about here. So here, if we see a is the coefficient or the constant, which accounts the voltage drop in the anode drop zone or cathode drop zone, the chemical composition and the factors all those material and process related factors that are affecting the heat generation due to the heat generation in anode drop zone or the cathode drop zone. I is of course the welding current in ampere.

While b is about the coefficient for the material resistance related factors, like say electrical resistivity of the metal is the big factor that is considered, though high electrical conducting metals will have the low b value, while the low electrical conducting metals will have the high b value and l is the electrode extension and I is the welding current. So if we see this equation, for small diameter electrode, large electrode extension and for high current values.

So for these three situations, a small diameter will be resulting in the higher electrical resistance for the flow of current, greater electrode extension will be offering more resistance for the flow of current, so higher electrical resistance heating and similarly higher value will be causing more welding due to the second factor. So the second factor dominates under these set of conditions. If the conditions are just reverse, where the diameter is large, electrode extension is short and the welding current is also low.

In that case, the role of the second factor is somewhat reduced and we will see that the first vector is dominating or governing the melting rate related thing, but it does not mean that we can achieve any kind of melting rate just by adjusting the welding current because there are number of factors that limit the lower and higher level of the welding currents, which can be used.

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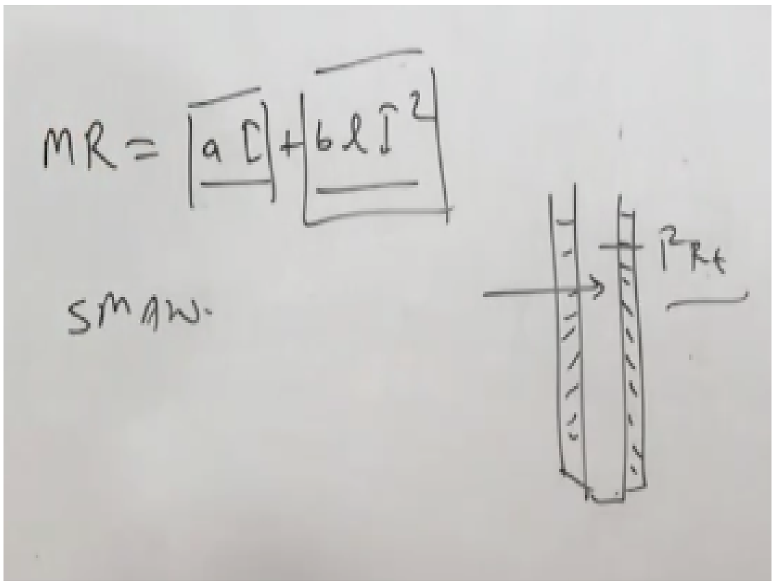

For example, in case of the shielded metal arc welding process, higher level of the current is limited by the situation or by the current value, at which thermal decomposing of the coating starts due to the flow of current, say this is electrode and this is the coating. If you keep on increasing the current value, then high I square or heating of the core wire can start damaging the coating much earlier than it should.

Because of this, we will not be getting the benefit of the coatings over the core wire in case of the SMAW. While in case of the Tungsten gas welding processes, it will be damaging the electrode due to the excessive I square RT heating. So electrode life is reduced if the excessive current is used. So now we will see another important aspect related to the arc welding processes and that is about the polarity.

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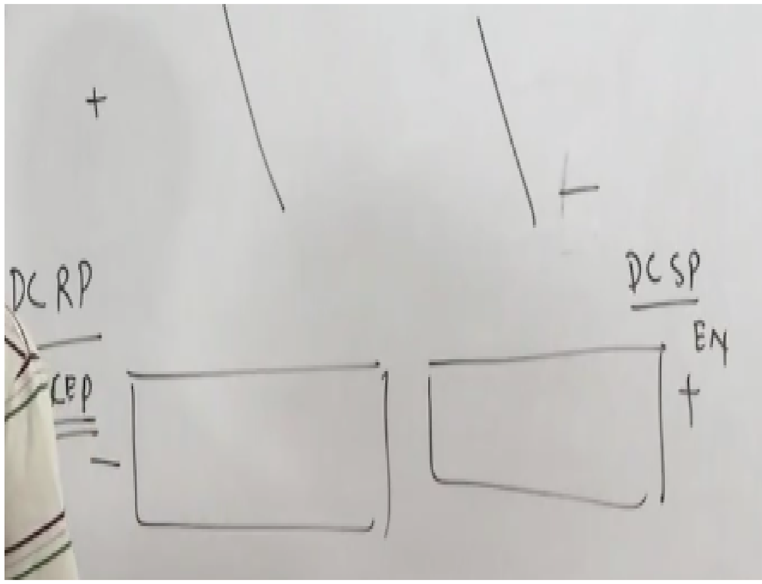

Like the electrode and work piece can be connected either to the positive or negative terminal or in case of AC, of course, these two will keep on changing. So when the positive terminal is connected to the electrode and negative to the work piece, in this case what we say, the DC reverse polarity where your work piece is negative and the electrode is positive.

While the reverse polarity or state polarity is one when the electrode is connected to the negative terminal of the power source and work piece is connected to the positive terminal of the power source. So which type of polarity is to be used that is what we will try to talk about. So this is called DC, state polarity or electrode negative DCEN or this is electrode positive DCEP or the reverse polarity. This is DCEN or state polarity.

So what are the changes associated with these change in polarities during the welding especially. In case of AC, since the polarity keeps on changing, so the distribution means, whatever factors are associated with the AC, they will be equally distributed in either side. So what is the effect of polarity?

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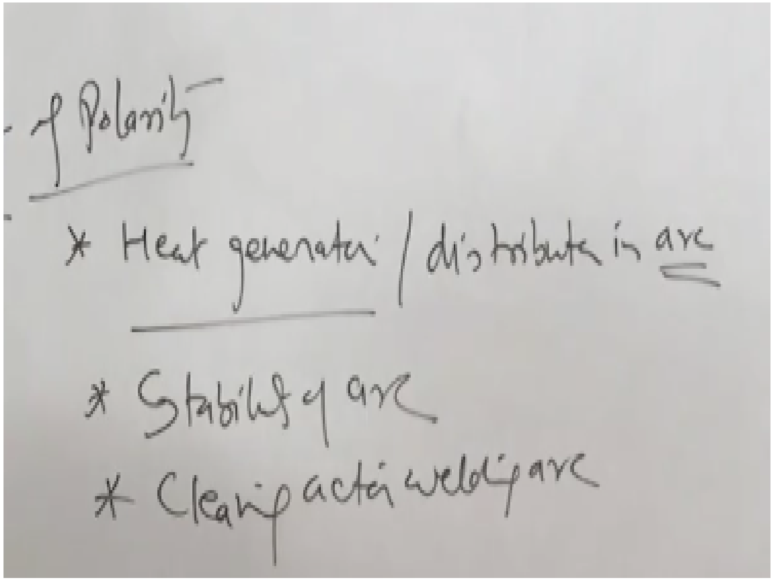

Polarity affects 3 things in very big way. One is the heat generation or heat distribution during the welding, like in case of welding arc. Second is it affects the stability of the arc, especially in cases where electrode is expected to, you mean the electrons for the good arc stability, so the change in polarity can affect the stability of the arc in those cases. And another is cleaning action which is offered by the welding arc when you are using a particular kind of the polarity.

So effect of polarity, these are the 3 main effects. So which type of polarity is used and these three aspects will be available, this choice will be available with regard to the cleaning action or arc stability or heat generation only when the DC is used over the AC.

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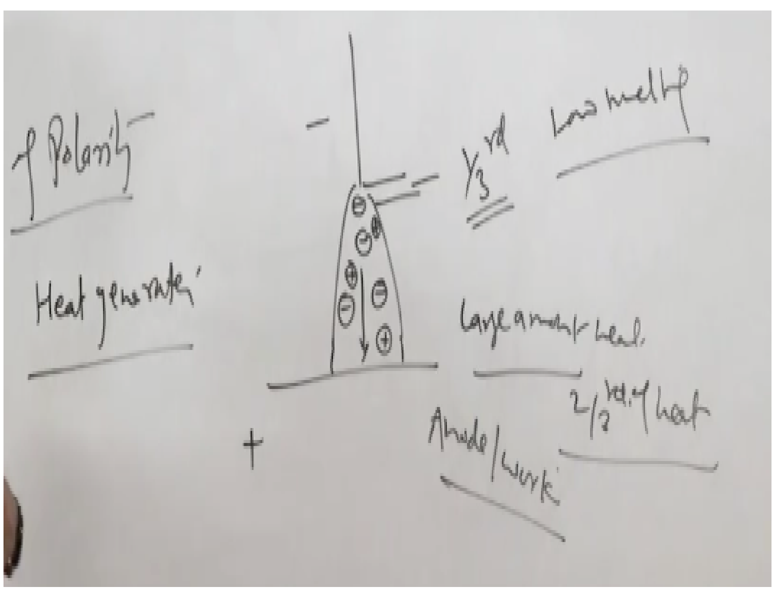

So what is the heat generation related aspect, generation or distribution related aspect. This is very important like when the state polarity is used like work piece is connected to the positive and the electrode in the negative. In this case electrons are emitted by the electrode and they will keep on moving towards the work piece and they will striking the work piece and impact will be generating lot of heat and so in this case since large number of the electrons will be impacting with the work piece continuously.

So which will be generating large amount of heat, which accounts to the two-third of the heat being generated in the anode side. So anode will be, anode or work piece will be heated, will be getting much more amount of heat as compared to the electrode while the electrode, in this case when ion current is very limited about 1 to 2%, so here the ions will be moving very slowly towards the cathode and they will be impacting at a very low velocity with electrode.

So heat generation in the electrode side or the cathode side is very limited it is about one-third of the total arc heat. So limited heat generation will be causing the low melting rate in case of the consumable arc welding process or it will be leading to the much better life of the electrode for the GTAW process. So this is about the heat generation. If you want less heat in the work piece side, then work piece will be connected to the negative terminal and electrode will be connected to the positive terminal.

While in the other case, if we want more amount of the heat, then of course electrode work piece will be connected to the positive terminal.

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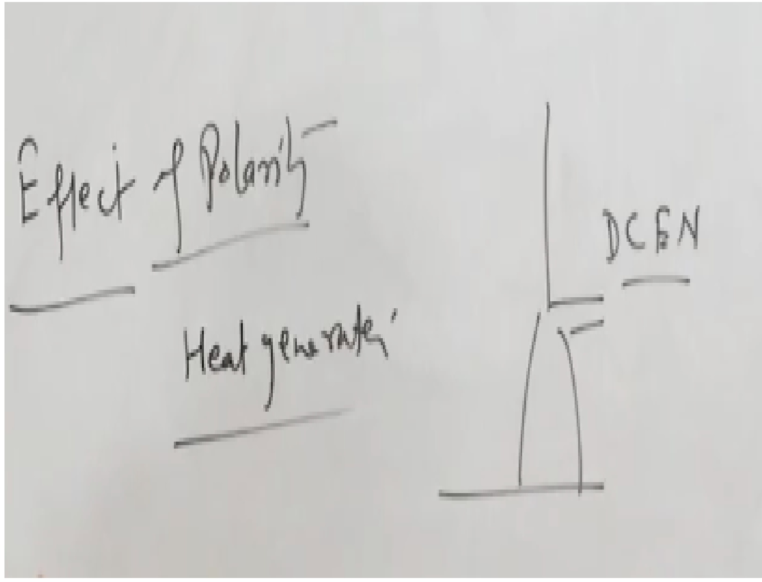

So to take this advantage in case of the Tungsten arc welding to have much life of the Tungsten electrode invariably the Tungsten arc welding process uses the DCEN polarity. So that heat generation in the electrode side is very limited and we get much better, it leads to the much lower amount of thermal damage to the electrode and which in turn results in much better electrode life.

If in other processes like submerged arc welding process if you want higher deposition rate. So in that case for submerged arc welding process, we want more heat is generated in the electrode side, so for that purpose we will be using the reverse polarity where electrode will be connected to the positive terminal and work piece will be connected to the negative terminal. So the higher amount of the heat generation in the electrode side will be leading to the higher melting rate.

So SAW invariable, in SAW and for the GMAW gas metal arc welding process DCRP or DCEN, both are same, or DCEP, electrode positive or the reverse polarity both are same and this kind of polarity is used to have the advantage of the higher melting rate. So this kind of facility s available only DC when we can select the type of polarity as per the requirement of the heat, either in the electrode side or in the work piece side, whether we want more heat or less heat in the work piece side.

If you want less heat in the wok piece side, like for the welding of thin sheets in that case, we will be choosing the reverse polarity, because in the case of reverse polarity heat generation in the work piece side is somewhat lesser. Now we will see another factor with the effect of the polarity apart from the heat generation.

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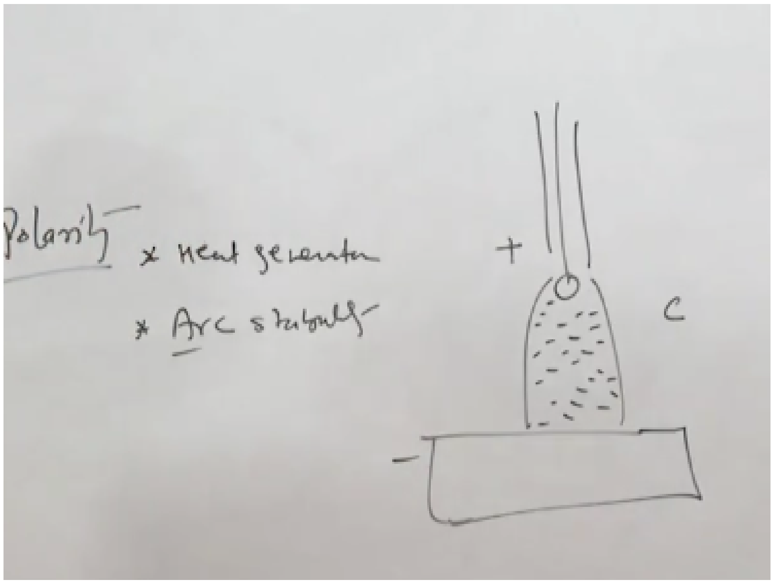

Another important factor is the arc stability. We know that electrode is expected to emit the electrons. Electrode if it is connected to the positive terminal and the work piece connected to the electrode is connected negative terminal and work piece connected to the positive terminal. So in this case electrode is expected to emit the electrons. So the electrons will be emitted. Normally these are either coated or these are designed to emit the electrons.

So they will be emitting the electrons very easily providing the gap charged, gap between the electrode and work piece full of the charged particles to make it electrically conducting. So that very good stable arc can be produced. But if the polarity is reversed then in that case, if the polarity is reversed means your electrode is now positive and work piece is negative. Work piece may not be necessarily of the low ionization potential elements, it may not have very good electron emitting capability.

So the poor emission of the electrons from the work piece side during the welding will be reducing the charged particle density in the gap between the electrode and work piece and which in turn will be increasing the resistance for the flow of current and increased resistance for the flow of current may lead to the extinction of the arc and unstable arc. So the change in polarity especially in case of the work piece, where work piece is expected to emit the electrons and if it does not have very good electron emitting capability, then it will lead to the poor stability of the arc.

So if the electrode is designed to have good electron emission and then switching over to the, like say changing the polarity from the state polarity to the reverse polarity, then this can cause the problem of the arc stability due to the poor stability of the work piece. While, in general electrodes are designed to have very good electron emission capabilities, so making the DCEN or state polarity always has to have the good arc stability.

The cleaning action is another important aspect, in cleaning action which is exploited in case of the gas metal arc welding process and the gas tungsten arc welding process, what is that?

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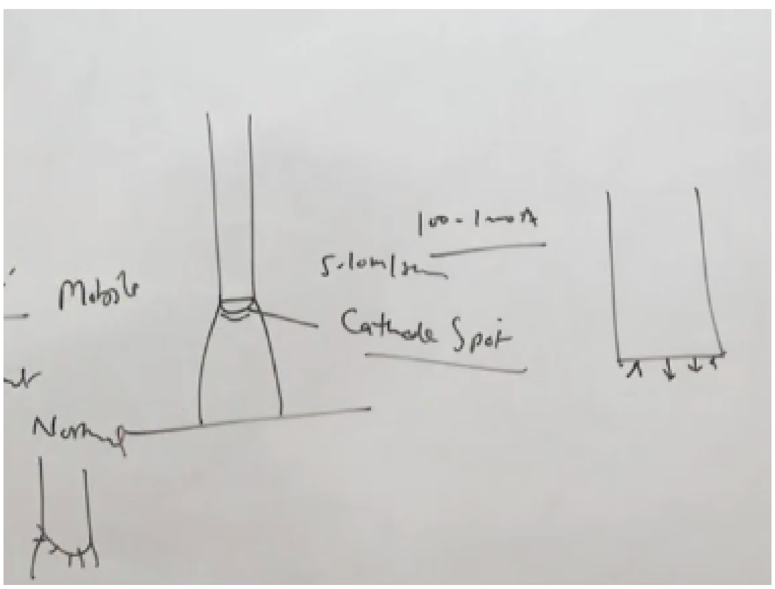

We know that electrons are emitted by the cathode and under certain conditions like say 100-1000 ampere of current range. Sometimes the cathode, which will be emitting the electrons, it emits the electrons from a particular place. And that place where from the electrons are emitted that is called cathode spot. So the location or the position in the electrode, which emits the electrons is called as cathode spot.

Three types of the cathode spots are normally found, like one is pointed, in this case electrons are emitted from the tip of the conical shape electrode. And one other is normal where ball shape tip of the electrode emitting the electrons from all entire area. And another is mobile cathode spot, mobile cathode spot will keep on changing its position and it will be like moving at 5-10 meter per second over the surface of the electrode.

In this case basically the location of the cathode spot keeps on changing. So this concept is exploited from the cleaning action point of view in the sense that if the work piece is made cathode and mobile cathode spot is formed.

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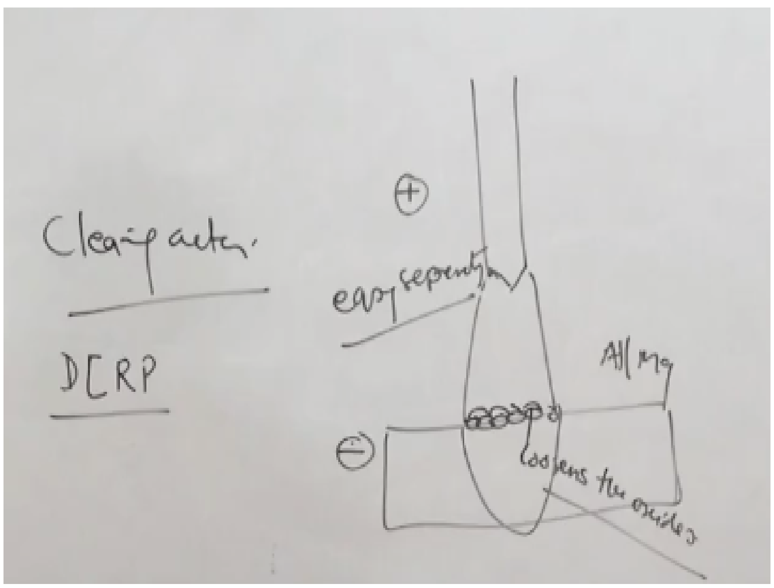

Like say this is Tungsten electrode or any other process electrode, like say in this case if the aluminium or magnesium, if they are welded using the GTW process making the work piece, negative and electrode positive. So in this case our work piece is expected to emit the electrons and if the mobile cathode spot is formed, the surface of the work piece, so mobile cathode spot formation actually loosens the oxides being formed.

So this loosening of the oxides due to the mobile cathode spot helps in easy separation from the molten metal and because of this, these oxides starts getting floated over the surface of the weld pool, so they can be separated easily. So this is the advantage of using the polarity favorably. So the use of the DCRP is intentionally used sometimes to exploit this concept of the mobile cathode spot formation, especially in case of aluminium and magnesium welding.

Because the formation of the mobile cathode spot helps to loosen the oxide layer and the loosened oxide layer starts floating over the surface of the weld metal and thus it can be separated easily, which in turn will help to produce a cleaner metal.

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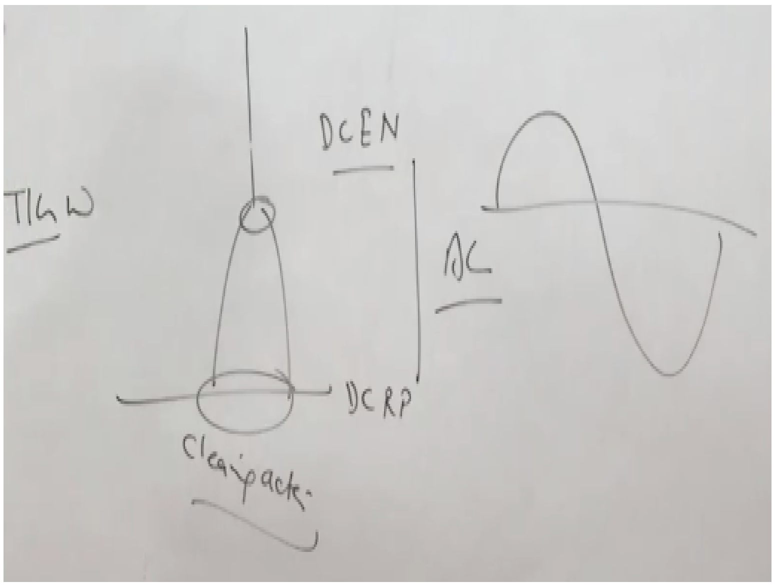

So if we see here like the process like GT welding or GTW process where use of straight DCE and polarity producing the lesser heat and more heat in the work piece site, while if the DCRP is used, in that case we get the much better cleaning action. So these are the two contracting requirements, we want that less heat is generated in any case for the much better life of the electrode.

At the same time, when aluminium and magnesium are welded, then the cleaning action is also achieved. But these two can be achieved using the two different types of the polarities. So in order to have a good balance between the two instead of using one, the AC is used. So the polarity will keep on changing. In one half, it will be DCEN and another half it will be DCRP. So it is common to use AC also in case of the GTW process, especially when welding the aluminium and magnesium.

So that the advantage of the lower heat generation in one half cycle and advantage of the cleaning action in the another half cycle can be achieved. So this is about the effect of the polarity.

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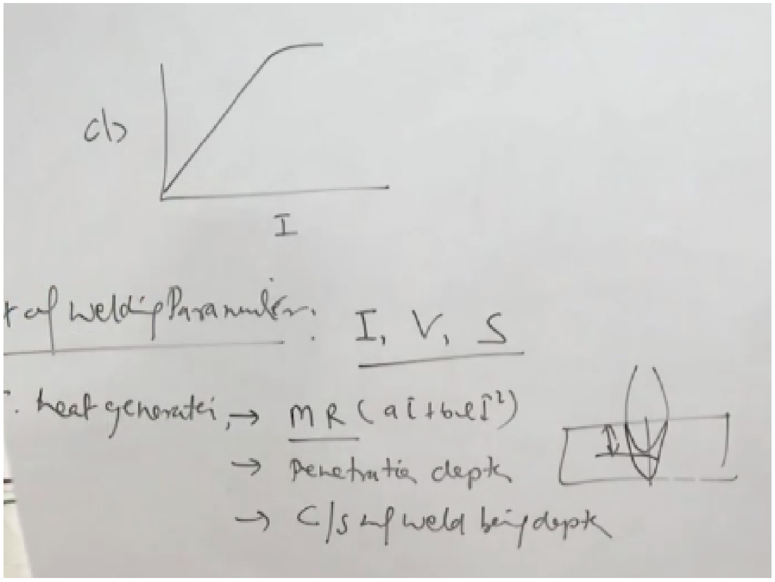

Now coming to the effect of welding parameters. There are 3 welding parameters, which are extremely important and determine the kind of joint, which is produced and these are like welding current, voltage and welding speed. So what we have to see, we know I directly affects the heat generation. Because the arc welding is a high current and low voltage process. So if the current is changed, then it affects the heat generation significantly.

So change in heat generation affects the melting rate, as we have seen from the AI + BLI square equation. This is one thing. Second it affects the penetration depth in the base metal. It is about depth up to which, like this is the plate, you just apply the arc, so how deep melting is taking place that determines the depth of penetration. So this depth in this case, like it is a partial penetration or it may be through thickness penetration.

So depending upon the welding current, we may penetrate through the thickness or it may be the partial penetration. It also effects the cross sectional area of the weld being deposited. Increase in current in general increases, like if we here have the current and cross sectional area, then in general it increases linearly and then it starts getting flattened or the slope starts decreasing gradually. So these are the 3 important factors related to the welding and effect of the welding current.

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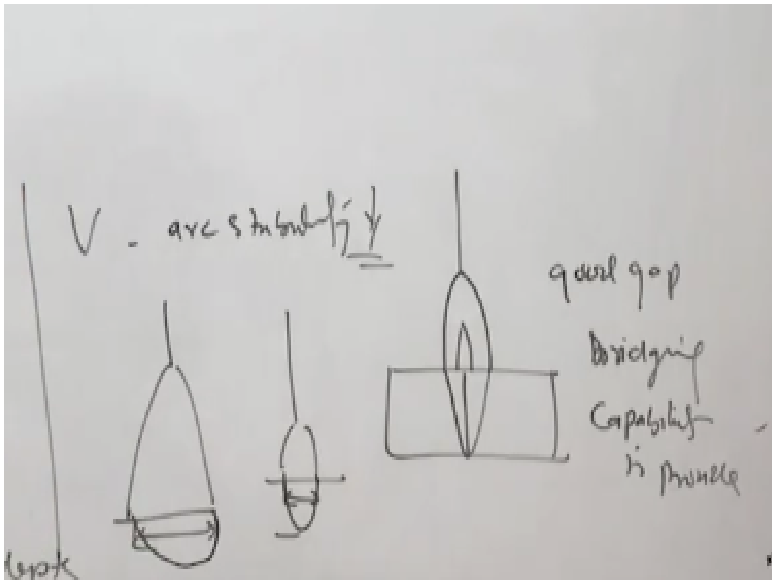

On the other hand, if we see the voltage, voltage does not play big role in generation. It contributes, but effect is not that high as that of the welding current, but it certainly affects the arc stability. If the arc voltage is not enough, that it will lower the stability of the arc. We know that if we see that, if the arc gap is short, then the arc voltage is very limited. Under identical conditions, if the gap is increased, then arc voltage increases.

So in this case, the area over which heat is applied is very limited as compared to the case when gap is increased. So when the gap is increased, the area over which heat is distributed is much larger. So it directly affects two aspects, one is width of the weld and another is depth of the weld. So the width is narrow when the arc gap is less, means arc voltage is less and the depth is more.

On the other hand, due to increasing or spread when the arc gap is increased, arc voltage increases and so we get the much wider the weld and the depth is shallow. So the shallow depth and the wider bead is obtained. The shallow depth and this kind of geometry may be good especially when the gap between the plates we welded is not very much even straight and in that case, the good gap bridging capability is provided by the wider arc site.

So if the gap is narrow, then the gap bridging capability is limited. If the arc voltage is increased, so the increase in width of the weld will provide much better gap bridging capability. So this is how we can see the effect of the welding arc, arc voltage. It affects the arc stability, the gap bridging capability and the bead geometry in terms of the width and the depth of the penetration and further if we see effect of the welding speed.

Welding speed directly affects the amount of heat being delivered to the base metal in per unit length. So if the speed is very, very low, then heat will be delivered continuously over a small area and it will result in the large cross section. So depth may be limited, but it is very wide. Actually by reducing the welding speed, we can keep on feeding the heat over the molten metal. This in turn does not help much in achieving the deeper penetration.

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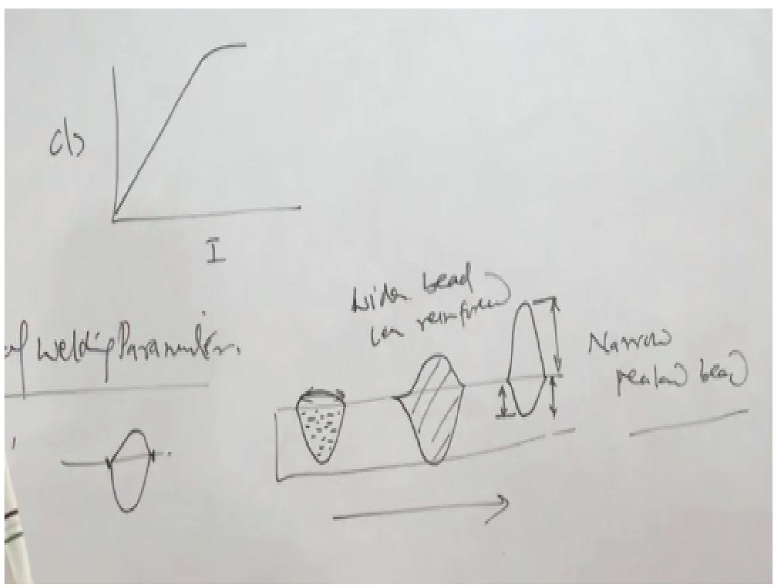

But it increases the width of the weld, thereby it increases the cross sectional area of the weld, but as this will be making the wider bead with less reinforcement. This height of the bead is not much because molten metal starts flowing sidewise. On the other hand, for an optimum speed, we will see that penetration is full and width is also limited and the distribution of the bead is also good. So here the reinforcement is limited, here reinforcement is good and the penetration is also good.

But if the speed is too high, so this is in increasing order of the speed. Further increase in the speed can decrease the heat delivery significantly this can lead to the reduced depth of the penetration and very peaked weed can be formed. So high reinforcement, very limited penetration and so both narrow and peaked bead is produced when very high welding speed is used and you know when we are moving very fast.

Then due to the high relative velocity with the ambient gas is, it can deflect the arc means, arc blow can also take place, sometimes the undercut is also formed because just little melting takes place both the sides, so here near the tow of the weld undercut is formed, which provides the easy size for the stress concentration and can deteriorate the performance of the weld joint, so now here I will conclude this presentation.

In this presentation, I have talked about the fundamental aspects related with arc welding and three fundamental aspects, I have talked the factors governing the melting rate and the effect of the polarity and we have seen that how the welding parameters affect the weld characteristics and certainly the change in the amount of heat being generated will be affecting the kind of solidification time and cooling rate experienced by the weld metal and heat affected zone.

And these changes in turn will be affecting the structure and the mechanical properties of the weld joint, so those things will be looking into the greater details when we will talk about the welding metallurgy related aspect. So here, now I conclude this presentation and in the next presentation, I will talk about the gas Tungsten arc welding process and submerged arc welding process. Thank you for your attention.