Advanced Manufacturing Processes
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Module - 4
Advanced Welding Processes
Lecture - 5
Electron Beam and Plasma Welding Processes

Welcome to this session on electron beam welding and plasma arc welding processes, under the course advanced manufacturing processes. These two are advanced welding processes being used nowadays in many applications. Let us discuss about the principles of these two processes, the requirements and their common applications, etcetera in this session.

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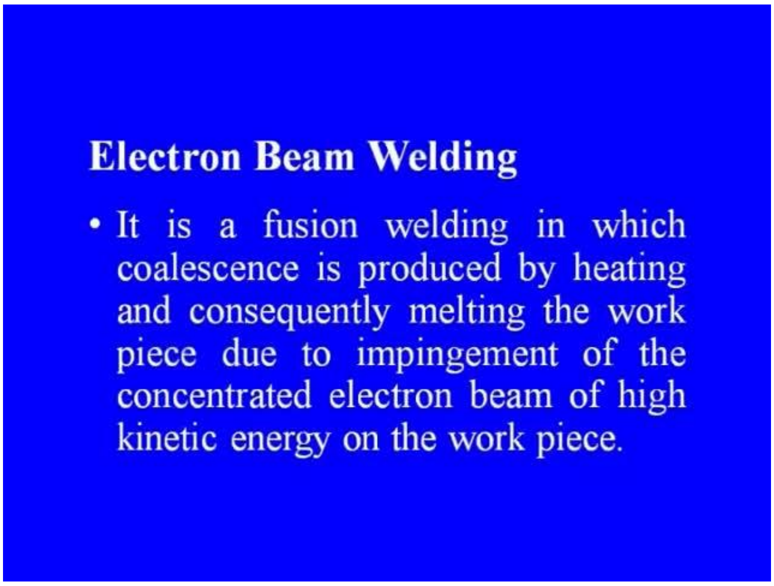

Let us discuss about the electron beam process first. This electron beam process is a fusion welding process in which, coalescence is produced by heating and consequently melting the work piece due to impingement of the concentrated electron beam of high kinetic energy on the work piece. As we have already discussed, while discussing the electron beam machining process, the principle is almost similar in which we have discussed like this. In electron beam machining also the basic requirement is the electron beam. Now, how we manipulate this electron beam? How we use this electron beam to work the work pieces or to cause effects on the work pieces? This is this is the technology we will be varying in case of electron beam machining, in case of electron beam welding. So, basic process remains same.

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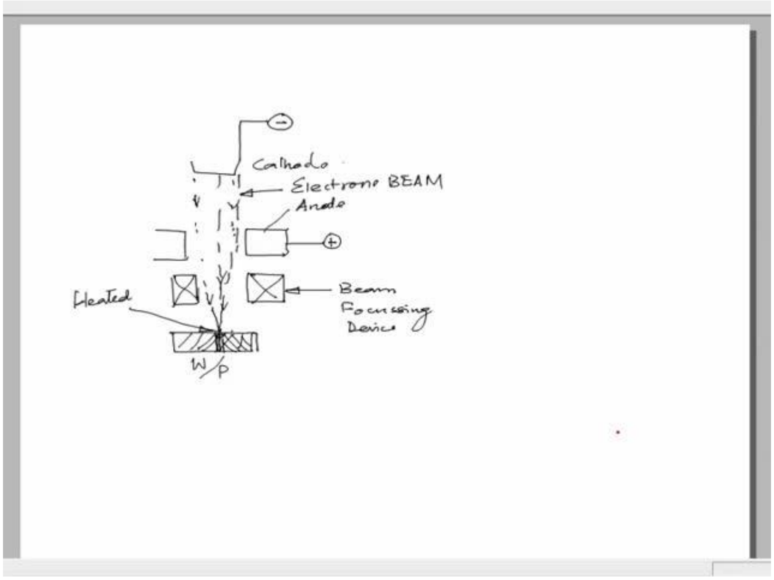

So, there will be one electrode, so or this is say we can say this is cathode. We can say this is a cathode, which will produce some electron beams or electrodes and they will be attracted towards an anode system. Anode system and this electron beam will be ultimately focused to to a particular spot, where the work piece will be placed. So, there will be a focusing mechanism on the way. As we have also discussed regarding this, so there will be a focusing, this is, this will be beam focusing mechanism, focusing device and this will be the work piece.

This is the electron beam, coming out from the cathode and this is nothing but the anode this is the electron beam. Now, in case of electron beam machining, we have found that this is upon heating by this electron beam on the work piece. So, this position gets heated up and consequently this heated position gets melted and evaporated out. Now, the same principle can be slightly modified. If we place two components here having the interface at this point, then this material and this material both interface having at this point and the beam is focused at the interface.

Now, as in the case of electron beam machining, so this interface of the two materials to be joined or heated interfaces are heated up by the application of this incoming electron beam because of this heating up of the surfaces. They will melt and they will get fused upon cooling. So, this is the basic principle involved in electron beam welding process as well. Now, let us look into different aspects and the process parameters, that is basically the conditions power conditions etcetera regarding this process.

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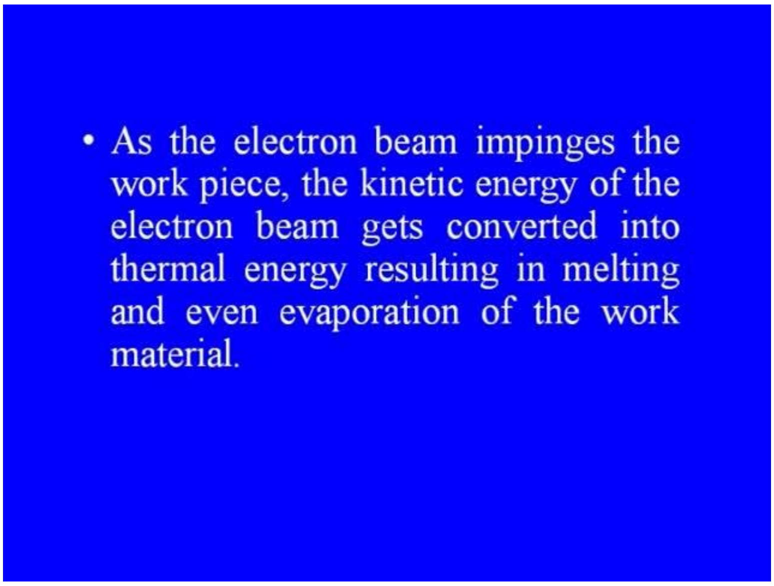

As we have already discussed, as the electron beam impinges the work piece, the kinetic energy of the electron beam gets converted into thermal energy, resulting in melting and evaporation of the work material. Thus basically, it is a thermal based process unlike the solid stage processes in which, the mechanical energy is being converted converted and used for softening into the material. Then the joining was done but here essentially this is a thermal process in which, the softening of the material takes place because of the heating of the electron beam.

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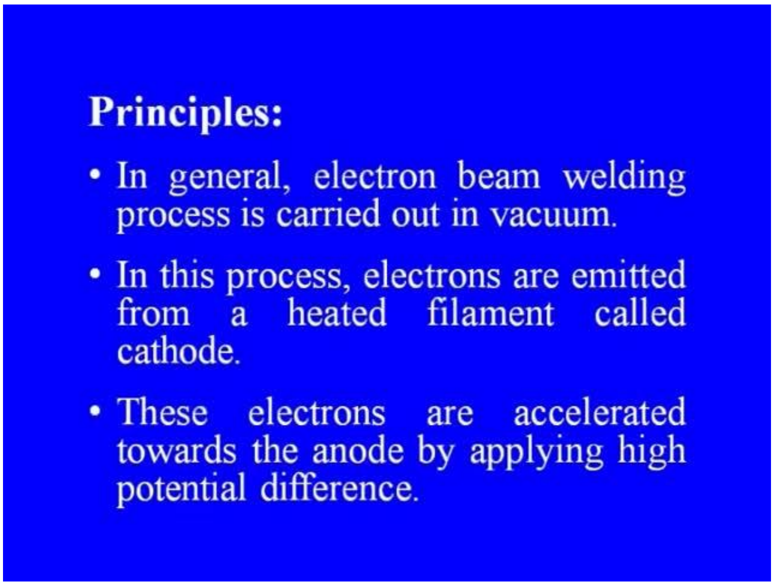

Let us see the principle. In general, electron beam welding process is carried out in vacuum. In this process electrons are emitted from a heated filament called cathode; that we have already discussed. How electron beam is generated in a setup? These electrons are accelerated towards the anode by applying high potential difference, which is similar to that of what we us in electron beam machining process.

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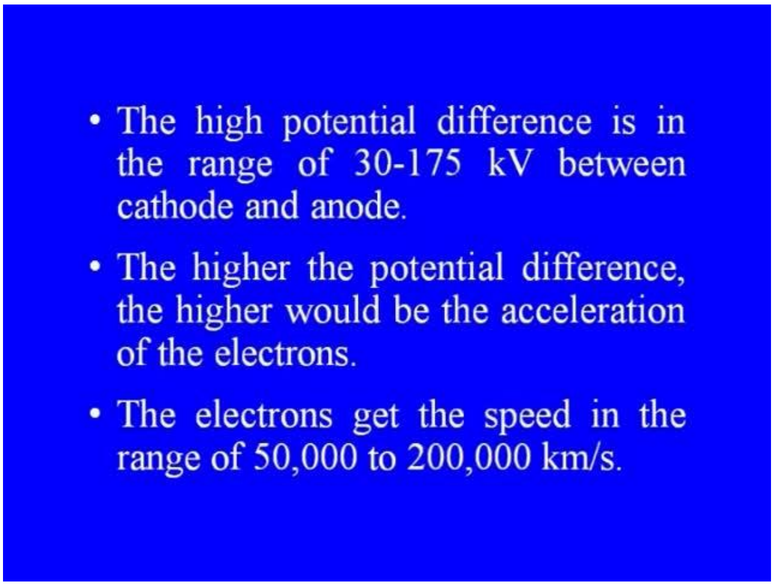

The high potential difference is in the range of 30 to 175 kilovolt between the anode and the cathode. The higher the potential difference the higher would be the acceleration of the electrons. The electrons get the speed in the range of 50,000 to 200,000 kilometer per second.

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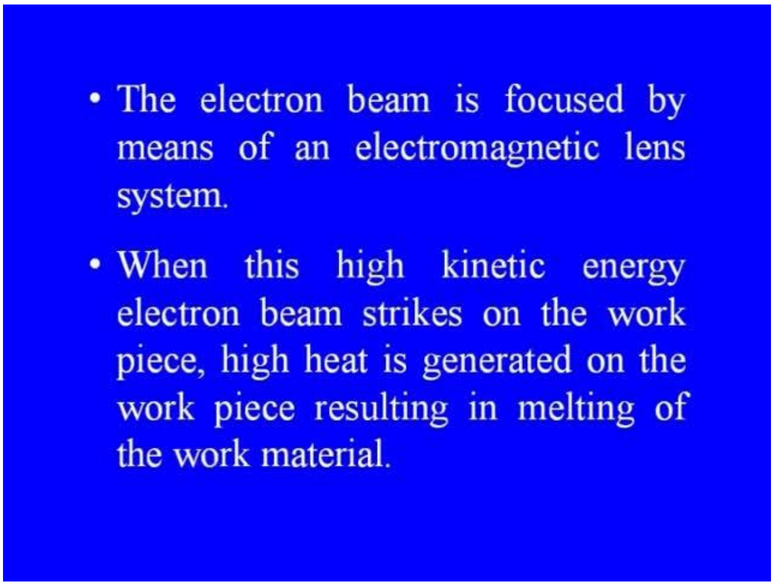

The electron beam is focused by means of an electromagnetic lens system, this also we have already discussed. How the lens is placed on the way or on the part of this electron beam, so that the beam can be converged and focused at a point of our interest, where the two surfaces or the two objects to be joined or placed? So, this is a critical critical component. How to focus the beam actually at the point of joining? When this high kinetic energy electron beam strikes on the work piece, high heat is generated on the work piece resulting in the melting of the work material.

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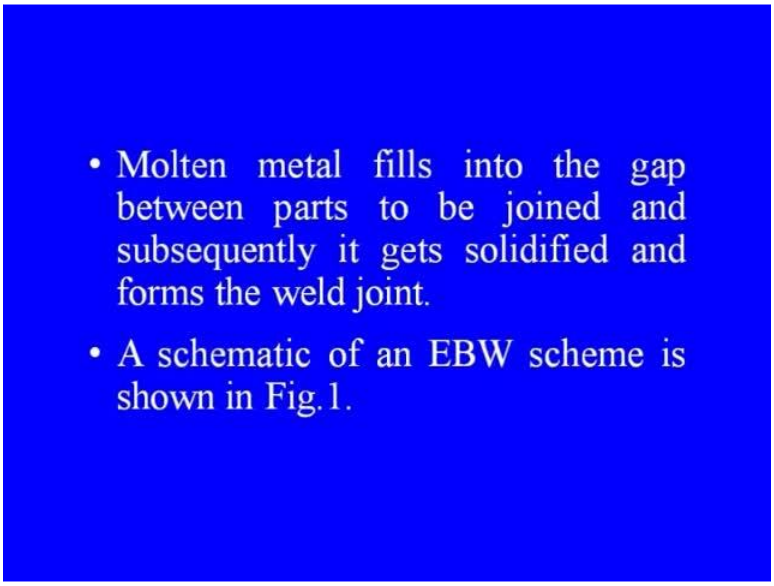

The molten metal fills the gap between the parts to be joined and subsequently it gets solidified and forms the weld joint. A schematic is shown in this particular figure which is in the screen.

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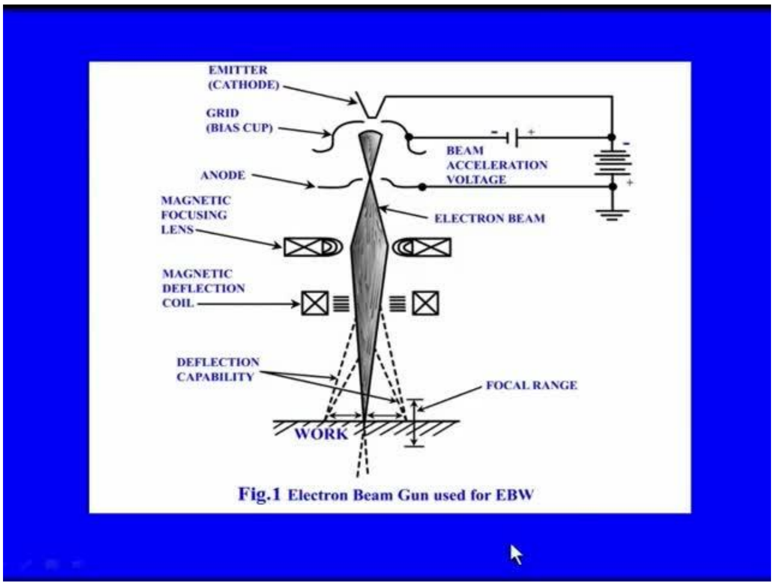

Fig.1 Electron Beam Gun used for EBW

So, here as as I have indicated already, so this is the cathode from which the electron beam will be coming out, this is the grid actually. So, this will be again connected to another voltage or potential difference with respect to the cathode, and this is the accelerating voltage that we can we can say this the anode. This connected to the positive end of the power supply, as we can see here power supply. This will be in the range of 35 to 175 kilovolt. Whereas, this grid voltage, grid voltage will be maintained at a lower value, which will be kept again negative with respect to the cathode.

This resultant electron beam coming out through this, which is being accelerated towards this will be controlled or focused rather by this focusing mechanism. These are the magnitude reliance’s or magnetic deflection coil etcetera are used to focus this beam onto the work surface, were we can keep the two pieces to be joined here. So, here the penetration of the beam is being shown as well as the scattering of the beam, possible scattering of the beam is also shown, so this can give give rise to some sort of heat effect, heating effect or heat effected zone, very near to the point of interest or where the joint is to be made.

Therefore, this is another process where we can except little bit of heat effected zone because it is a basically a thermal based process. However, this can be minimized with proper control of this field or this parameters and this distance as well. This distance is also very important distance, that is the focal distance, where we will keep the work piece with respect to the to the beam set up. These are few important considerations here and of course, as a hole this entire arrangement should be in a vacuum environment.

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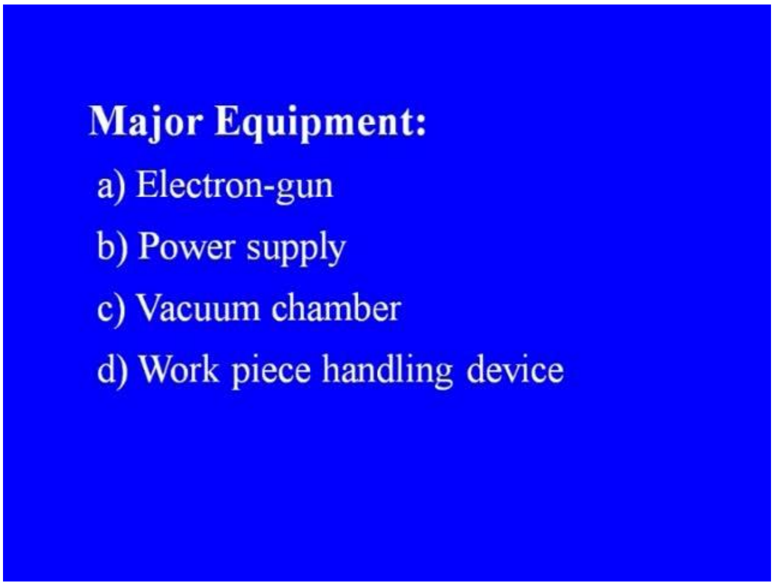

The here major equipment required are consist of the electron gun, power supply unit, the vacuum chamber, then work piece handling device etcetera. Let us look into the electron gun assembly.

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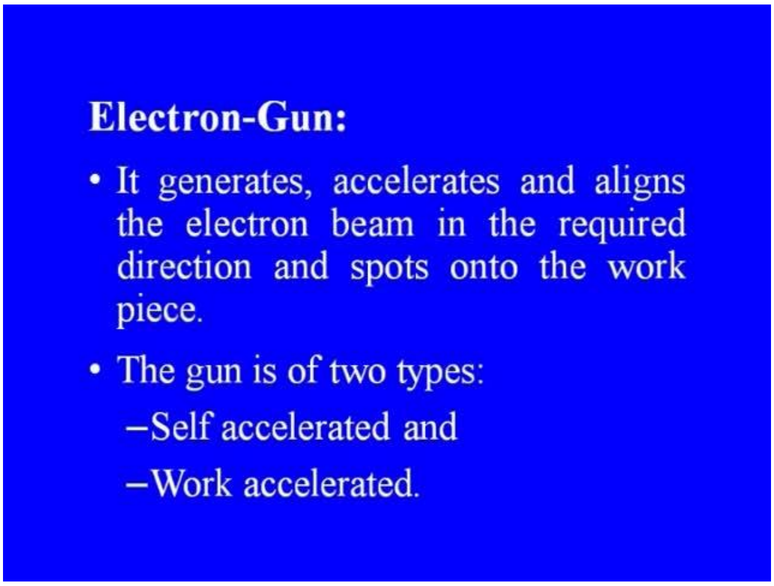

The main function is to generate accelerate and and the electron beam, in the required direction and spots onto the work piece. This gun could be of two types, one is self accelerated type and other one is work accelerated type.

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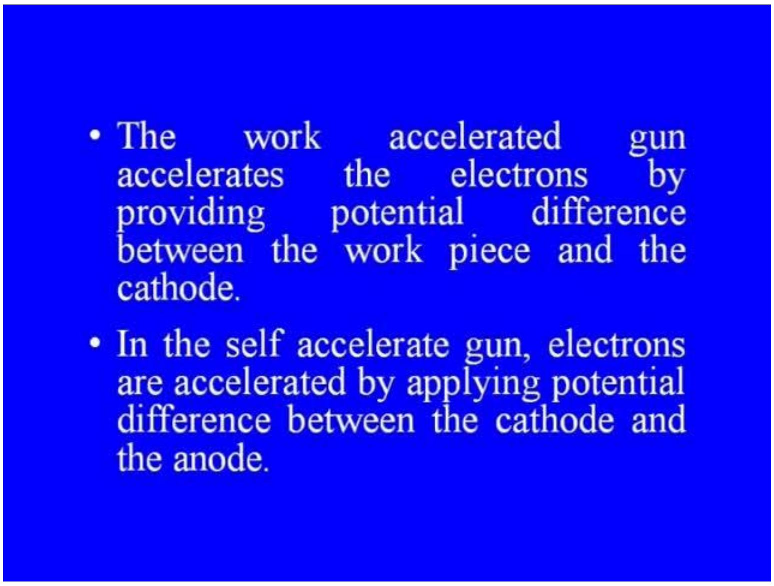

The work accelerated type gun accelerates the electrons by providing potential difference between the work piece and the cathode, where as in the self accelerated gun electrons are accelerated by applying potential difference between the cathode and the anode. The anode and the cathode are enclosed within the gun itself.

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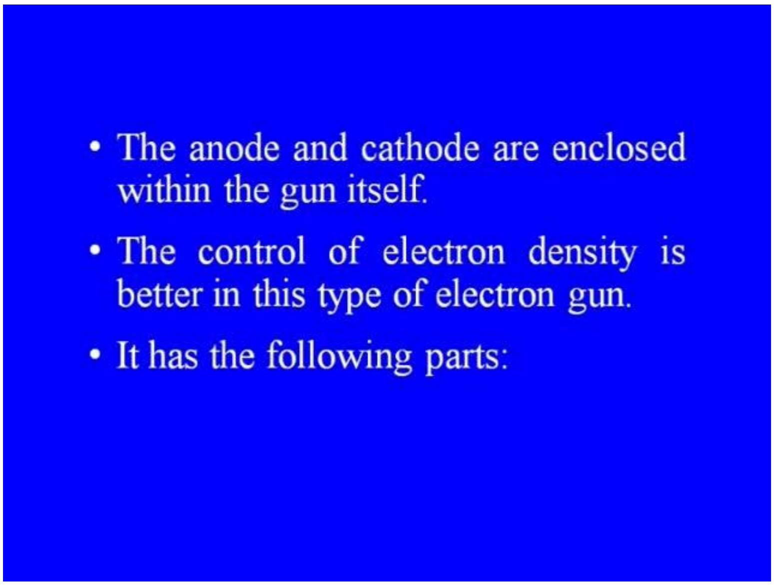

Therefore, the construction of the gun is very, very critical. It is highly compact also and it needs lot of mechanisms like cooling as well as insulating the anodes and the cathodes etcetera. Therefore, the construction of the gun is complicated here and the complex as well the control of electron density is better in this type of electron gun.

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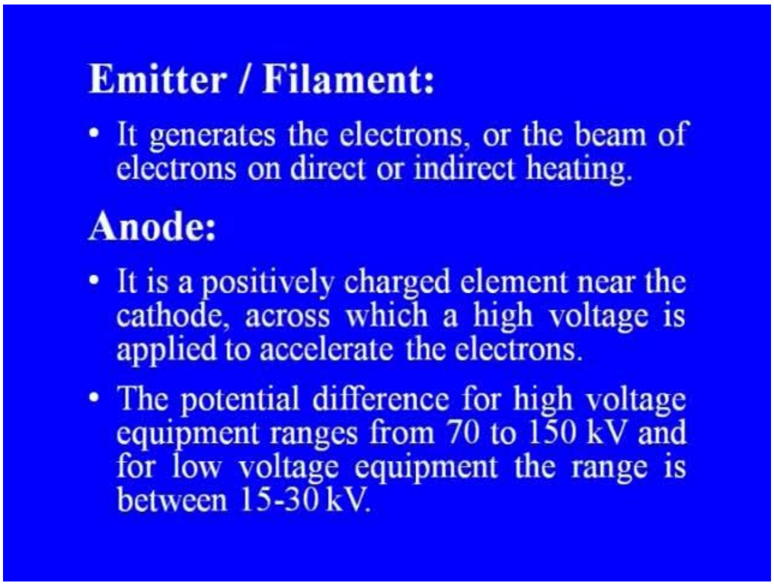

It has the following parts like, the emitter or the filament, which will be responsible for emitting electrons. This emission of electrons will takes place because of the direct or indirect heating of the cathode, which is usually done by applying potential difference. Then let us look at the anode, it is a positively charged element near the cathode across, which a high voltage is applied to accelerate the electrons.

The potential difference for high voltage equipment ranges from 70 to 150 kilovolt and for low voltage equipment the range is between 15 to 30 kilovolt. Now, let us talk about the grid cup, which we have seen already in a figure we have displayed. There is a small grid near to the cathode and which we have seen that the grid was kept at relatively negative voltage with respect to the cathode.

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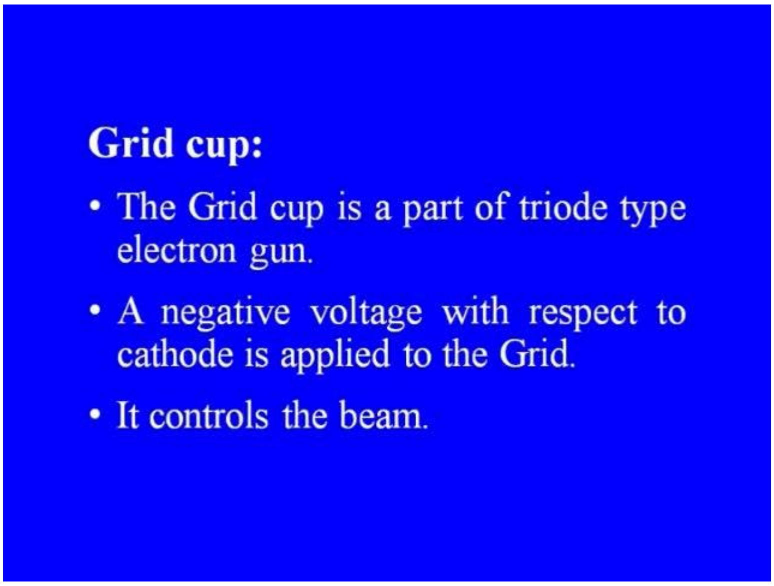

There was a separate supply for that power supply connected to that a grid, which is always maintained the negative voltage with respect to the cathode itself. Of course, because we know cathode itself is is connected to the negative terminal of the power source. However, grid should be again negative with respect to the cathode so here here is the difference between the grid and the cathode. The main function of this gird is it controls the beam. The next unit is electron focusing unit.

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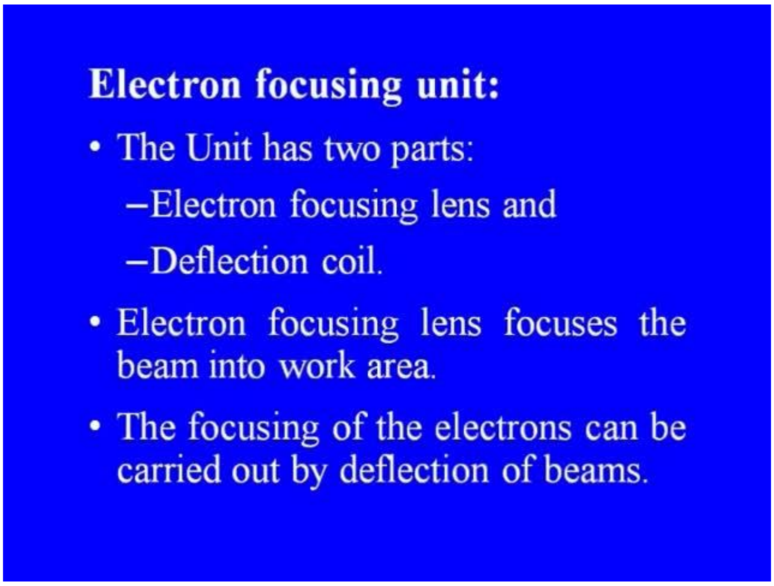

The unit has basically two parts, electron focusing lens system and the deflection coil. The electron focusing lens system focuses the beam into work area, the focusing of the electrons can be carried out by deflection of the beams. The electromagnetic lens system contains a coil encased in iron.

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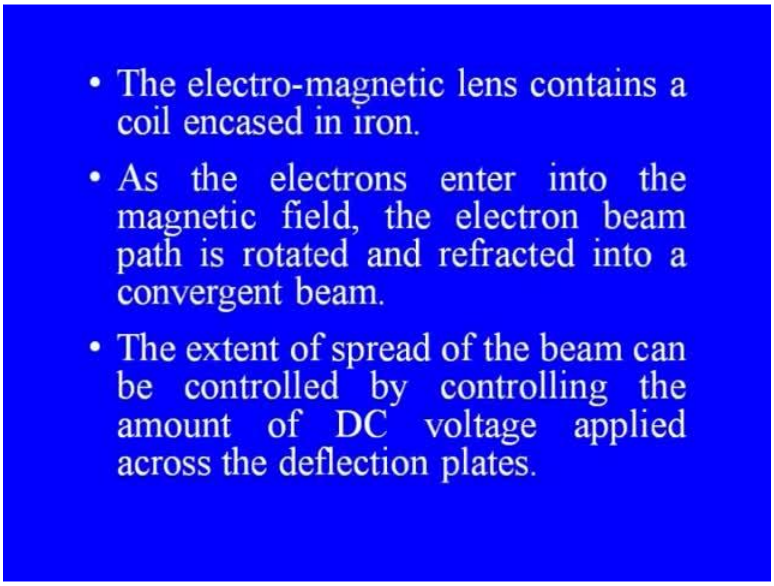

As the electrons enter into the magnetic field, the electron beam is rotated and refracted into a convergent beam. The extent of spread of the beam can be controlled by controlling the amount of DC voltage applied across the deflection plates. So, this control voltage is very, very important as far as the controlling of the deflection of the beam is concerned. Now, let us look at the electron gun power supply.

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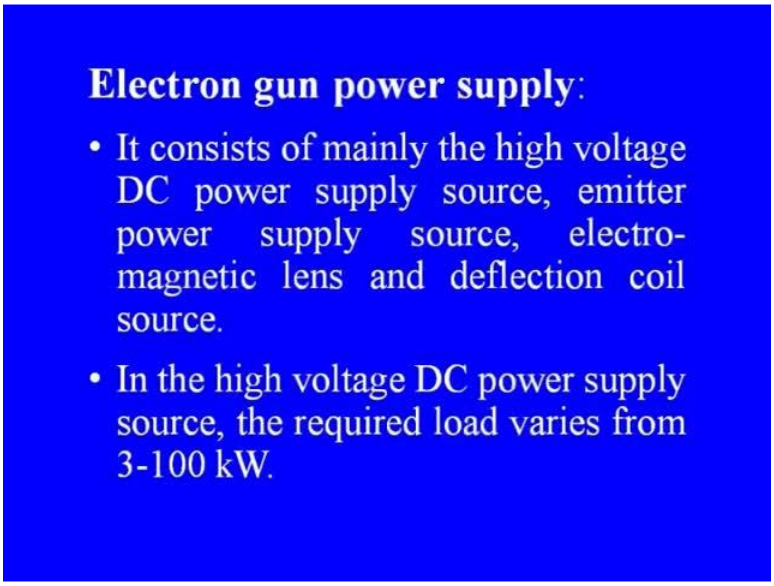

It consist of mainly the high voltage dc power supply source, emitter power supply source, electromagnetic lens system and deflection coil source. In the high voltage DC power supply source, the required load varies from 3 to 100 kilovolt.

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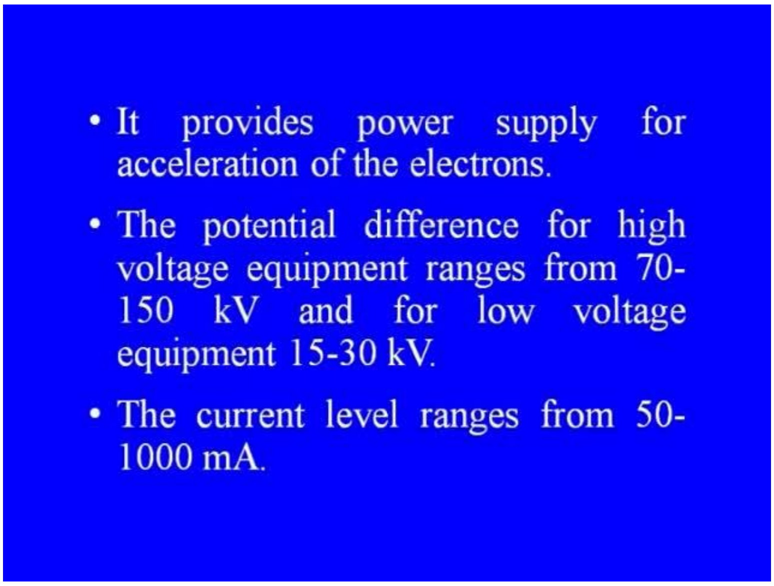

It provides power supply for acceleration of the electrons, the potential difference for high voltage equipment ranges from 70 to 150 kilovolt and for low voltage equipment 15 to 30 kilovolt. However, the current level ranges from 50 to 1000 milli ampere.

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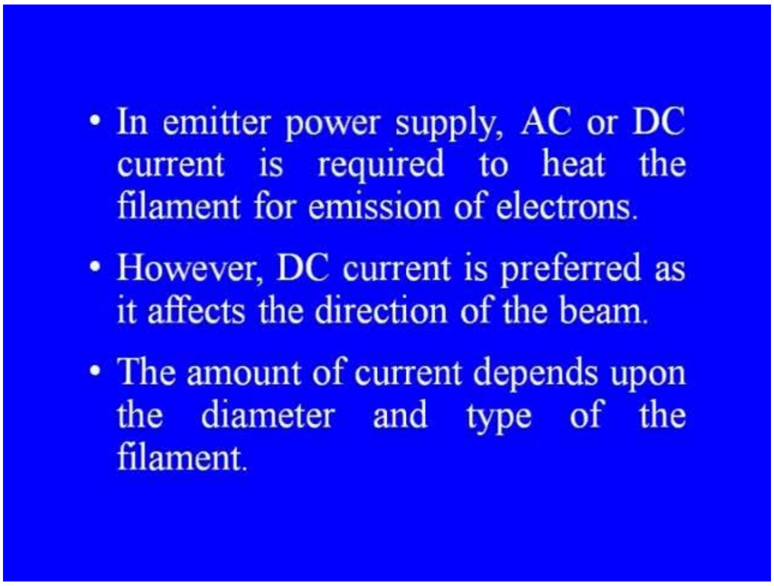

In emitter power supply on the other hand AC or DC current is required to heat the filament, for emission of electrons. Also we have indicated earlier, the electrons are emitted because of the heat, of the heating of the cathode, which is being done by either AC supply or DC supply. However, DC current is preferred always. As it affects the direction of the beam the amount of the current depends upon the diameter and the type of the filament.

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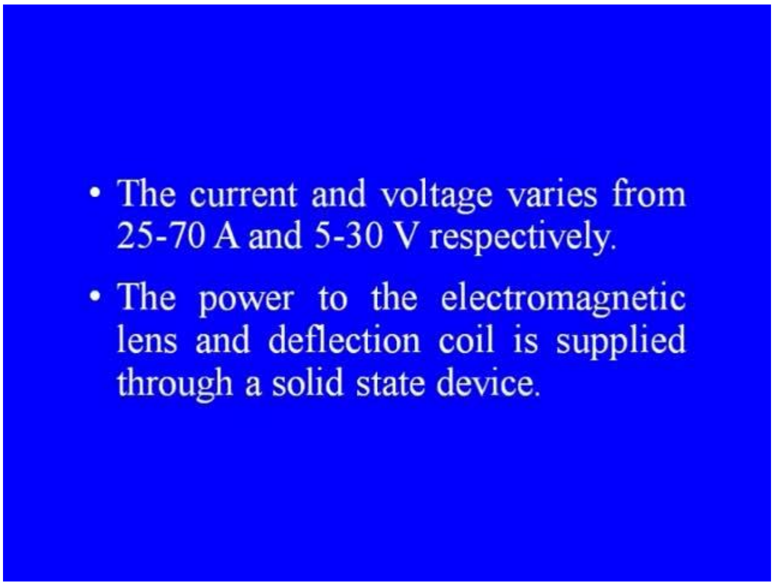

The current and voltage varies from 25 to 70 ampere and 5 to 30 volt respectively. The power to the electromagnetic lens and deflection coil is supplied through a solid state device. Now, let us look at another important sub system of this entire electron beam welding system. That is vacuum chamber, as we have already indicated the entire electron beam welding process should be carried out inside the vacuum chamber.

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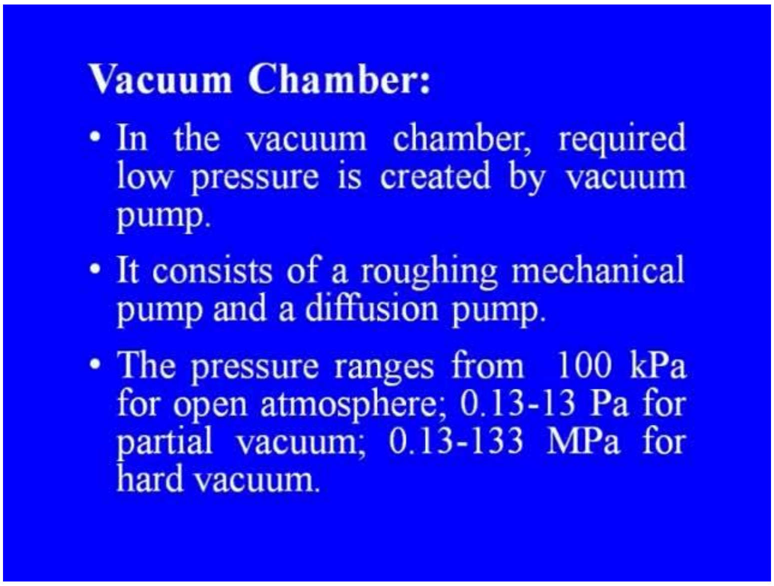

In this vacuum chamber low pressure is created by vacuum a pump, which consist of a roughing mechanical pump or a diffusion pump the pressure ranges from 100 kilopascal for open atmosphere and then 0.13 to 13 pascal for partial vacuum, then 0.13 to 133 mega pascal for hard vacuum.

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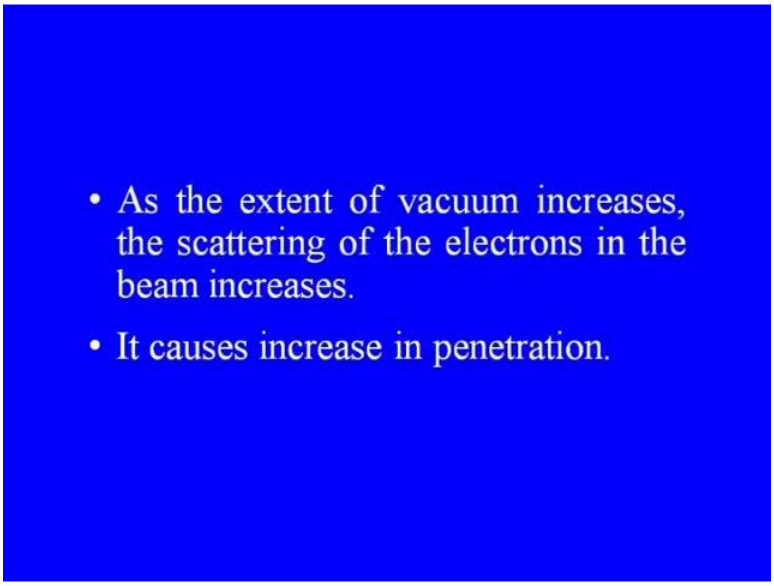

As the extent of vacuum increases the scattering of the electrons in the beam also increases, it causes increase in penetration. Now, let us look at the work piece handling device.

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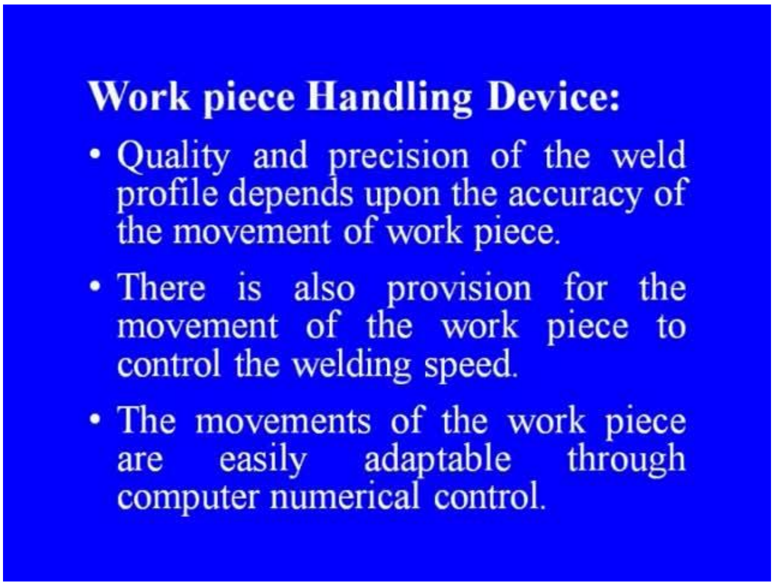

Quality and precision of the weld profile depends upon the accuracy of the movement of the work piece. There is also provision for the movement of the work piece to control the welding speed. The movements of the work piece are easily adaptable through computer numerical control. Now, let us look at the advantages of this process.

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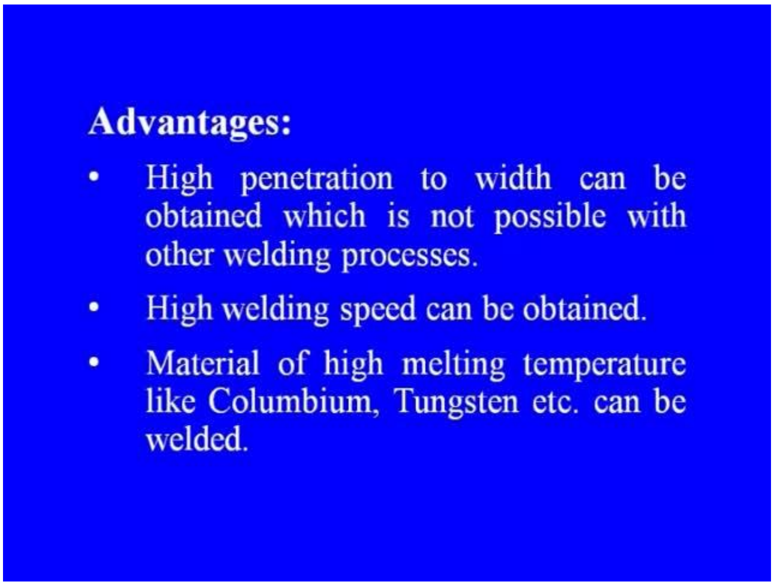

In this process high penetration to width can be obtained, which is not possible with other welding processes. Then high welding speed can be obtained. Material of the high melting temperature high high melting point materials like columbium, tungsten etcetera can be welded very easily by this process, because we can obtain very high temperature by this electron beam.

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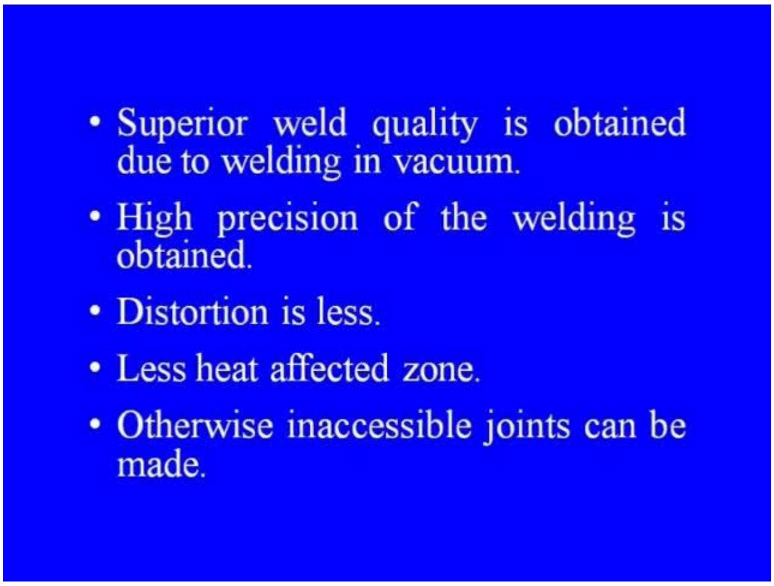

Then superior weld quality is obtained due to the welding in vacuum. This is another important aspect, where the in process oxidation possibility is reduced because of the vacuum. We used and then of course, the affect of atmospheric nitrogen also get reduced because of the shielded environment. Then high precession of the welding is is obtainable. It is a very precessioned process, distortion is less, highly focused that is that is why the distortional nearby distortional is very less or the weld distortion is also less. Then the heat affected zone is very minimum, although it is a thermal based.

There will be some heat affected zone as we have already indicated. However, how minimal this heat affected zone we can keep that is where another performance criteria of this process. Means this can be restricted to a very minimal zone and in many a cases, difficult to assess points like some points needs to be access through a very small constriction restriction, which is very, very difficult to reach through some conventional welding rod etcetera. It can be welded, as this beam electron beam can be focused through a very narrow slit.

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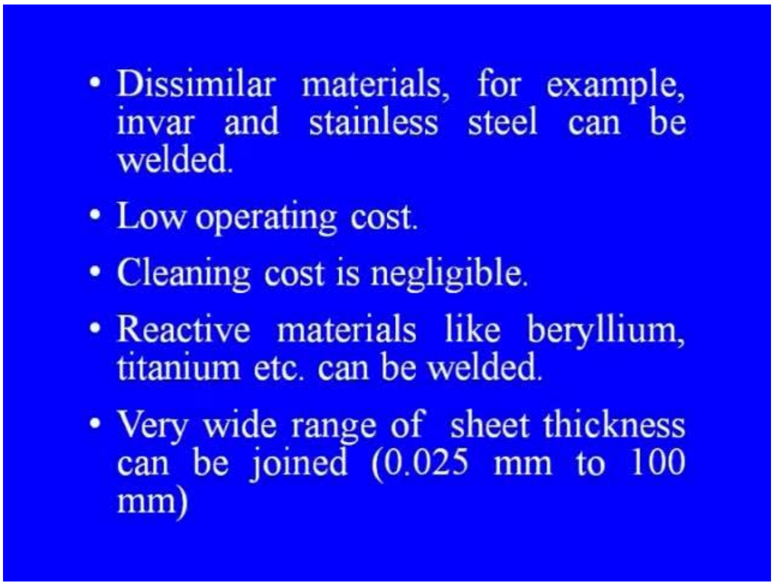

Another important advantage of this process is dissimilar materials for example, invar and stainless steel can be welded, which are otherwise difficult to weld. Then equipment cost is high, but operating cost is low, cleaning cost is almost negligible. It is a clean process. Then reactive materials like beryllium, titanium etcetera can also be welded. Very easily, very wide range of sheet thickness can be joined like, it may be as low as 0.25 millimeter and then as high as 100 millimeter thick plates can also be welded, which is quite significant. Let us note quickly the applications of this electron beam welding process as well.

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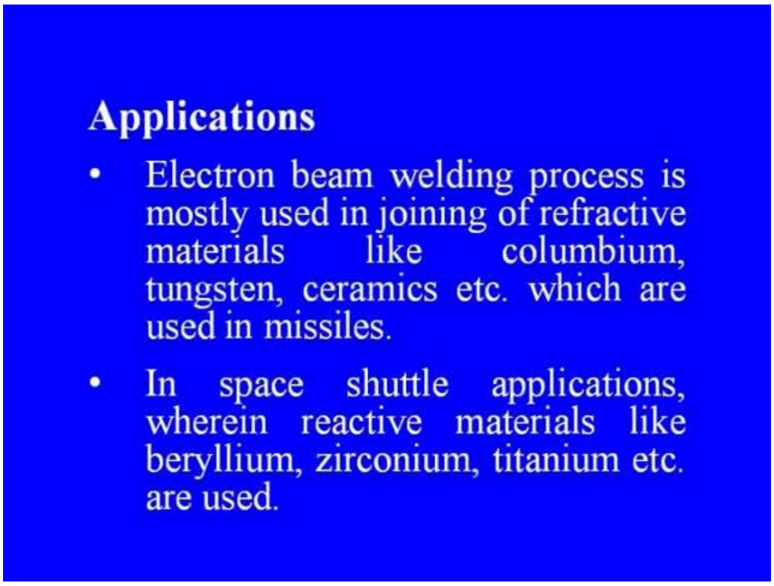

This process is mostly used in joining refractive materials like columbium, tungsten ceramics etcetera, which are used in basically in missiles. In space shuttle applications wherein reactive materials like, beryllium, zirconium, titanium etcetera are used.

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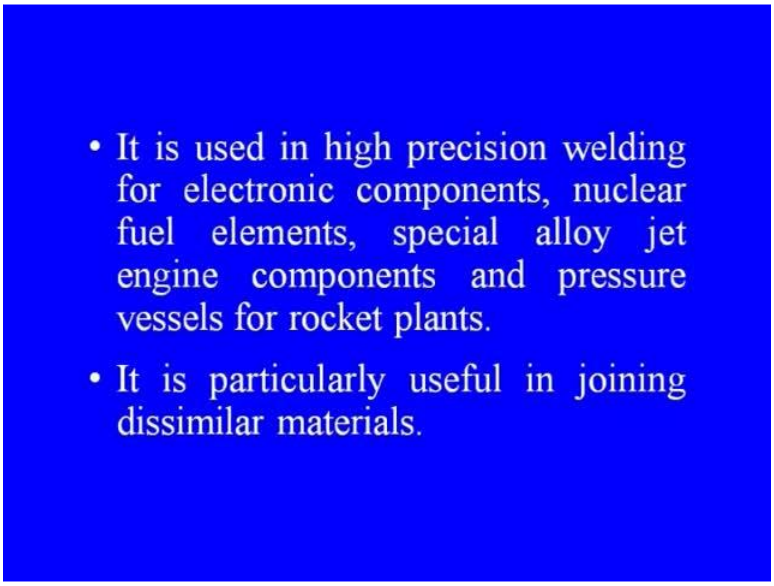

This electron beam welding process is used in high precession welding for electronic components nuclear fuel elements special alloy jet engine components and pressure vessels for rocket plans. It is particularly useful in joining dissimilar materials. Now, let us move on to another thermal based welding process, but it is a precision welding process and this is also considered as one of advanced welding processes. This is plasma arc welding process, in short it is known as PAW process.

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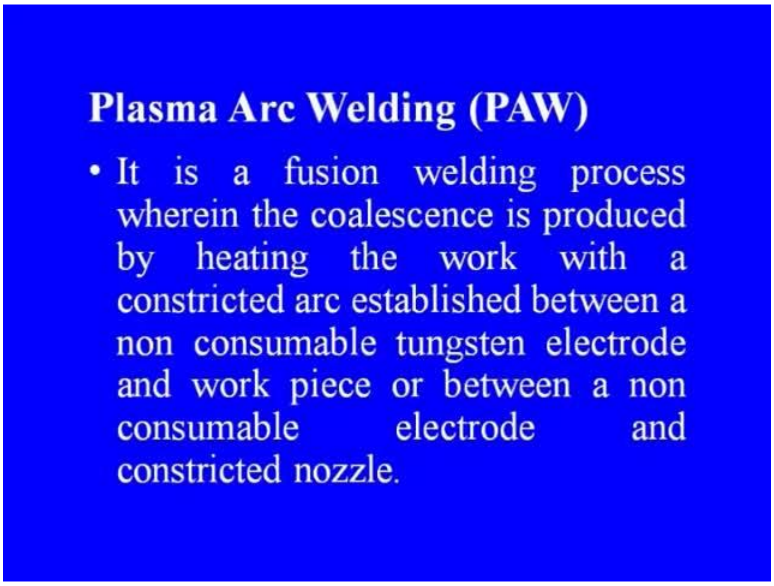

This is again a fusion welding process, wherein the coalescence is produced by heating the work with a constricted arc established between a non-consumable tungsten electrode and work piece or between a non-consumable electrode and constricted nozzle. Therefore, this is a significant in that. So, here electrode is non-consumable, that mean tungsten electrode you can keep on using for a long period time.

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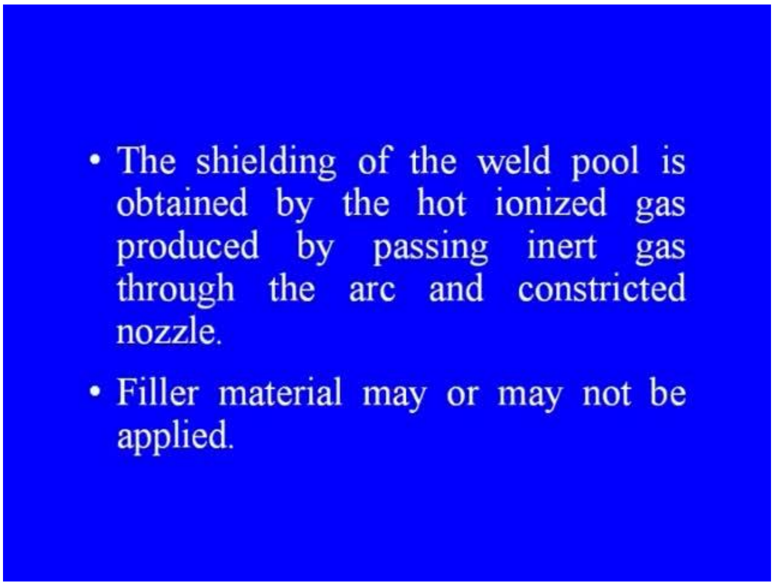

The shielding of the weld pool is obtained by the hot ionized gas produced by passing inert gas through the arc and constricted nozzle. Filler material may or may not be applied. In this process, let us see the principles of operation of this process PAW process in this work pieces.

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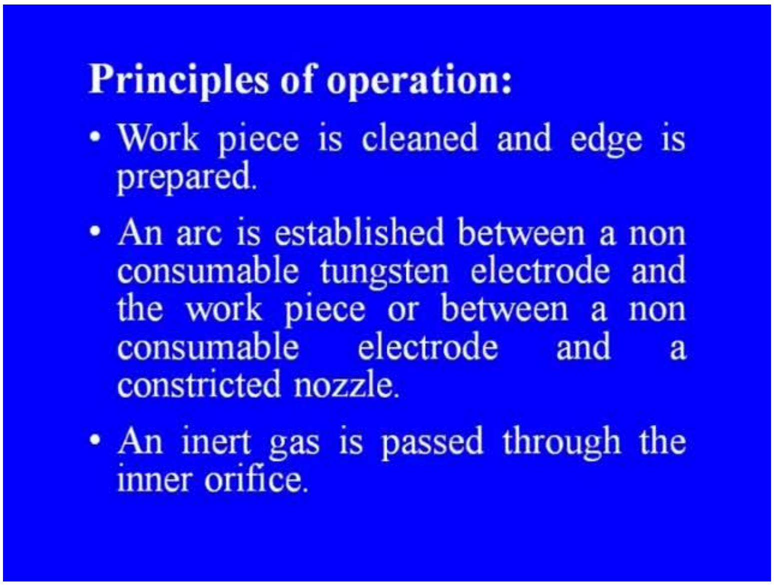

Cleaned and edge preparation is needed an arc is established between a non-consumable tungsten electrode and the work piece or between a non-consumable electrode and a constricted nozzle, which is a pre requisite. We can say the arc is to be produced and then heat will be produced as a consequence of this arc. An inert gas is passed through the inner orifice. In fact this inert gas will be responsible for producing the arc.

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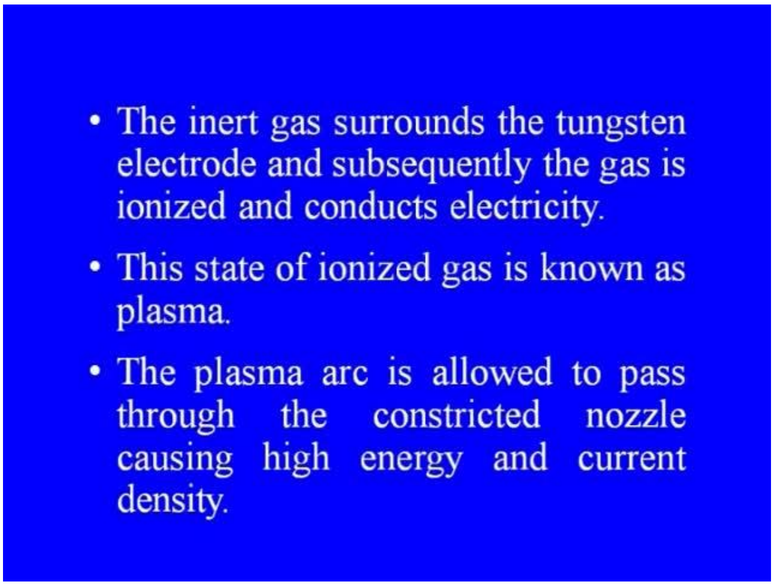

The inert gas surrounds the tungsten electrode and subsequently the gas is ionized and conducts electricity. This state of ionized gas is nothing but the plasma, what we call normal as plasma. The plasma arc is allowed to pass through the constricted nozzle causing high energy and current density.

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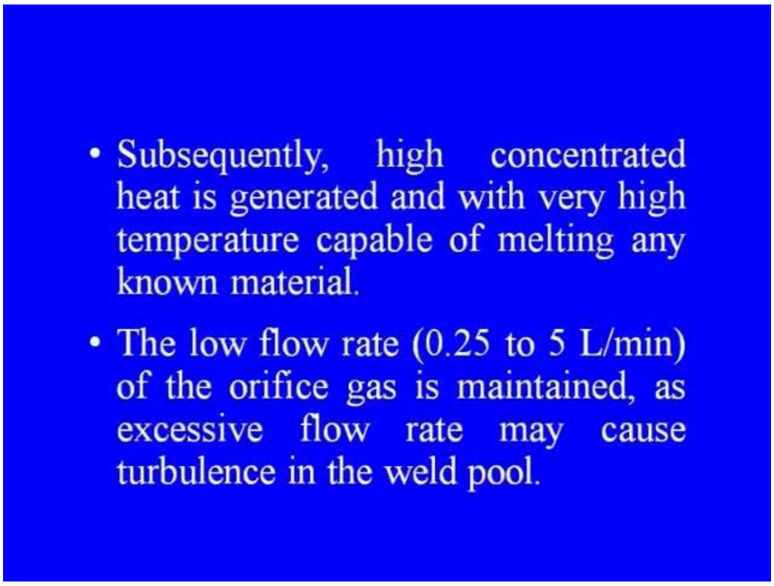

Subsequently high concentrated heat is generated and with very high temperature is also generated, which is capable of melting any known material. That means the temperature trends weld is very high, the low flow rate, which is in the order of 0.25 to 5 liter per minute of the orifice gas is maintained. As excessive gas flow rate may cause turbulence in the weld pool, therefore it should be precisely controlled within a within an allowable rate only range.

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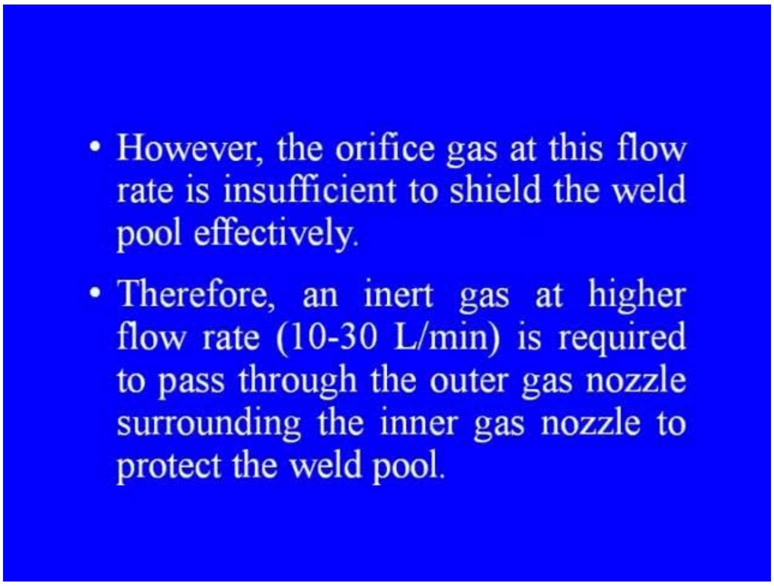

However, the orifice gas at this flow rate is insufficient to shield the weld pool effectively. Therefore, an inert gas at higher flow rate, which is in the range of 10 to 30 liter per minute, is required to pass through the outer gas nozzle surrounding the inner gas nozzle to protect the weld pool. Now, let us see the plasma arc types, welding types. There are generally two types that is being employed.

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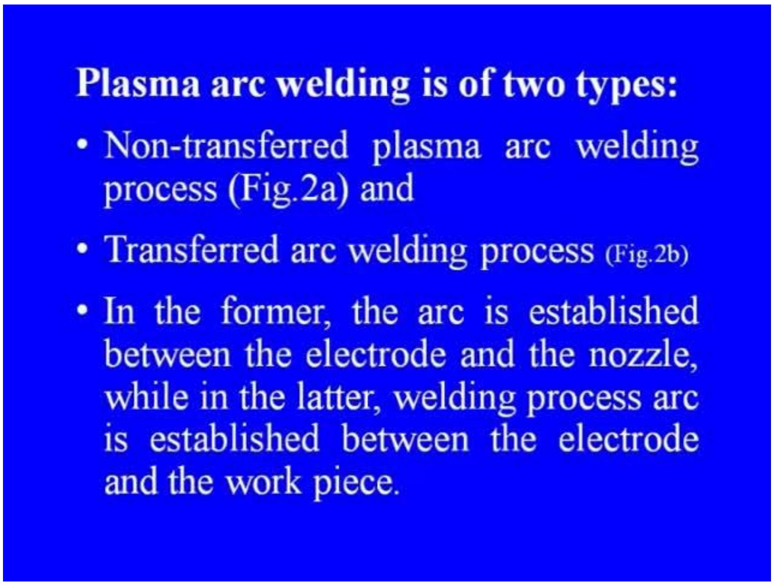

One is called non transferred plasma arc welding process and the other one is transferred arc welding process. In non transferred plasma arc welding process, the arc is established between the electrode and the nozzle. Whereas, in the transferred arc welding process the arc is established between the electrode and the work piece. That means work piece itself is considered as one of the suppliants. So, these are the schematics of these two transferred and non transferred arc.

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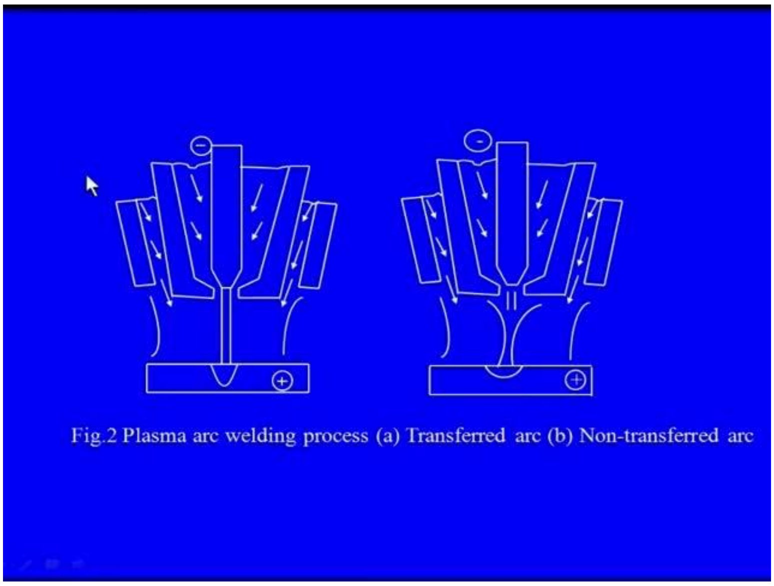
Fig.2 Plasma arc welding process (a) Transferred arc (b) Non-transferred arc

Welding system on the screen you can see. So, this is the transferred arc, here the work piece is one of the ends between, which the arc is being generated. This is the cathode and this is the arc is being produced. Whereas in case of non transferred, arc is between the nozzle and the electrode. This is being, this is being directed to the work piece.

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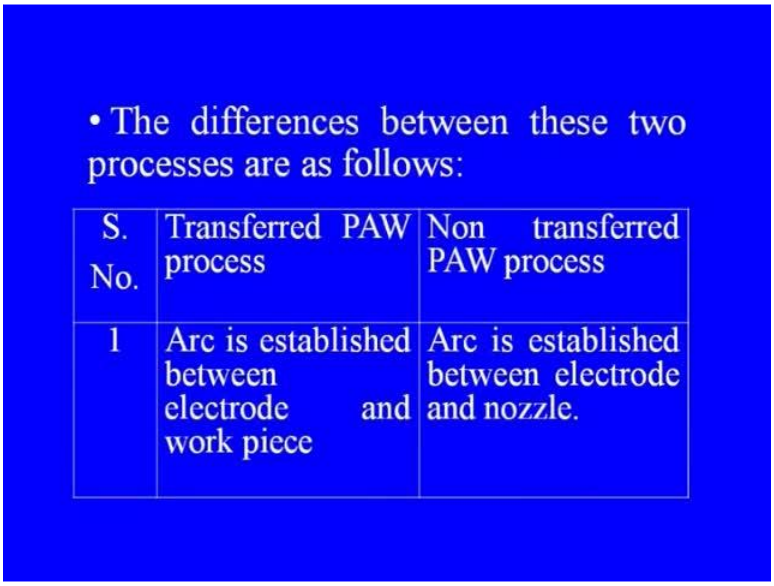

• The differences between these two processes are as follows:

S. No.	Transferred PAW process	Non transferred PAW process
1	Arc is established between electrode and work piece	Arc is established between electrode and nozzle.

If if we look at the differences between these two processes, then in transferred plasma arc welding process arc is established between the electrode and the work piece. Whereas in non transferred arc is established between the electrode and the nozzle.

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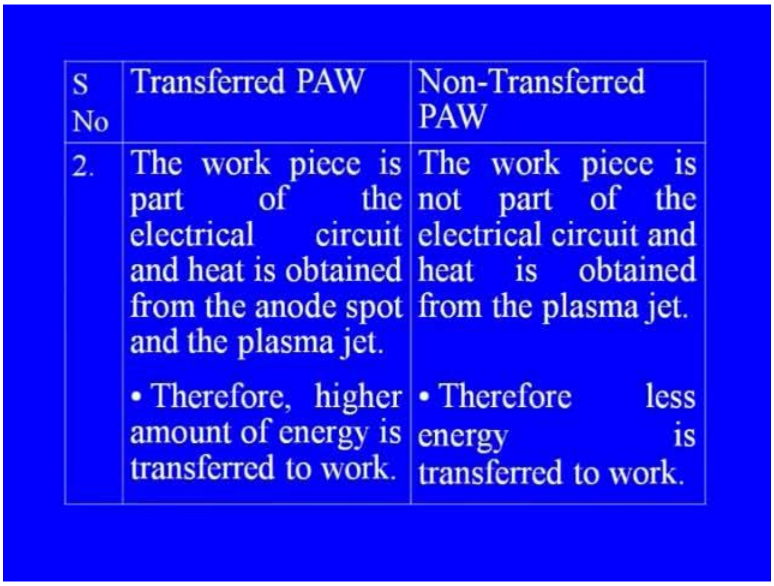

S No	Transferred PAW	Non-Transferred PAW
2.	The work piece is part of the electrical circuit and heat is obtained from the anode spot and the plasma jet. • Therefore, higher amount of energy is transferred to work.	The work piece is not part of the electrical circuit and heat is obtained from the plasma jet. • Therefore less energy is transferred to work.

This we have seen in the symmetric also, just now we have seen. In transferred arc, system the work piece is part of the electrical current and heat is obtained from the anode spot and the plasma jet. While in case of non transferred arc, the work piece is not part of the electrical circuit and the heat is obtained from the plasma jet. In transferred arc, higher amount of energy is transferred to the work, since it is directly work work piece is also a part of the circuit. However, in non in case of non transferred arc energy transferred is less as the work piece is not part of the circuit.

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3.	This process is useful for welding	This process is useful for cutting
4.	Higher penetration is obtained so thicker sheets can be welded.	Less penetration is obtained so thin sheets can be welded.
5	Higher process efficiency	Less process efficiency.

Therefore, the transferred arc system is basically preferred in case of welding applications, while non transferred arc system is basically preferred in cutting applications. In transferred arc, high penetration can be obtained and therefore, thicker sheets can be welded. It gives higher processing efficiency as well, whereas in non transferred arc a high penetration cannot be obtained, it is relatively less than that of transferred arc system. There are different sections within the torch in which, this arc is inverted.

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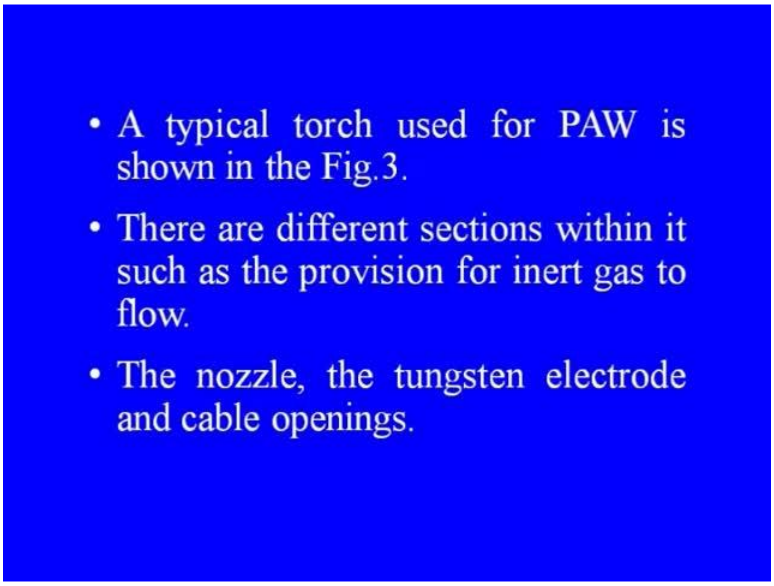

We can see the symmetric of this torch, in which this plasma arc is invented. So, there are the construction of this torch, which is highly complicated. Again, this houses cooling system, as well as power supply systems, then gas supply system. The nozzle and the tungsten electrode and cable openings are also being placed here.

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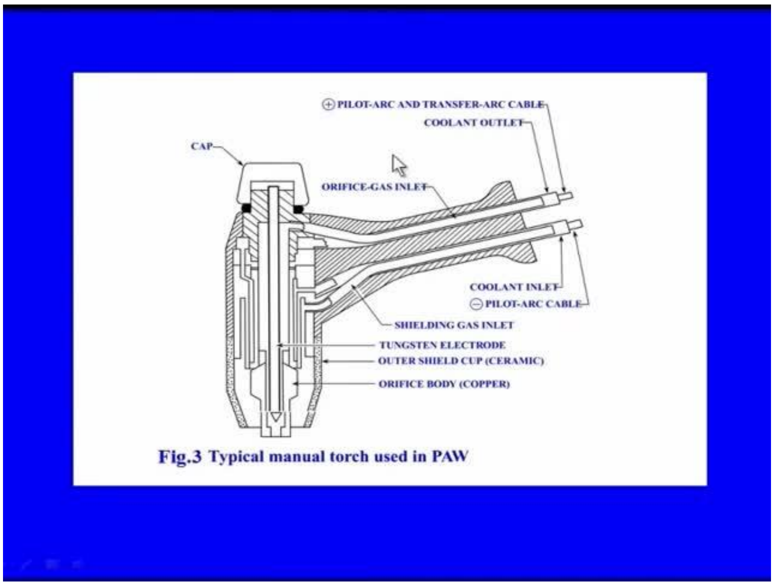

So, this in the screen we can see the torch, the convention one typical plasma arc torch, in which we can see. So, this is the inlet system for the cooling system, this is, this goes like this outlet. So, here inside the electrode, this is the tungsten electrode. This we can see tungsten electrode, which will be responsible for producing the arc basically and this is the shielded cup, outer shielded cup, cup this shields the entire arc as well as the electrical power supply system. As well this is the orifice body, this is the orifice gas inlet through which this orifice gas comes inside.

This is the inlet for shielding gas, the system inlet. Coolant inlet is inside this and this power supply is connected to this, as well as this this is to anode and this is to cathode. So, they are three connections we can see. One is for gas one is for coolant and other is for the electric power supply, similarly all these three there at this end. So, this consist of the torch system through which, through this end we can except the arc to come out.

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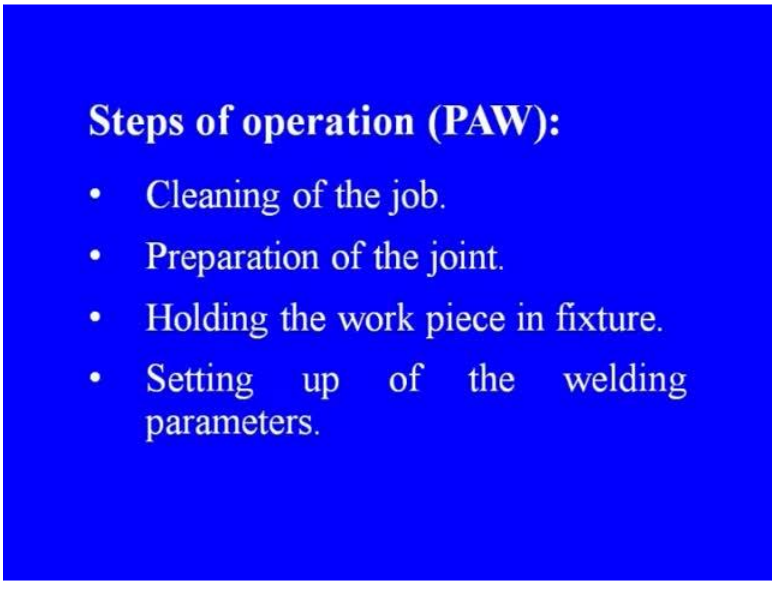

These are some typical steps of operation in plasma arc welding process. First of all the job needs to be cleaned, then the edges to be prepared, the edges of the surfaces to be joined to be prepared, cleaned and mid parallel. Then the holding the work piece in the fixture, then we should set up the welding parameters.

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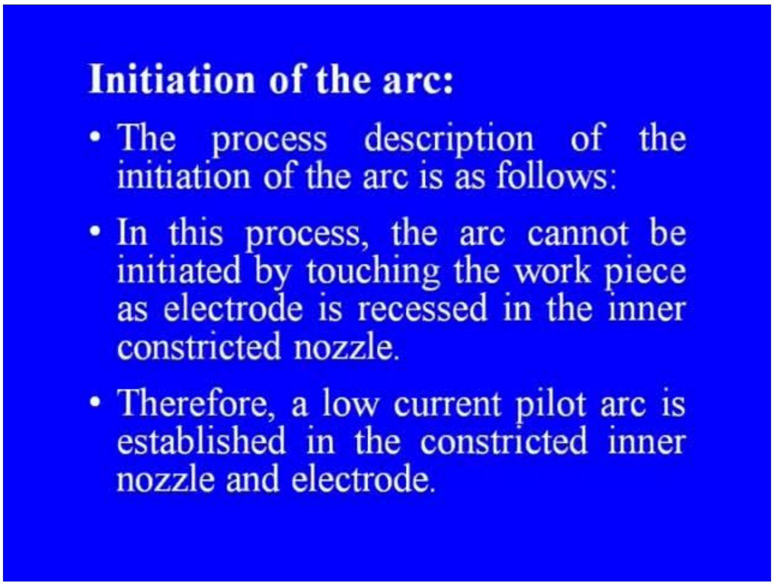

Then initiation of the arc is important and it is little slightly different also. In this particular case, the in this process, the arc cannot be initiated by touching the work piece, as the electrode is recessed in the inner constricted nozzle, that we have seen in the previous figure. The electrode is inside that and therefore, this cannot be touched and the arc can be produced as in the case of conventional arc welding processes, where generally the work piece is touched by the the electrode and the arc is initiated.

Then it is detached and the arc is continued. However, in this case it is not possible because electrode is quite inside. Therefore, a low current pilot arc is established in the constricted inner nozzle and the electrode, which will be responsible for producing the or initiation of the arc. Once it initiated, it will sustain.

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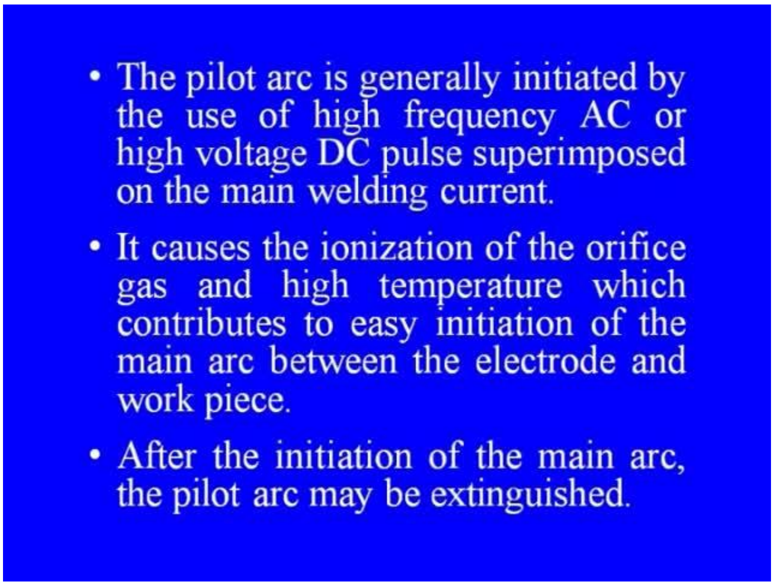

The pilot arc is generally initiated by the use of high frequency AC or high voltage DC pulse superimposed on the main welding current. It causes the ionization of the orifice gas and high temperature which contributes to easy initiation of the main arc between the electrode and the work piece. After the initiation of the main arc the pilot arc may be extinguished.

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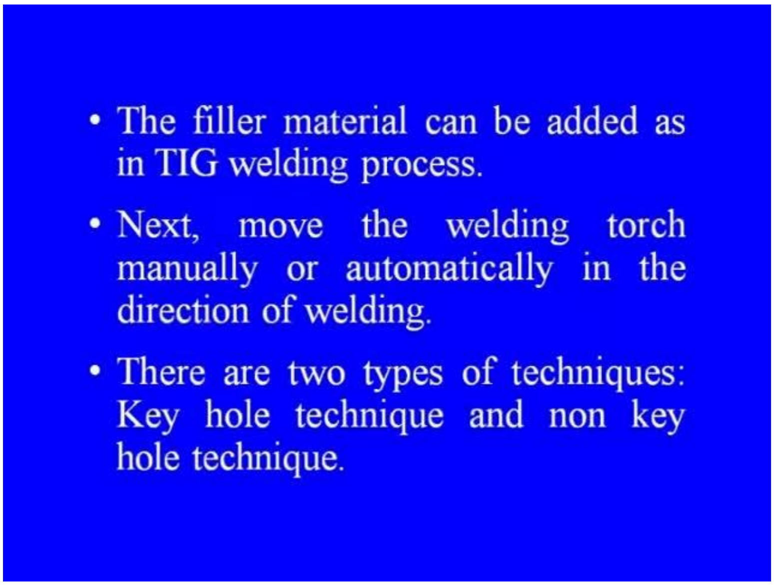

The filler material can be added as in the TIG welding process. Next, we have to move the welding torch manually or automatically in the direction of welding. There are two types of techniques involved in this process, one is key hole technique and the other one is non key hole technique.

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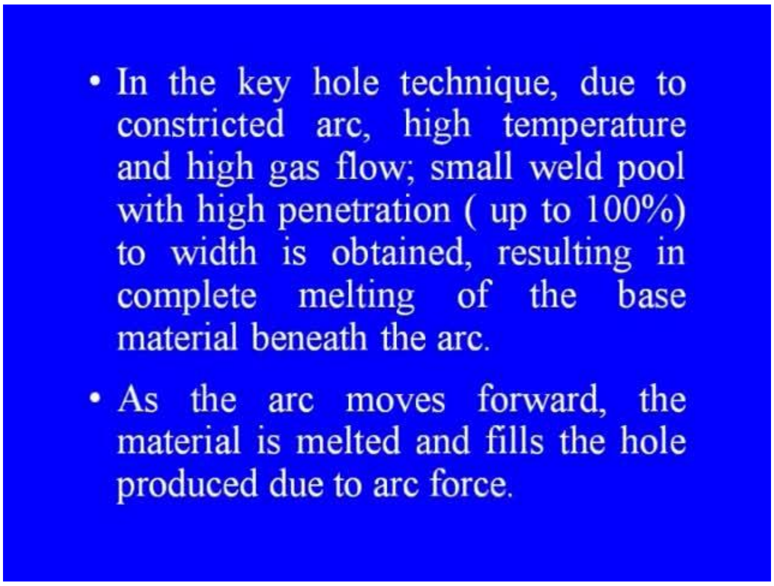

In the key hole technique, due to constricted arc high temperature and high gas flow small weld pool with high penetration, which can be up to 100 percent of the width can be obtained. This results in complete melting of the base material beneath the arc. As the arc moves forward, the material is melted and fills the hole produced due to arc force.

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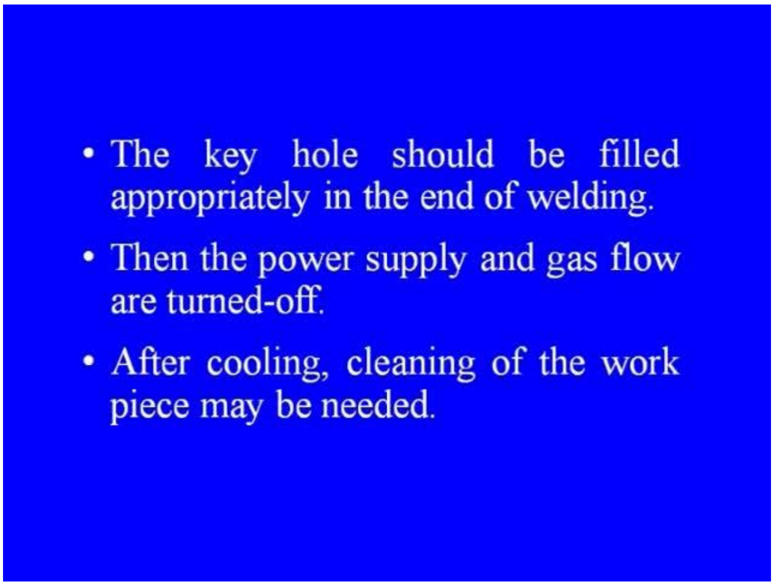

The key hole should be filled appropriately in the end of the welding. Then the power supply and the gas flow are turned off, after cooling cleaning of the work piece may be needed. Now, let us look at the equipment and the consumables required in this process.

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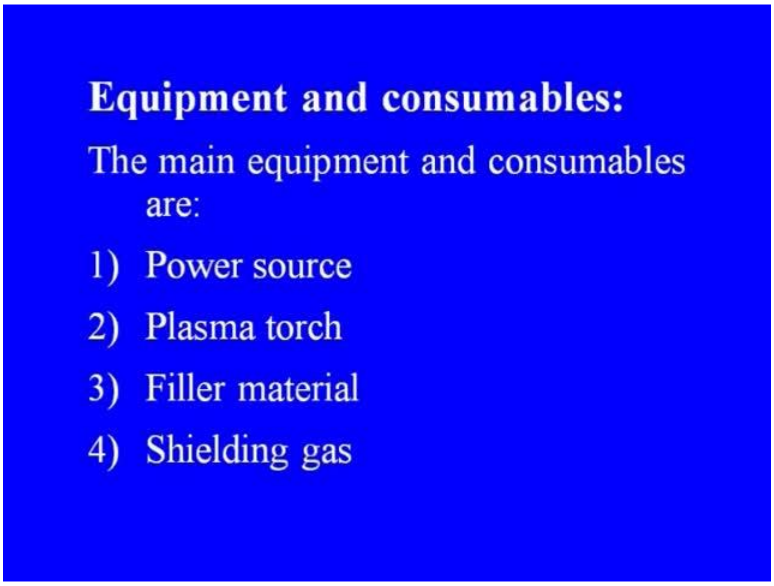

The main equipments are power source, the plasma torch, filler material, the shielding gas.

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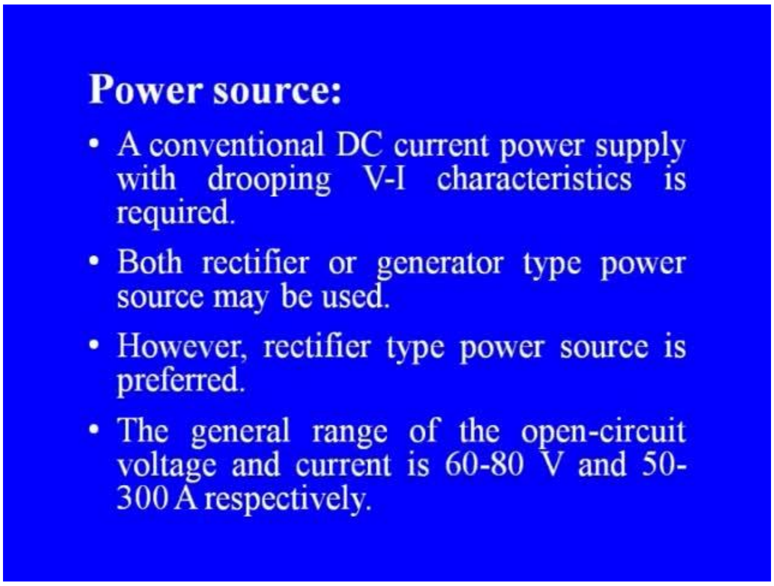

The power source is a conventional DC current power supply source, with drooping VI characteristics, current voltage characteristics. Both rectifier or generator type of power source may be used. However, rectifier type power source is preferred. The general range of the open circuit voltage and current is like 60 to 80 volt and 50 to 300 amperes respectively.

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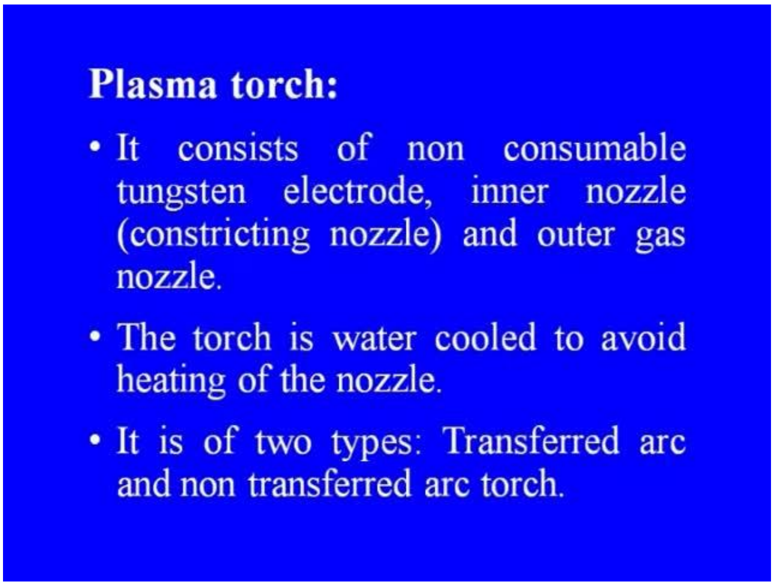

Then the plasma torch is consist of non consumable tungsten electrode, as we have already indicated. The inner nozzle will be there, which is constricting nozzle and outer gas nozzle will be there. Then the torch is water cooled to avoid heating of the nozzle, although the cathode heating is required, but the nozzle should be cooled. It is also of two types, transferred arc and non transferred arc torch, that we have already discussed.

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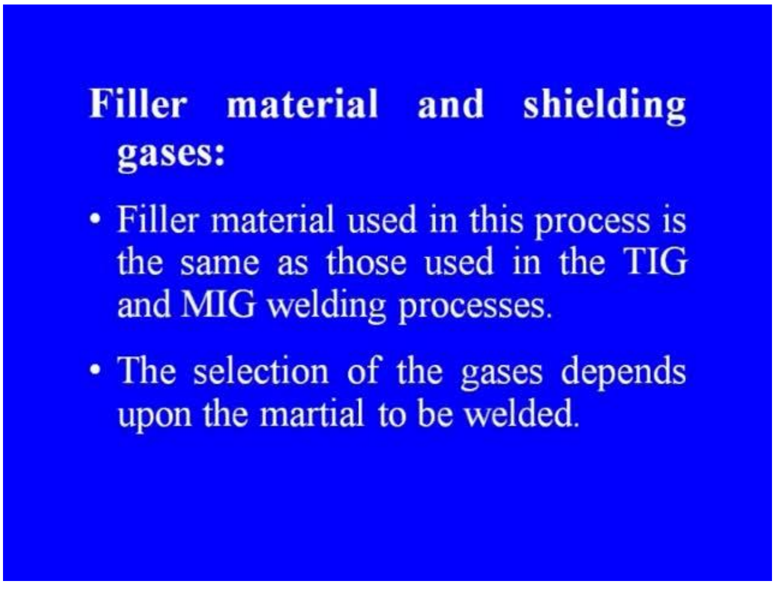

Then the mode of filler material and shielding gases: Filler material used in this process is the same as that used in the TIG and MIG welding processes, the selection of the gases depend upon the material to be welded.

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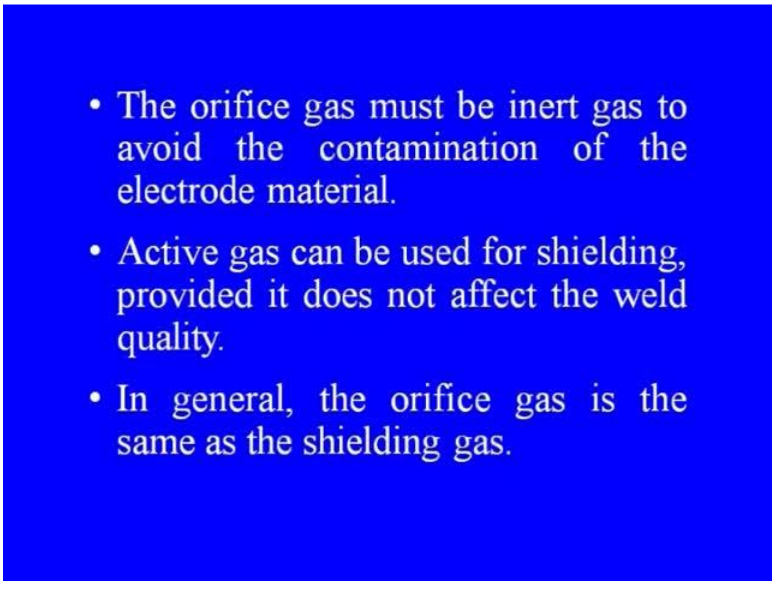

The orifice gas must be inert gas to avoid the contamination of the electrode material. Active gas can be used for shielding, provided it does not affect the weld quality in general. The orifice gas is the same as the shielding gas. Now, let us quickly look at the applications of this process plasma arc welding process.

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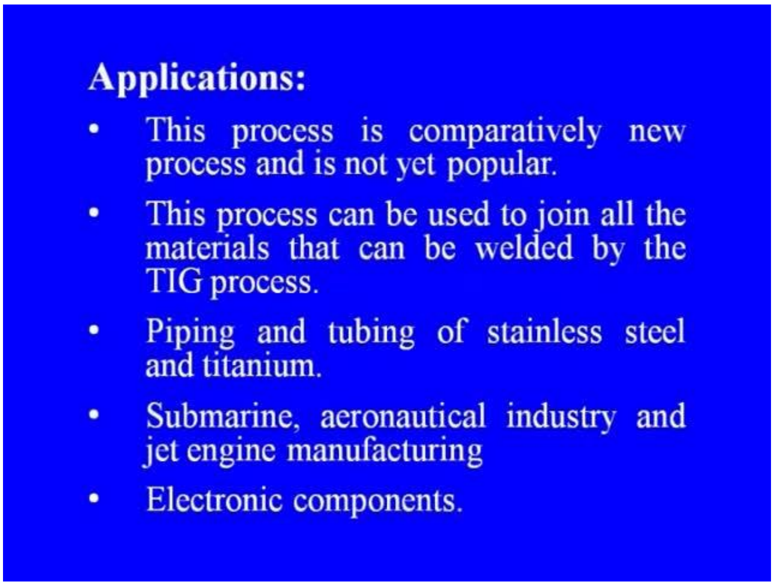

This process is comparatively new process and is therefore, not yet very popular as that of the other established processes. However, one can except that this process will come up in the popular category very soon. This process can be used to join all the materials that can be welded by the TIG process. Therefore, the versatility we can see is very high. Piping and tubing of stainless steel and titanium can be welded. Then submarine and aeronautical industry and jet engine manufacturing industry, this is used. Then for welding of electronic components also, this process is used quite widely used. Now, let us note the advantages of this process.

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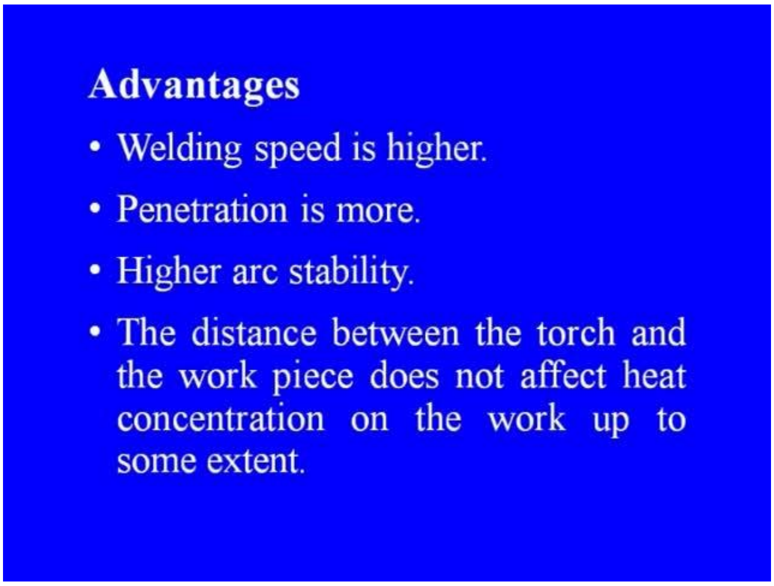

In this process, welding speed is quite high, penetration is quite more and higher arc stability can be obtained. The distance between the torch and the work piece does not affect the heat concentration on the work up to a considerable or reasonable extent.

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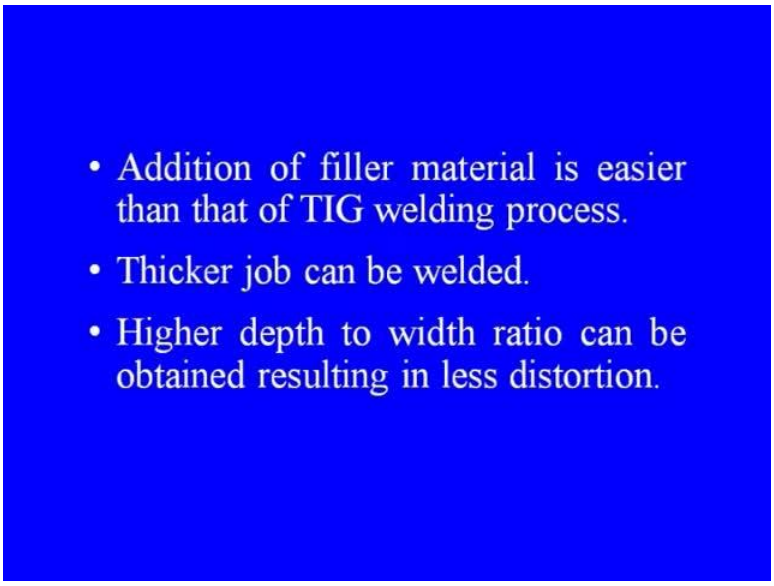

Then addition of the filler material is easier than that of the TIG welding process. Then thicker job can be welded and higher depth to width ratio can be obtained resulting in less distortion. Let us not forget to, not the disadvantages of this process as well.

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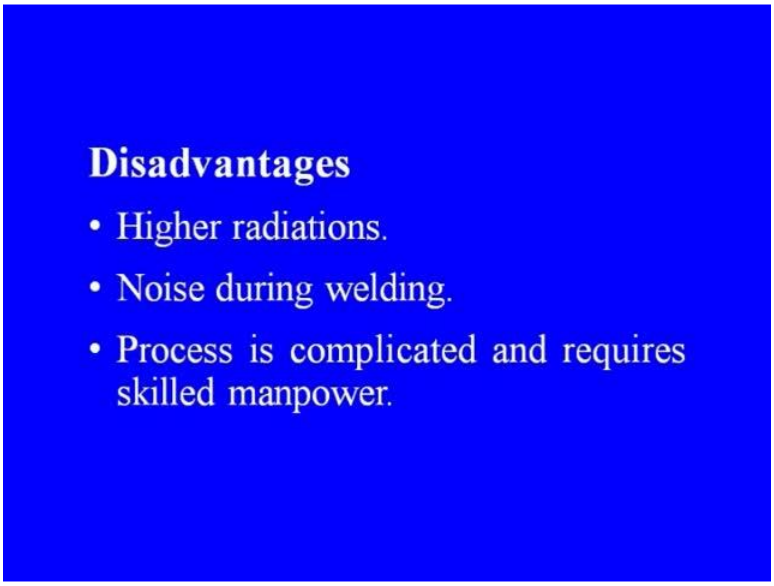

This creates higher radiations as the plasma is involved which can be a deteriority point as far as the human health is concerned. Then the noise during the welding, that is also a concerned as far as the operators health is involved, process is complicated and requires skilled manpower.

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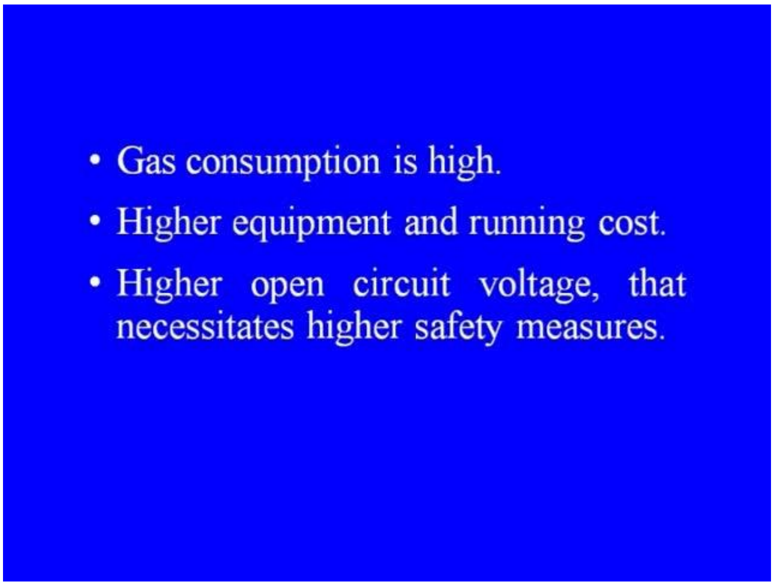

Thus then the gas consumption is high, here this shielding gas is required. Then higher open circuit voltage is required, which necessitates higher safety measures. Now, at the end, let us summarize what we have discussed today. In this particular section, we have discussed two important advanced welding processes. Metal joining processes, that is of about are thermal in nature, one is electron beam welding process, the other one is plasma arc welding process. We have discussed the principles of operation of these two processes, we have discussed the main components involved in these two processes and then their applications also. We have discussed, we hope this section was interesting and informative.

Thank you.