Welding Engineering
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Module - 2
Physics of Welding Arc
Lecture - 1
Introduction

Arc welding processes are extensively used in industry for the development of the weld joint in the fabrication of various engineering systems. Because of the extensive application of arc welding processes, it becomes important to understand the physics of the welding arc which helps in developing the sound weld joint. So, we know that in arc welding processes, the heat generated by the welding arc is used for melting the faying surfaces of the base material, so as to develop the weld joint.

This arc can be established between the electrode and the base material. This electrode can be of the consumable or non consumable type. Sometimes, this arc can also be established between the nozzle and electrode. So, depending upon the condition whether in a process, the arc is being established between the electrode and a work piece or between the nozzle and the electrode, it is stability and the ease of handling is affected.

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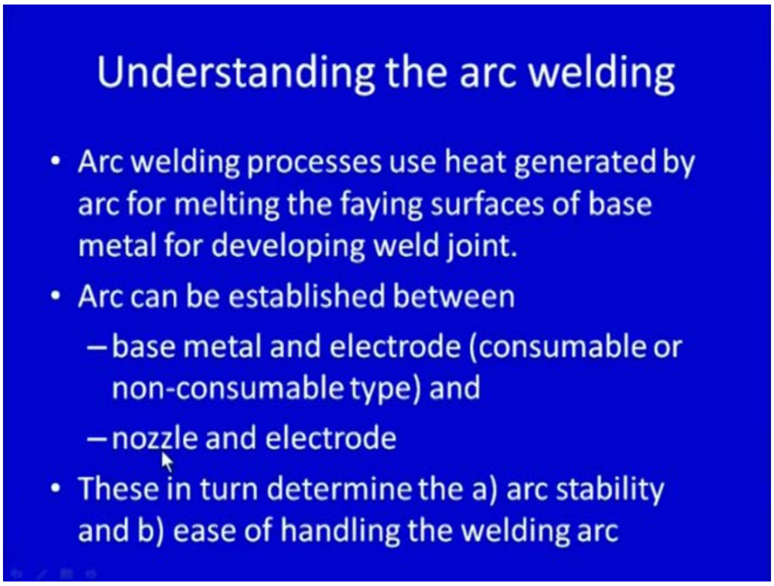

Depending upon the situation whether arc is established between the base metal and the electrode or between the nozzle and electrode, it dictates the arc stability and ease of handling the welding arc.

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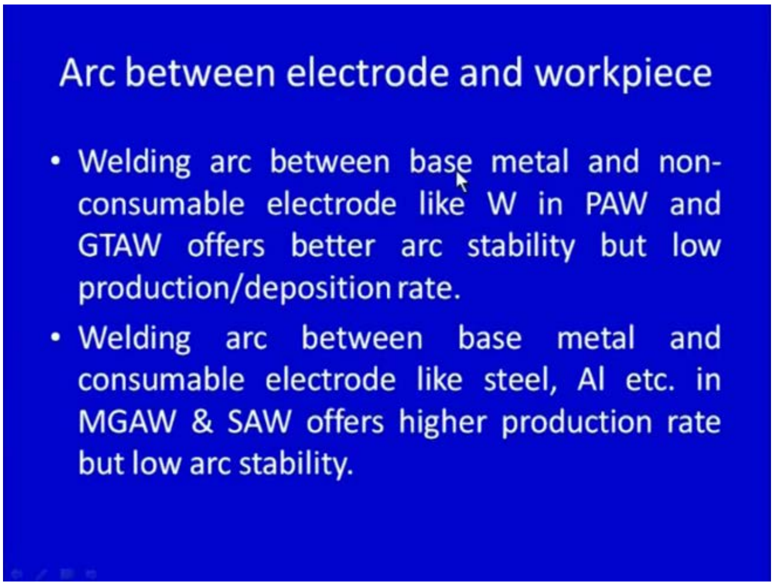

So, when an arc is established between the base metal and the non consumable electrode like tungsten, in case of the plasma arc welding process and the gas tungsten arc welding process, it offers the better arc stability. But, the production rate is low. So, having the arc between the base metal and the non consumable electrode, it results in the better arc stability. But, since it uses non consumable electrodes, the production rate or the deposition rate is very low in these processes.

When the welding arc is established between the base metal and the consumable electrode like steel or aluminum, in case of GMAW and the submerged arc welding processes, it offers the advantage of higher production rate. But, the stability of arc is low. So, whether arc is established between the base metal and the non consumable electrode or between the base metal and the consumable electrode, each has its own advantages and disadvantages in terms of the arc stability and the production rate.

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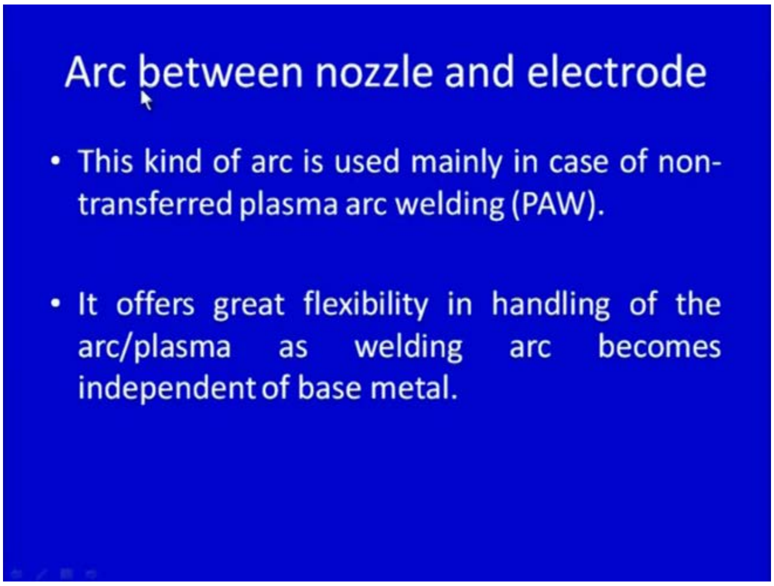

When the arc is established between electrode and the nozzle, then this kind of arc is mainly used in case of the non transferred plasma arc welding process. When this kind of arrangement is used, it offers a great flexibility in handling of the arc because the welding of the base metal does not form the part of the welding circuit. So, because of this, it offers a great flexibility in handling the arc or plasma as the welding arc becomes independent of the base metal.

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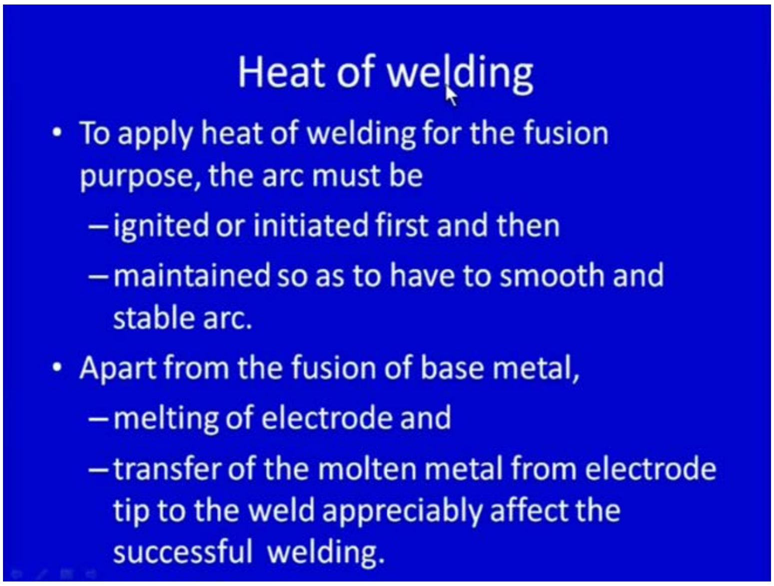

The heat of the welding which is generated in the arc welding processes, the same is used for melting the faying surfaces of the base metal for the welding purpose. That arc must be ignited first and thereafter it must be maintained, so that the smooth and stable arc is produced. The heat is also generated uniformly for uniform penetration of the weld. At the same time, apart from the fusion of the base metal, how the melting of the electrode is taking place and how it is transferring from the electrode tip to the weld pool, that appreciably affects the success of the welding.

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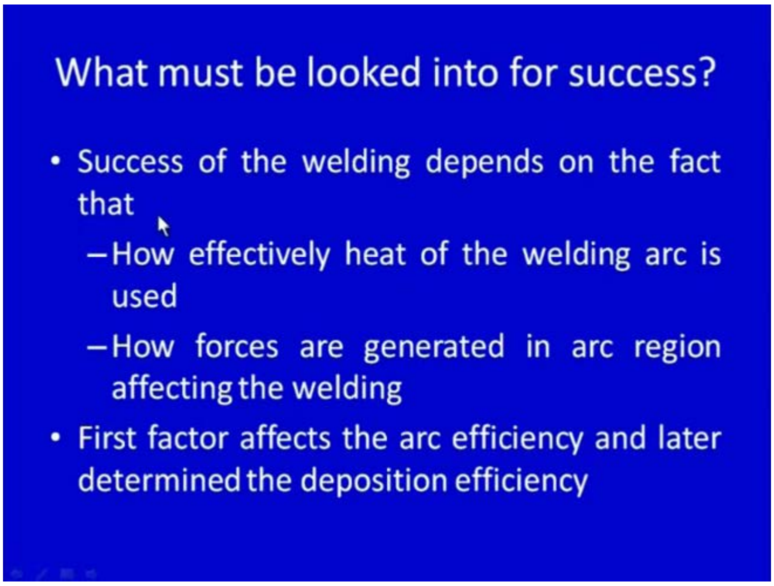

So, therefore if we see, the success of the welding depends upon the fact that how effectively the heat generated by the welding arc is used for melting the faying surfaces of the base metal. Thereafter the solidification of the weld metal will be resulting in the weld joint. Also, how the forces are generated in the welding arc region, that also affects the success of the welding. So, if we talk of the first factor, how effectively heat of the arc is being used for developing the weld? That affects the arc efficiency, while the force generated in the arc region affects the deposition efficiency, because it dictates the spattering which will be taking place during the welding.

So, if the forces are helping the smooth metal transfer from the electrode tip to the weld pool, then the deposition efficiency is found to be higher as compared to the situation where spattering takes place due to the variety of the forces which are generated in the arc region. Therefore, it becomes important to understand the various aspects related with physics of the welding arc, which includes the mechanisms of the arc initiation and its maintenance, the various zones which are developed in the arc region, and their role in the welding.

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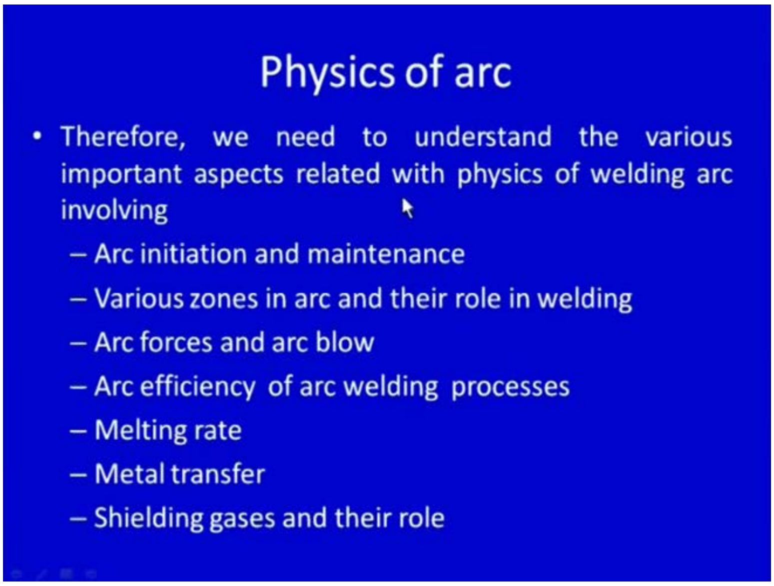

We know that 5 different types of the zones are developed in the arc region and each has its own effect in development of the weld joint, like a cathode drop zone, anode drop zone and the plasma region. These are the 3 main zones affecting the heat being generated in the each region which will be affecting the melting of the electrode as well as of the base material.

The arc forces are determining the mode of metal transfer and the arc blow tendency. Then, how effectively heat is being used in particular welding process affecting the arc efficiency? So, how can we calculate the arc efficiency and what is its significance? Why the different arc welding processes offer the different arc efficiency? That will also be taken up. The melting rate depending upon the heat being generated in the anode or the cathode aside will be dictating the melting rate of the electrode and the base material will be affecting the deposition rate. So, factors affecting the melting rate as well as the factors limiting the melting rate in a particular process will also be taken up in detail.

Then, the mode of metal transfer, that is how smoothly and efficiently the metal is transferred from the electrode tip to the weld pool, that determines the soundness of the weld joint as well as the deposition efficiency. The different shielding gases which are used in the gas metal arc welding process, gas tungsten arc welding process, and how these shielding gases affect the soundness of the weld joint, that will also be taken up in detail in the various lectures related with the physics of the welding arc.

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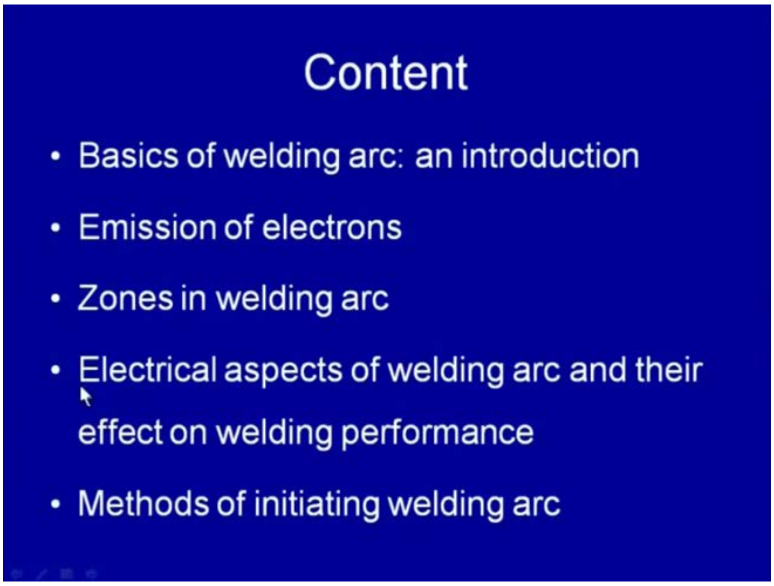

So, in the physics of the welding arc, this will be the first lecture which will be talking about the various important aspects related with the physics of the welding arc. This includes the basics of the welding arc, the important conditions required for a igniting the welding arc, the maintenance of the welding arc like emission of the electrons under the different zones which are observed in the welding arc and their role in that development of a successful weld joints and the heat generation.

The electrical aspects are related to the welding arc and their affect on the welding performance or the performance of the weld joint produced by the arc welding processes. This includes mainly the effect of the welding arc, welding current, and the current voltage which in turn will be affecting the heat generation and the quality of the weld joint which will be produced. The methods which are used for initiating the welding arc will also be describe in respect of the principals and other welding processes where they are used. If we see the welding arc is nothing, it is just an electric discharge between the cathode and anode, and this discharge takes place in the form of the flow of current for very short duration.

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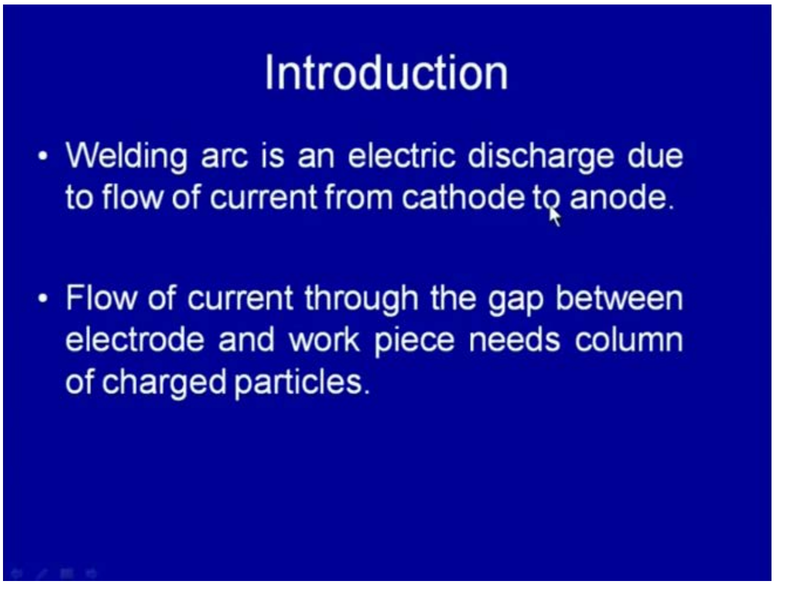

But, when this flow of current between the cathode and anode is maintained for a longer time, we get that discharge in the form of the welding arc. Whatever heat is generated by this electric discharge which is stable for longer duration, if that is used for melting the faying surfaces, we can say that as welding of the metals or welding of the plates by using the welding arc. But, for that purpose it is important that whatever electric discharge is developed, that remains stable and that is maintained for a longer duration.

But, for this flow of current, to have the flow of current and to maintain that flow of current so that we can have a stable arc, it is necessary that the gap between the cathode and the anode is maintained. For that purpose this gap must have the charged particles which are termed as the column of the charged particles. This must be present between the cathode and anode which can be in the form of the electrode and the work piece. So, to have the welding arc, it is necessary that there is a flow of current through the gap between the electrode and work piece. For that purpose, the gap should have a column of the charged particles and these charged particles are mostly produced in the form of the free electrons and the positive ions.

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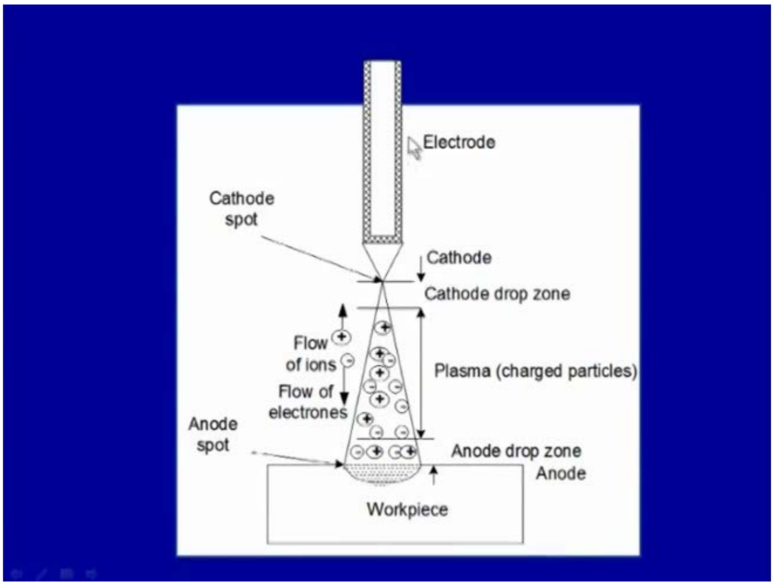

We see the schematic diagram showing the electrode and the electrode tip, say if it is cathode and the electrons will be moving from the cathode towards the anode, and this is work piece which is made anode. So, in this welding arc, for the flow of current from the cathode towards the anode, it is necessary that this gap between the work piece and the electrode or between the cathode and the anode is having enough charged particles. These charged particles are mostly in the form of the ions and electrons. The presence of these charged particles in turn affect the electrical conductivity of the gap. It is important that there is sufficient number of the charged particles of current, so that the flow from the electrode towards the work piece can take place.

So, we have seen that it is important to have the sufficient number of the charged particles in the arc gap or in the gap between the cathode and the anode or between the electrode and the work piece, so that the electrons can flow from the cathode side to the anode side to have a smooth and stable arc. Now, we will see that from where these charged particles come in and how they affect the welding arc and its ignition aspects.

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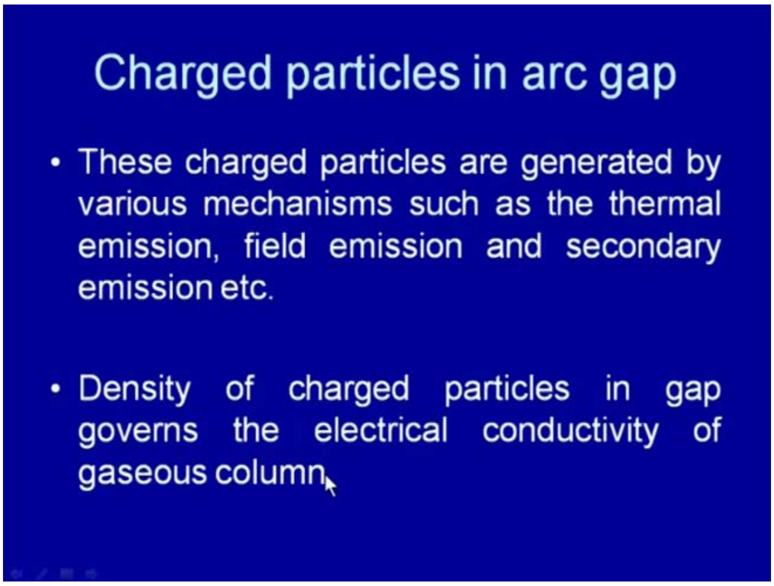

The charged particles are generated through the various mechanisms such as thermal emission, field emission and the secondary emission. These are the different mechanisms and these mechanisms can work singly or in combination with the other mechanisms during the welding processes.

We will look in to the details based on which the electrons are released by these mechanisms, and if the more number of the charged particles are present in the gap the electrical conductivity between the gap of the electrode and work piece will be better. The flow of electrons will be good which inturn will improve the stability and the smoothness of the welding arc, and the heat generated by the arc can be used successfully for melting the faying surfaces of the base metal, and for development of the weld joint.

Therefore, it is important to generate sufficiently large number of the charged particles in the arc gap, so that reasonably good electrical conductivity between the electrode and work piece can be achieved. So, how these electrons come in the arc region or how these charged particles come in the arc region we will see that in an electron or in an electric arc, electrons are released from cathode due to either electric field or the thermo ionic emission.

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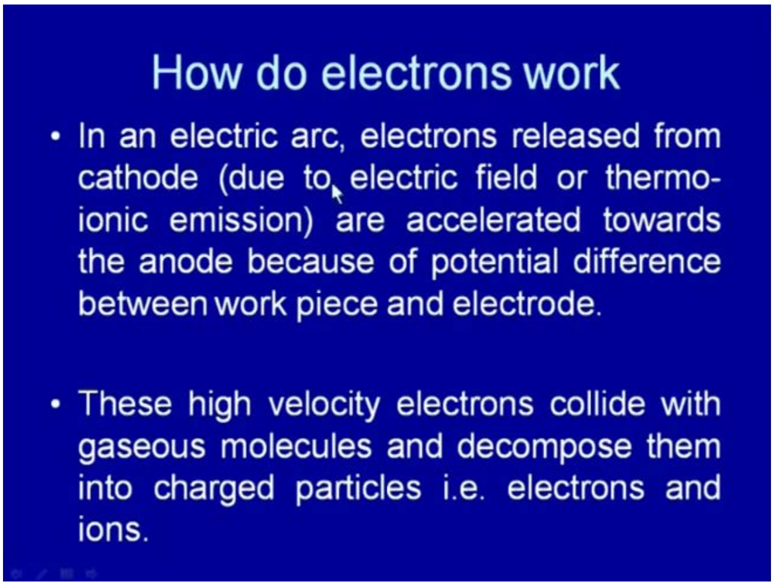

These electrons are accelerated towards the anode side because of the potential difference between the electrode and work piece. Once the electrons are released by either of the mechanism, whether it is the thermo ionic emission or the field emission, these electrons are accelerated towards the anode. Once electrons start moving at high velocity, these may collide with the other gas molecules present in the arc gap. This can result in further secondary emission through which electrons can be released further.

So, this flow of electrons from the cathode side to the anode side result in significantly high percentage of the welding current. While ions start moving from the anode side to the cathode side because of their heavy weight, the ion current is found to be significantly less than the electron current. These high velocity electrons which collide with the gaseous molecules decompose them and further produce the charged particles in the form of electrons and ions. So, this is how when the electrons are released by any of the mechanism, whether it is a electric field or the thermo ionic emission, these are accelerated towards the anode.

During their acceleration, when these collide with the gaseous molecules present in the gap, these gaseous molecules are decomposed further into the charged particles to produce more number of the charged particles in the arc gap. These inturn increase the electrical conductivity and facilitate the flow of current through the arc gap to produce a welding arc. You can see these charged particles move as per their polarity. For example, negatively charged particles will be moving towards the anode and the positively charged particles will be moving towards the cathode.

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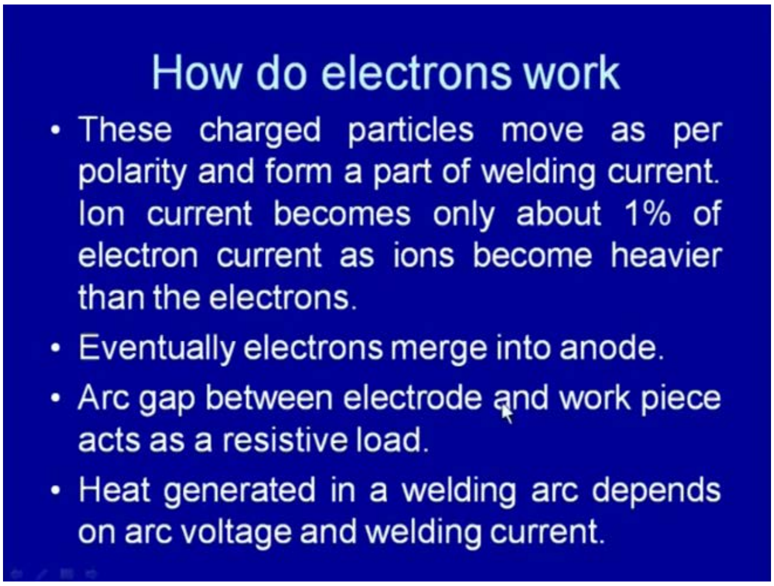

Accordingly, they form the part of the welding current. Ion current becomes only about 1 percent than the electron current, because ion becomes heavier than the electrons. Eventually, these electrons moving from cathode side to the anode side merge into the anode. The arc gap between electrode and the work piece acts as a resistive load. So, when the electrons are moving through the gap between the electrode and work piece, the gap acts as the resistive load.

According to the flow of the current and the resistive load which is available in the arc gap, the heat is generated. Accordingly, the heat generated in the welding arc is governed by the welding arc voltage and welding current. Higher voltage and the higher welding current in general results in the increased heat generation and the rapid melting of the faying surfaces, which in turn results in the higher welding speed. So, the charged particles and their presence in the arc gap, affect the heat generation, welding speed and the soundness of the weld joint.

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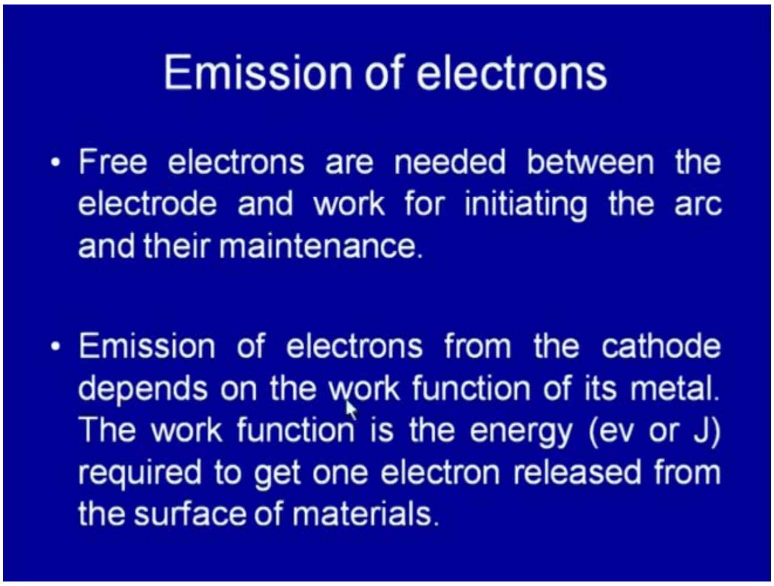

The emission of the free electrons between the electrode and work piece is needed for initiation and maintenance of the arc. For the emission of these electrons from the cathode, some work is required to be done. Because, these electrons are not automatically released by the cathode and in the process the resistance for emission of the electrons and their ability to emit the electrons from the cathode side is measured in terms of the work function or ionization potential.

These are the 2 parameters which are mainly used as the ability of the cathode material to emit the free electrons where, work function is the energy required to get 1 electron released from the surface of the material. So, those materials having the lower work function release the electrons easily by using lesser amount of the energy, while the materials having the higher work function require lot of energy to release the electrons. That is why, the materials like the calcium and sodium having the low work function easily release the electrons required for initiation of the arc. That is why these elements are frequently used with the flux materials for facilitating the easy ignition of the arc.

If, we see another parameter which is used to see the ability of the cathode material to emit the electron ionization potential, this is another parameter that shows the ability of a metal to emit the electrons. It is defined as energy per unit required for release of the charged particles. For removing the electron from an atom, ionization potential is found to be different for the different materials.

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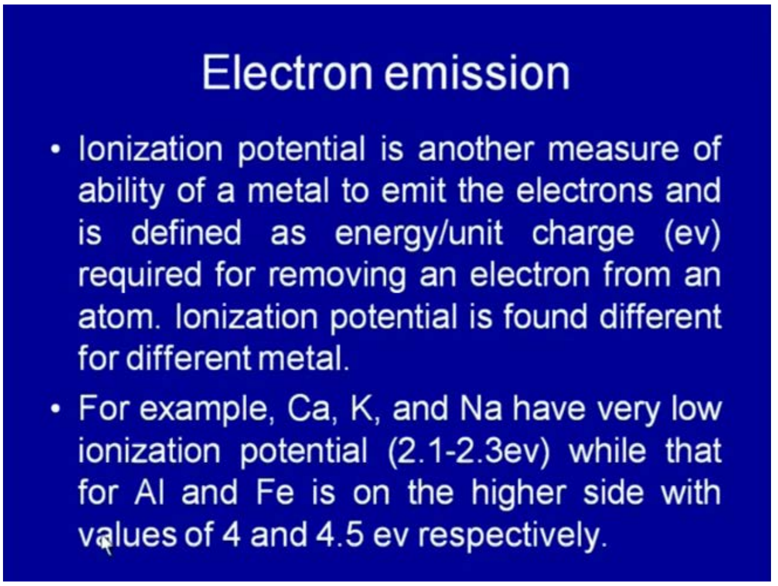

For example, calcium, potassium and sodium have very low ionization potential ranging from 2.1 to 2.3 electron volt. For aluminum and iron, it is found to be on the higher side with the values of a 4 and 4.5 electron volt. This suggests that electrons can be released easily by the calcium, potassium and sodium metal systems. But, they will require lot of energy for releasing the electrons in case of aluminum and iron.

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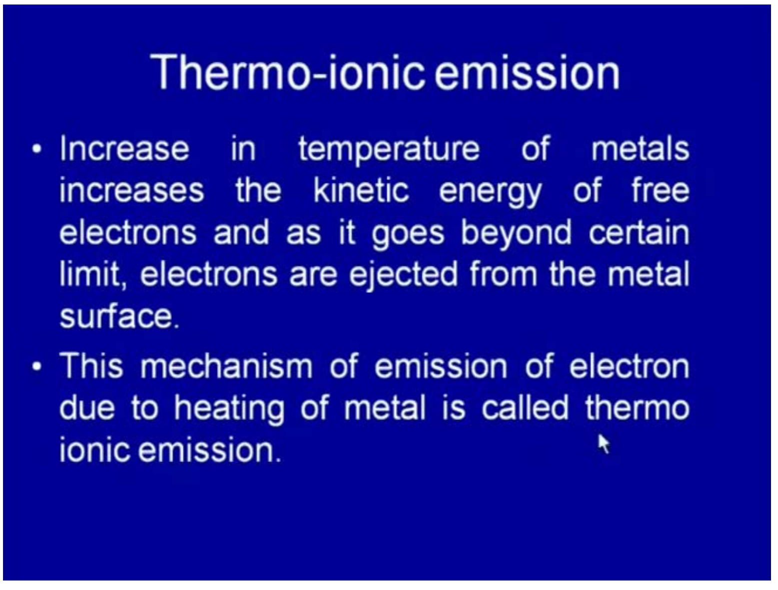

That is why, calcium, potassium and sodium elements are normally added with the flux and coating so that electrons can be easily released for initiation and maintenance of the arc. These are frequently added in the form of fluxes and coatings in the bare electrodes.

Thermo ionic emission is one of the mechanisms through which electrons are emitted and generated in the arc gap.

The principal of this mechanism is very simple. Increase in temperature of the metal increases the kinetic energy of the free electrons. As soon as this energy of the free electrons goes beyond a certain limit, electrons are ejected from the metal. But, it happens only at high temperature. So, those metal systems which are with the standard high temperature only, can emit the electrons by the thermo ionic emission.

So, this emission mechanism of the electron is primarily based on the heating of the metal, that is why it is called thermo ionic emission. If we see through the electrical current supply, if the metallic system is heated to too high temperature, then the thermo ionic emission electrons can be released and these electrons can be further used for establishing the arc.

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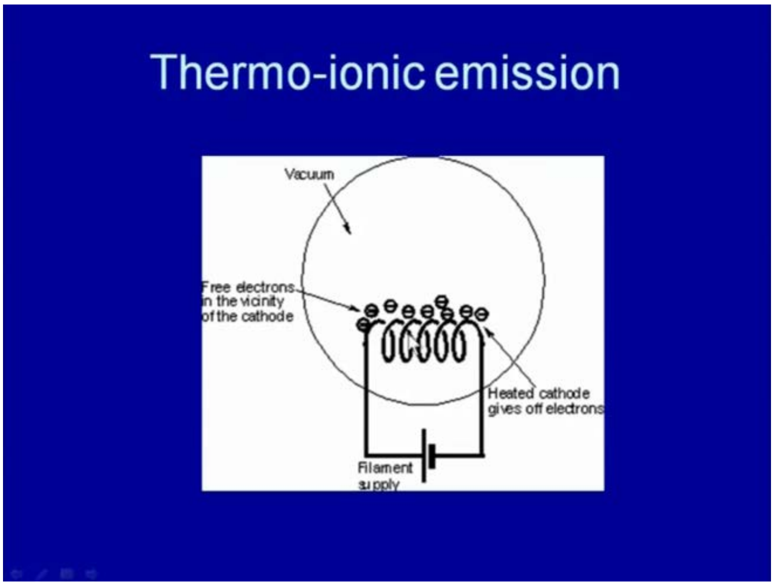

So, if the large number of electrons are present around the cathode which has been heated to the high temperature, these electrons can be used for initiation of the welding arc.

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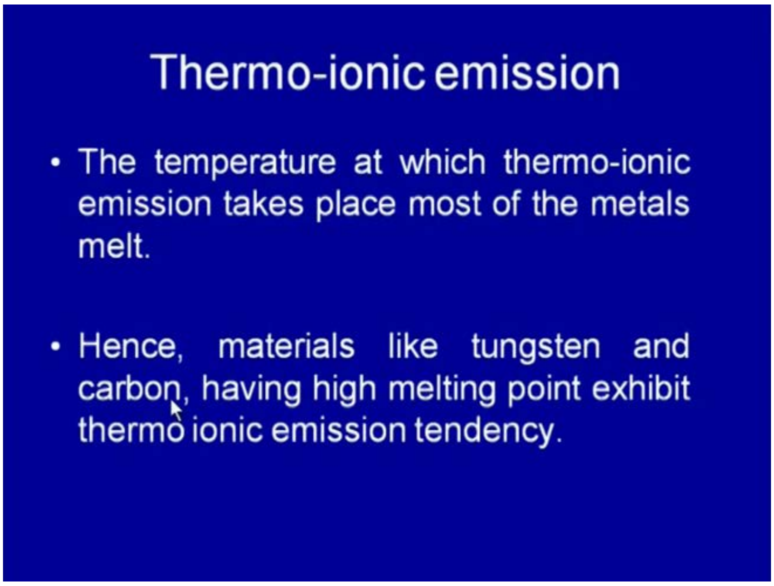

The temperature at which the thermo ionic emission takes place is too high. That is why, most of the metals melt under those temperature conditions. They are not found suitable for thermo ionic emission. However, the materials like tungsten and the carbon, having very high melting point, they exhibit thermo ionic emission. That is why when they are heated they can emit the electron without getting melted. But, the other metal system, the temperature conditions under which the thermo ionic emission can take place with them, they reach to the molten state.

That is why, they are not be able to emit the electrons easily. Before reaching to those temperature conditions, they come to the molten state. That is why, the refractive materials like carbon and tungsten can be used as an electrode materials for emitting the electrons by thermo ionic emission process. In the tungsten electrode welding process and the plasma arc welding processes, tungsten electrodes are normally used for emission of the electrons by thermo ionic emission process, so that electrons are released and the welding arc is easily established and maintained.

Because of the good thermal emissivity of the electrons and good ability of these 2 material systems to emit the electrons, the welding processes based on the either carbon arc welding or tungsten arc welding provide very easy and smooth arc initiation and the arc stability. Similarly, here we can see that, if the tungsten or any other material system is heated to the too high temperature, then the electrons are released. However, we put another metal with the positively connected to the positive pole forming an anode.

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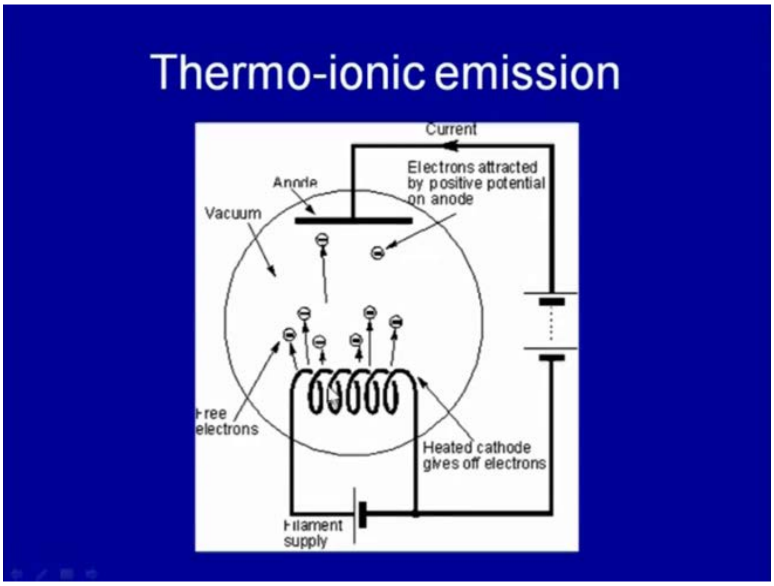

So, these electrons from the cathode side will start moving towards the anode and the flow of current will start. The same principal is used in the welding arc, where the cathode is heated and the generation of the heat from the tip of the cathode releases the electrons. These free electrons starts moving towards the anode, which is positively charged and which is connected to the positive terminal of the power supply. During this movement from cathode to the anode, these are accelerated to too high speed. When they are moving at high speed, they collide with the gaseous particles. The gaseous molecules present in the gap between the anode and cathode which in turn results in an emission of the electrons by the secondary emission.

So, this is how thermo ionic emission and can be clapped means, here the secondary emission can also play an important role in generation of the charged particles in the gap between the electrode and the work piece. If we see another approach of generation of the electrons in the arc gap is a field emission where the high potential difference between the electrode and the work pieces maintained. So, that the development of the high strength electromagnetic field helps to pullout the electrons from the surface of the metal. When these electrons are released from the surface the arc is established or discharge takes place between the electrode and a work piece.

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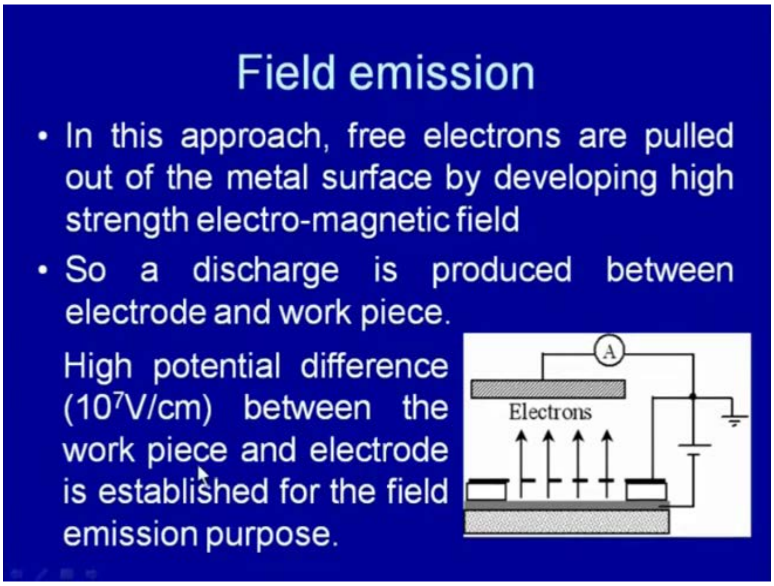

But, it is important to have very high potential difference between the electrode and the work piece. High potential difference of the order of ten thousand ten raise to the power seven volt per centimeter is used for developing the high strength electro static electromagnetic field between the electrode and work piece, so that electrons can be released from the cathode surface and the arc can be initiated and then can be maintained. So, this method where high strength electromagnetic field is used for emission of the electrons between the components involved between the electrode and the work piece, this mechanism is called the field emission. But, it is important to have very a high strength electromagnetic field which is generally obtained by having the high potential difference between the electrode and work piece.

The secondary emission is a third approach or third aspect where electrons are generated in the arc gap. In this approach mainly, the high velocity electrons already generated either by the thermo ionic emission or by the field emission, move at high velocity towards the anode.

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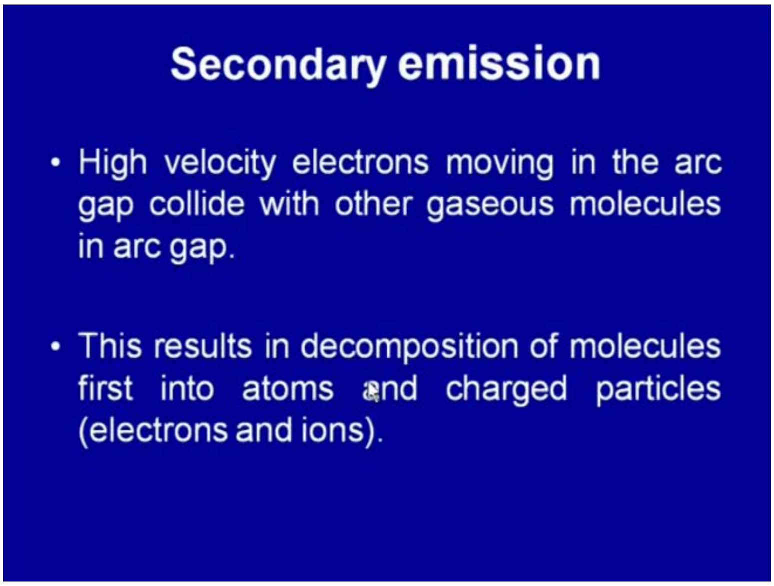

These electrons collide with the other gaseous molecules present in an arc gap, which in turn result in the decomposition of the gaseous molecules into the atoms and the charged particles that is an ions and electrons. So, it has to produce the charged particles required for having the good electrical conductivity between the electrode and work piece for initiation of the arc and maintenance of the welding arc. If we see the welding arc between the electrode and the work piece, this gap can be divided into different zones depending upon the way by which the potential drop between the electrode and work piece takes place.

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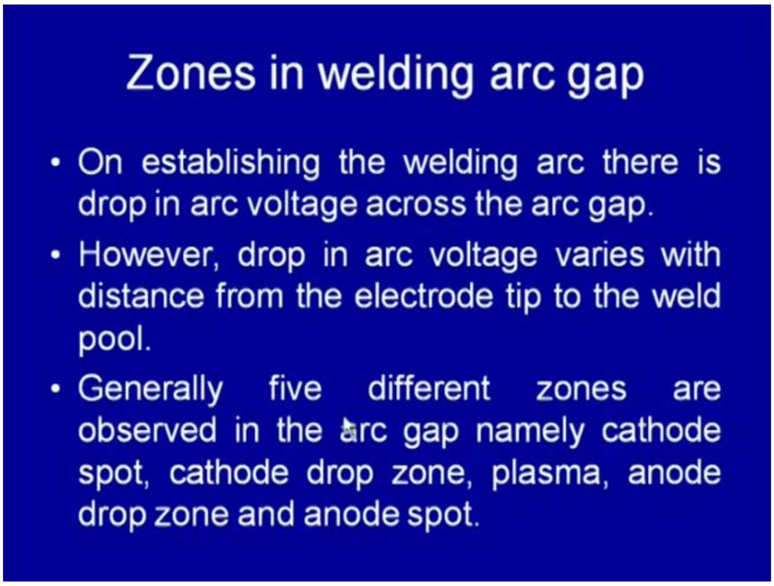

The way by which heat is generated, different zones are created on establishing the welding arc. There is a drop in arc voltage across the gap. This rate of the arc voltage drop varies with the distance from the cathode up to the anode. So, this drop in the arc voltage varies with the distance from electrode tip to the weld pool or to the anode. Generally, the 5 different zones are identified in the arc gap.

These are the cathode spot, cathode drop zone, plasma anode drop zone and the anode spot. Each region plays a specific role in the arc zone which effects the heat generation as well as temperature in each of the area. Depending upon the kind of metal system, different types of the cathode spots have formed. The voltage drop or potential drops in the cathode drop region, plasma and the anode drop region can be observed. So, we will look into the detail about each of these zones and their role in the arc region.

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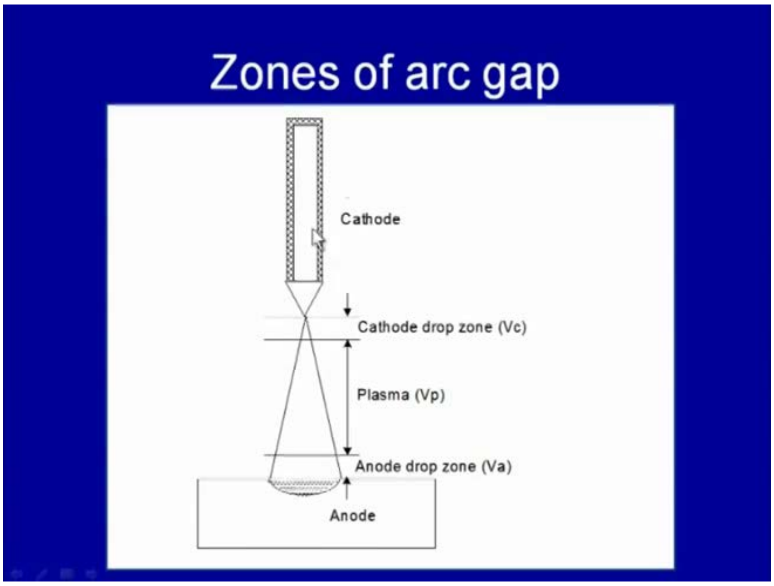

Gap wise, if we see in the welding arc zones, then the tip of the cathode from the gap between the electrode tip and the work piece is termed as arc gap. The tip of the electrode is termed as the cathode spot, from where electrons are released. These released electrons are moving towards the anode, where they merge with the anode. So, this entire gap is called the arc gap and the area where this electron merging is called the anode. The region very close to the cathode is called the cathode drop zone, where sharp gradient in the voltage drops takes place. Similarly, a sharp drop in anode drop region, means the anode also takes place.

So, as far as space is concerned the gap or a space between the electrode and the work piece or cathode and anode can be divided in to 3 zones, that is the cathode drop zone, plasma and the anode drop zone. The 2 other zones are basically, the cathode spot and the anode spot. Cathode spot or anode spots are the regions where from either electrons are released or the electrons merge with. So here we will, what is the role of the cathode drop zone, plasma and the anode drop zone in successful welding? We will also see, how do these zones affect the welding aspects?

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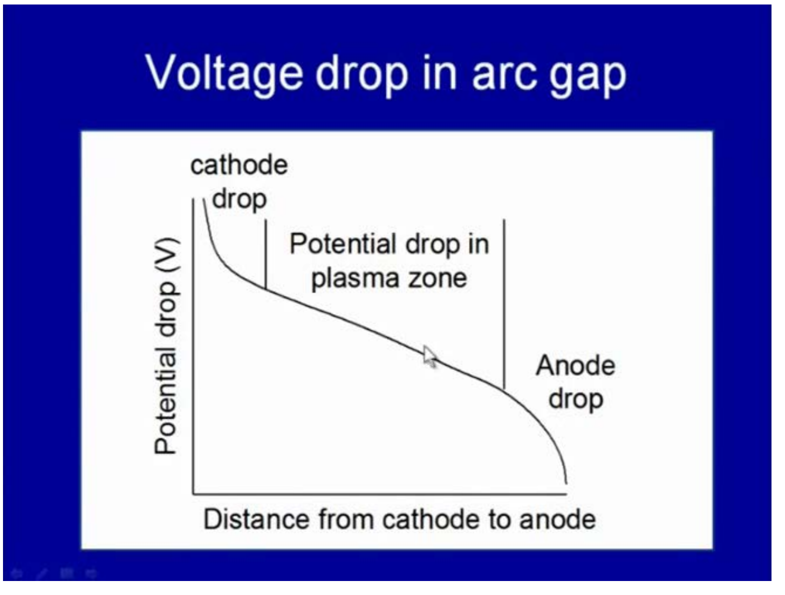

If we see here, the sharp drop in the potential takes place in the cathode drop zone as well as in the anode drop zone. Here, this diagram basically shows the variation in the potential drop as a function of the distance from the cathode towards the anode. As we have seen in the last diagram, we can see the variation in distance from the electrode tip or the cathode tip towards the anode side.

This region is a cathode drop region. As we start moving away from the cathode tip towards the anode, with the increase of the distance there is a variation in the anode drop. Because of this, there is a very sharp drop in the potential with the increase of distance from the cathode spot towards the anode side. So, here this sharp drop is because of the closeness of the arc region with the cathode which transfers some of the heat from the arc zone towards the cathode. So, the heat transfer from the arc zone towards the electrode reduces the temperature in the region very close to the cathode. This results in the cathode drop zone and the low temperature in turn decreases.

A number of charged particles present in the cathode drop zone and a reduced number of the charged particles in the cathode drop zone causes a high drop in the potential difference. Similarly, in the anode drop zone also, because of the high closeness of the zone of arc with the anode or with the work piece, the heat generated is transferred away from this zone towards the base metal or towards the anode.

This results in the significant reduction in temperature of this area which is close to the anode. The reduced temperature results in the reduced ability of the charged particles in this zone and reduced number of charged particles in this zone cause a sharp drop in the potential drop.

While, in case of the plasma zone, the temperature gradient is almost constant and that is why in this zone the charged particles and the densities are almost uniform. This in turn results in uniform potential drop in the plasma zone. If we see here, the heat generated or heat from the anode drop zone is basically used to melt the anode side. The heat generated in the cathode drop zone is mainly used for melting of the cathode side, while the heat generated in the plasma zone is not much used either for melting of the anode or the cathode.

However, a fraction of the heat is definitely transferred from this region towards the anode and towards the cathode. Accordingly, it contributes towards the melting, However, most of the heat generated in the plasma region is transferred towards the surrounding or to the shielding gasses which are covering to the plasma and to the arc gap.

So, here the sharp drop in the anode potential like the cathode drop region results in the cathode drop voltage and the anode drop region results in the anode drop voltage. If we multiply this anode drop voltage with the welding current, then we can get the amount of heat generated in the anode drop region. Accordingly and similarly, if you multiply the welding current with the voltage drop in the cathode drop region, then we can get the heat generated in the cathode drop zone.

So, here we can see that, what is the role of the anode drop region, anode drop potential and its relations with the heat generated in these zones. So, here this shows all those 5 zones and the 5 regions which are there in the arc zone. These are like cathode spot very tip of the electrode from where the electrons are released and the region very adjacent to the cathode tip is a cathode drop region.

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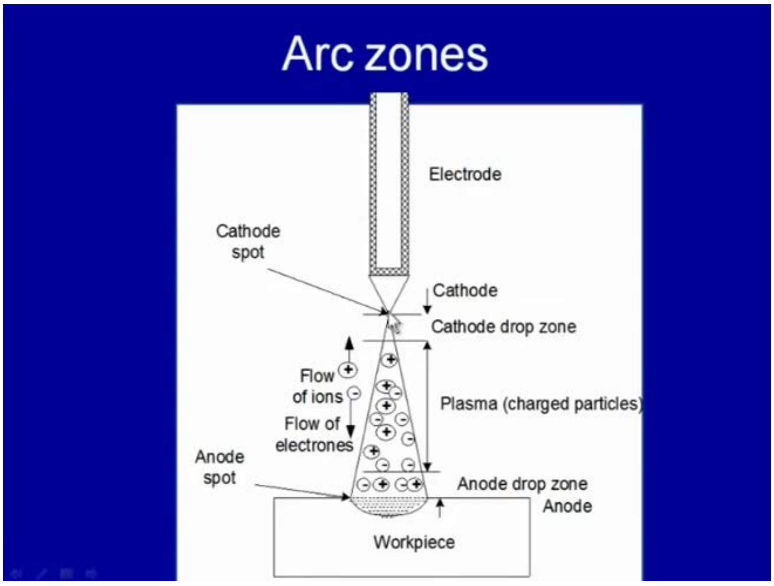

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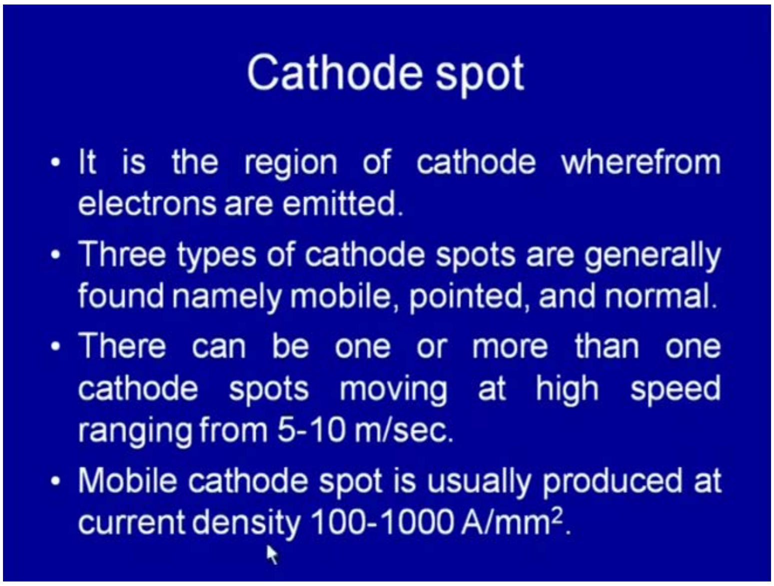

If we see here, the region where all these electrons merge with the anode is called anode spot. The region very close to the anode spot is called anode drop region. The gap between the anode drop region and the cathode drop region is called the plasma, where the presence of the charged particles basically facilitate the flow of the electrons from the cathode side towards the anode side. This results in the smooth and stable arc. We will see in detail about the cathode drop, anode drop region and the plasma regions and their role in the welding

The cathode spot region is, as I said, it is the region of the cathode where from electrons are released and the various types of cathode spots are formed during the welding depending upon the metal system and the electrode geometry. The 3 types of the cathode spots are generally formed. These are the mobile cathode spot, the pointed cathode spot and the normal cathode spot. There can be one or more than 1 cathode spots moving at very high speed.

In case of the mobile cathode, spot mobile cathode spot is usually produced at high current density. When it is produced it results in better cleaning action of the cathode side. That is why, when the aluminum welding is done normally, work piece is made cathode, so that the development of the mobile cathode is spot. This results in the automatic cleaning by loosening of the oxide layer formed by reaction of the gases like oxygen with the metals of like aluminum and magnesium and stainless steel.

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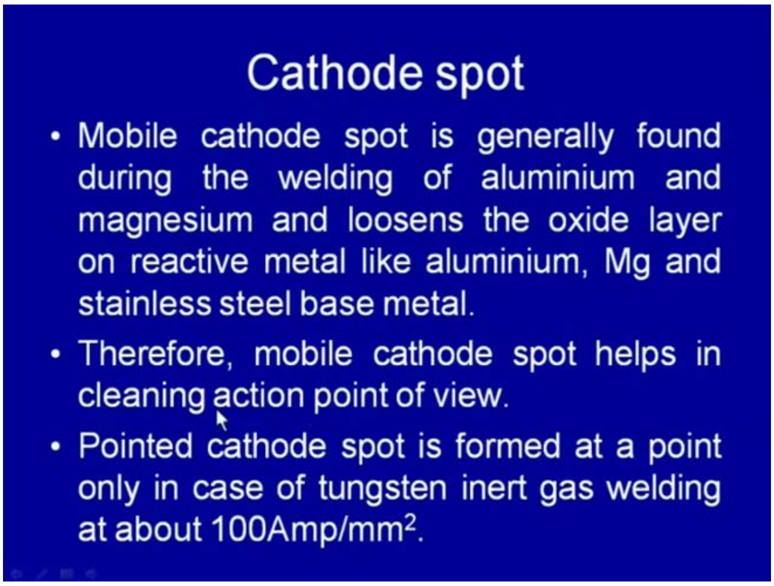

So, those metal systems form the mobile cathode spots like aluminum, magnesium and stainless steel. The formation of the mobile cathode spots loosens the oxide layer formed on the surface. This loosening helps in cleaning of the weld metal. Cleaning of the metal during the welding, reduces the development of the inclusions in the weld joint.

Therefore, cathode spot helps in cleaning or a cleaning action point of view. It is good to avoid the presence of the inclusions in the weld joint.

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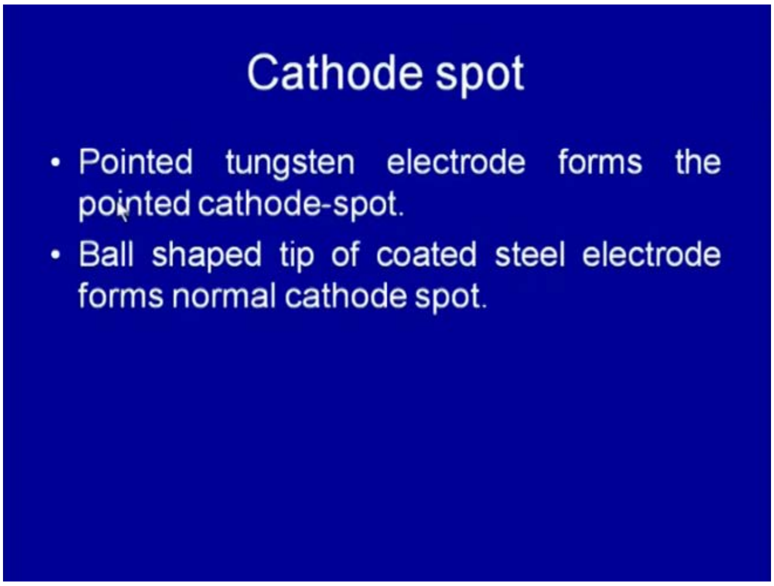

In case of the pointed cathode spot, it is formed mainly when the pointed electrode tip is used, like in case of the tungsten inert gas welding. When tungsten inert gas welding is used, use of the pointed cathode helps to develop the pointed cathode spot at around the current density of 100 ampere per meter square. So, the pointed cathode spot is found in case of the tungsten electrodes when it is used in case of the tungsten inert gas welding processes. When the ball shaped tip coated steel electrode is used, we get the normal cathode spot. It will be having some circular section for the circular shape at the tip of the electrode, while in case of the pointed it will be pointed or conical shape with the different degree of angles.

Cathode drop region is the region very close to the cathode and a very sharp drop in the voltage takes place in this region. This happens primarily due to the cooling effect which is due to the extraction of heat from the arc region by the cathode. This reduction in this extraction of the heat or this cooling effect of the cathode results in the sharp drop in the region close to the cathode, the voltage drop in this region affects the heat generated near the cathode.

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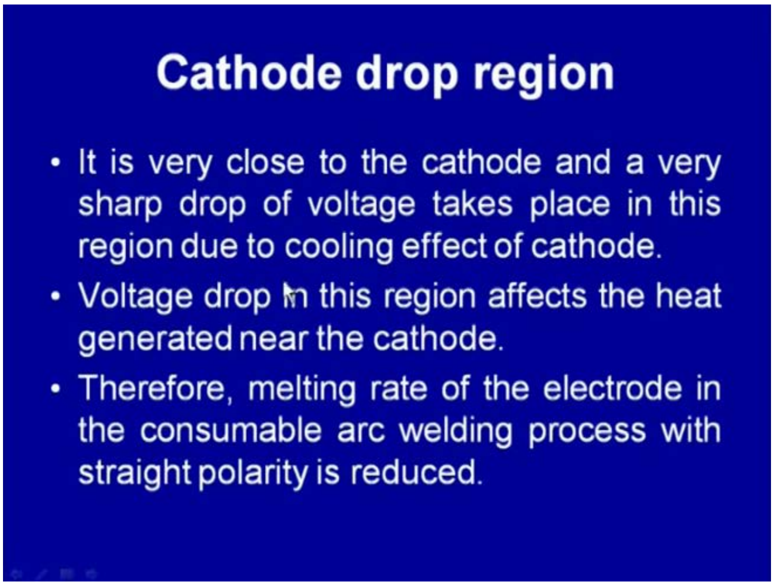

So, higher the voltage drop, higher the heat generation near the cathode. Therefore, melting rate of the electrode in the consumable arc welding processes is affected by the kind of polarity which is used by the electrode, that is the cathode or the anode. If the heat generated in the cathode side is more or in the anode side is more, accordingly the melting rate is affected during the welding. So, if the electrode is made anode, then more heat generation in the anode side results in the higher melting rate, in case of the consumable arc welding processes.

So, when the straight polarity is used, straight polarity means the electrode is negative and the work piece is a positive. So, the melting rate of the electrode, in case of the consumable arc welding process, will be directly governed by the heat generated in the cathode side. This in turn is influenced by the voltage drop in the cathode drop region. So, in the case of straight polarity, the heat generated in the cathode drop region affects the melting rate of the electrode. So, the value, the welding speed will also be affected.

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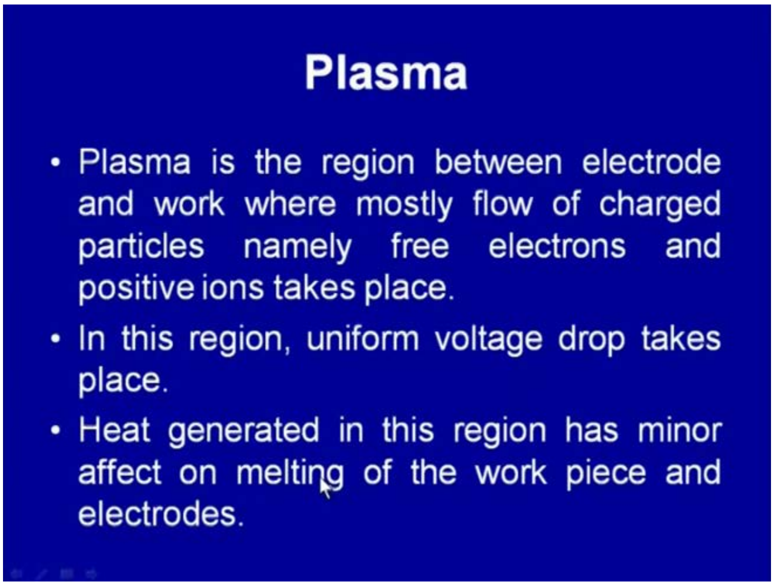

Plasma region is another region between the electrode and the work piece where mostly the flow of the charged particles namely, electrons and the positively charged particles like ions takes place in this region. Uniform voltage drop takes place and heat generated in this region has minor effect on the melting of the work piece and the electrodes. As most of the heat is lost to the surroundings and the gases are present all around the arc region, very few percentage of the heat generated is in the plasma region which is used for melting of the cathode and of the work piece. In the anode drop region, like the cathode drop region also, sharp drop in the potential and the arc voltage takes place.

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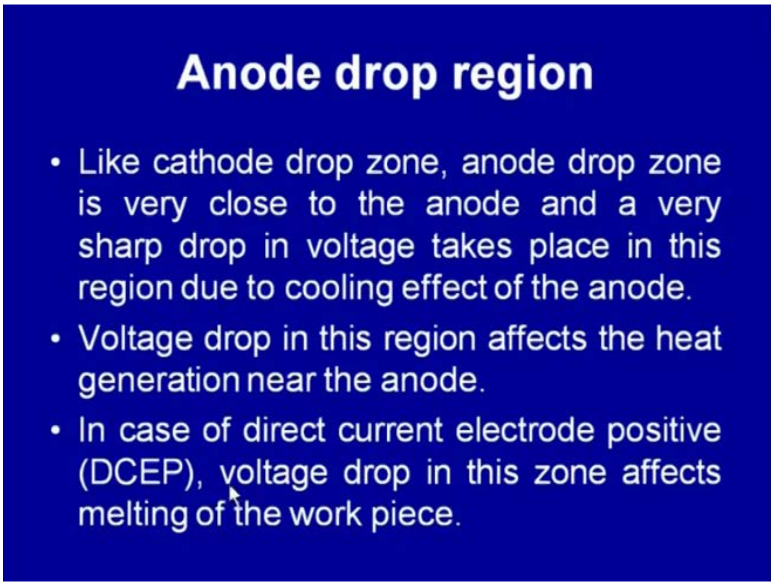

So, like a cathode drop region, anode drop zone is very close to the anode and a very sharp drop in the voltage takes place in this region. The region for this is also the same, that is a cooling effect offered by the anode due to the rapid extraction of the heat being generated in the arc region. The voltage drop in this region also affects the heat generated near the anode.

In case of the direct polarity, where electrode is made positive and the work piece is made negative, here voltage drop in this zone affects the melting rate of the work piece. So, here whether we are making electrode positive or the electrode negative, in both the cases, the voltage drops in the anode drop region and the cathode drop region will be affecting the melting rate and the welding speed. That will depend up on the kind of polarity which is being used.

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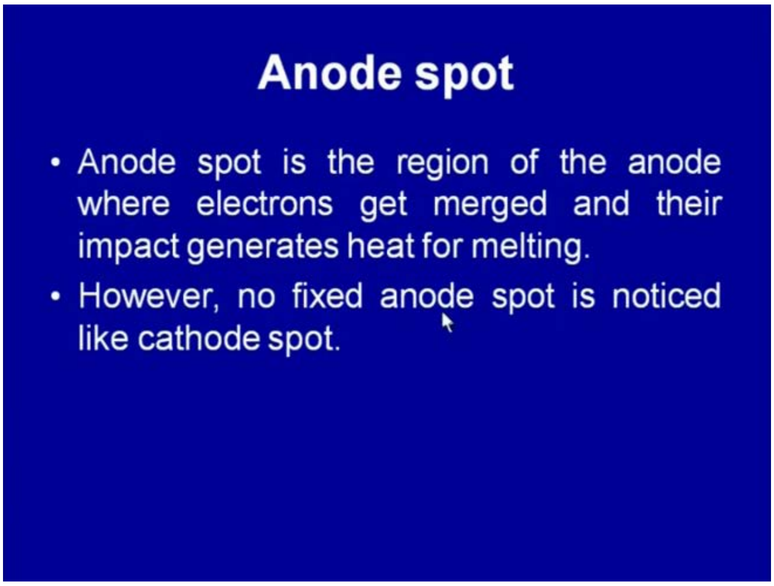

The last region in the arc zones the last zone is the anode spot. Anode spot is the region in the anode side where electrons get merged. Once they impact with anode, with this impact some heat is generated which is used for melting of the anode. However, since the very large area is covered in case of the work piece, if it is made anode, then there will not be any fixed region like cathode spot region where this merging of the electrons will be taking place. That is why no fixed anode spot is noticed during the welding like cathode spots.

Now, I can summarize this presentation in which we have begun with the physics of the welding arc where we have seen the role of the free electrons and the ions in the welding arc. We have also seen the different mechanisms through which the electrons are emitted and the factors that affect the electrons emission related with the different metal systems. We have also seen the different zones found in the arc region and what is their role in the welding process. We will go through the details of the various aspects later such as the physics of the arc welding in the coming presentations.

Thank you for your attention.