

Advances in Welding and Joining Technologies
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Lecture - 02
Fundamentals of Welding and Joining Part II

Now, one of the important aspect of the Arc Welding process that the how to decides or how to design the power sources for different welding processes.

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Arc Welding Power Sources

Requirement of a power source is to deliver controllable current at a voltage according to the welding process being used

Power sources can be classified in two categories

- ✓Constant current or falling characteristic power source
- ✓Constant voltage or flat characteristic power source

17

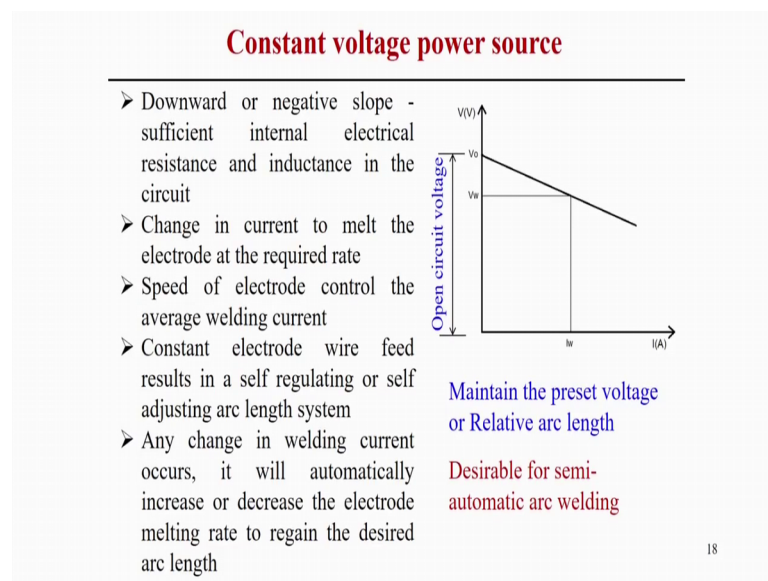
So, that definitely there is a requirement of a power source to deliver the controllable current and voltage according to the welding process used.

So, we know that specifically in welding process the power source is used in such a way, that high amount of the current and the low voltage, basically low voltage in the sense that around current raisings may be more than 100 amps and voltage is around 20 volt. So, as compared to the normal electrical connection so, but this requirement for this requirement specifically used for the welding process needs to develop the different sources, but there is another aspects also; that during the process or when you creates the arcs to maintain the arc and to continue the welding process over the time.

So, in that case 2 different characteristics of the power source can be defined. So, one is the constant current source or otherwise it is it is also called the falling characteristic

power source and second one is the constant voltage or flat characteristic power source. So, these 2 different type of the power source. How the current or voltage can be adjusted during the welding process when we use some consumable electrode or normal electrode or in the process if there is some change in the arc length, arc length or if there is a presence of any agents or this surface oxides layers present in that work piece surface; that actually tends to makes some variation in the either welding current or voltage. So, based on this the applicability of the power source in welding process is defined basically in these; two categorization.

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Let us see the first one is the constant voltage power source. What are the typical characteristics of this type of power source? And why it is required? First thing if we look into that this type of power source can be used in case of semiautomatic arc welding process; that means, semi arc welding automatic semi automatic arc welding process there is a probability of variation of any voltage or current relatively small since is automated process as compared to the any kind of manual process.

So, in that case the typically downward negative slope type of characteristics so, that characteristic defines the relation between the voltage and current. If you see from the figure that voltage and current it is follow almost linear or in other way we can say it is a almost flat characteristic of the power source; that means, relation between the linear relation between the voltage and current.

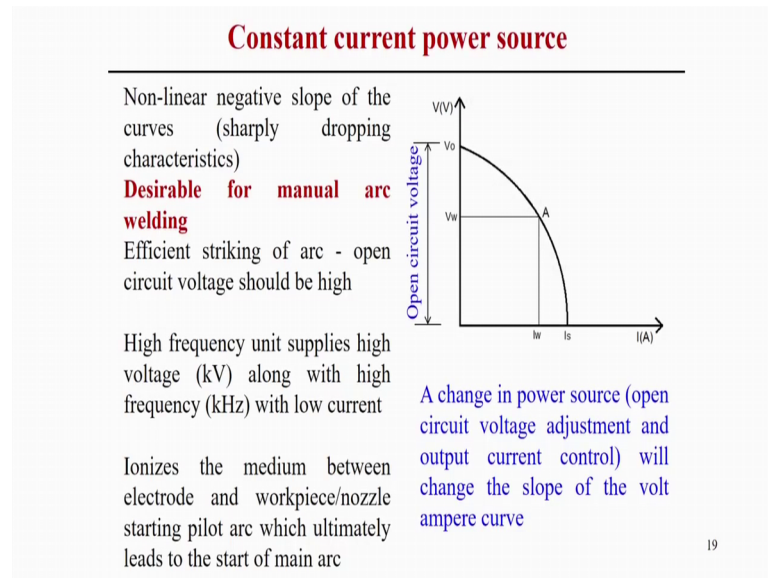
So, this type of power source is characterised by that first is the sufficient internal electrical resistance and inductance in the circuit. So, that the just small change in the current probably there may be the changes accordingly the there may be the try to maintain the almost constant voltage by changing the current.

So, change in current is accompanied by the process is basically the melt the electrode at the required rate. So, the sense of change in current is basically reflected by melting the electrode. So, that it will try to maintain the constant voltage of the power source. Speed up also speed of electron as well also control the average welding current and constant electrode wire feed basically the is the self-regulating or self-adjusting creates the self-adjusting arc length of the system.

So, in this case the pre state always try to maintain the desired arc length by maintaining the constant voltage, but if during the process if there is a small variation of the change in the arc length that is automatically adjusted by melting the electrode material, definitely in case of the consumable electrode. So, any change in the welding current occurs in this case it automatically increases or decrease the electrode melting to regain the design desired arc lengths.

So, to maintain the desired arc length it is also to maintain the constant voltage power source. So, figure if we see that from the figure that it is starts from the open circuit voltage. So, that open circuit voltage is just to start the arc welding process. And then from the open circuit from the open circuit voltage there is a drop, but drop rate is very low in this case and of course, it is a negative slope and that actually desirable characteristic of the constant voltage power source. And of course, it is more suitable for the automation of the arc welding process.

(Refer Slide Time: 06:36)



So, if you look into the another type of the power source; that is, constant current power source in this case we can see from the figure the relation between the voltage and current can be represented like that. It is a non-linear way and there is a sharp dropping of the voltage with a small change in the current. So, that is called the sharply dropping characteristic of the power source. So, definitely in this case the during welding process it is always try to maintain the constant current, but by accordingly by changing the voltage.

So, this type of power source is typically useful in case of manual arc welding process. If you look into the manual arc welding process, it is starts with the by sticking of the arc; that means, by sticking of the arc; that means, open circuit voltage is very high. And then after that after sticking of the arc then we will after that we try to maintain the constant arc between the work piece of electrode.

But manually it is not very easy to maintain always the constant arc. So, there is the highly chance of the desirable that there is may be the continuous change in the arc load. So, that is accommodated by this type of typical characteristic power source. And if we look into that definitely the high frequency unit supplies the high voltage and along with the high frequency with low current.

So, initially when you try to create the arc, that that ionizes the medium between the electrode and the work piece material. And so, that it is starts the pilot arc which

ultimately leads to the start of the main arc. So, to maintain a change with the to maintain this type of arc welding process to create the arc the it should follow this type of typical characteristic of the power source; that starts with the very high open circuit voltage. And then drop of the voltage is actually occurs means rapidly and that follow very non-linear path and also it is a sharply dropping characteristic it follow in this case.

So, this type of power source is basically desirable of the manual arc welding process. And it reflects that it in changing the power source; that means, open circuit voltage adjust and out and also control the output current. And that basically represented by the change of the slope; that represented by the change of the slope in this volt versus ampere characteristic graph of this type of power source.

So, here you can see that 2 types of the power source, one is the constant another is the constant current. So, one is suitable for the manual arc welding process that is the constant current power source is suitable for manual arc welding process and another is suitable for the automatic arc welding process. That is the constant voltage power source is suitable for the automatic arc welding process.

So, basic things is that if we try to sustain the welding process; that means, after creating the arc and to maintain the arc gap between the work piece an electrode. We need depending upon the application applicability of the whether it is manual or whether it is automatic, based on that power source can be power source can be set accordingly.

(Refer Slide Time: 10:26)

Role of shielding gas

Protecting the arc and molten weld pool from contamination by the atmosphere

- ✓ Directly use shielding gas
- ✓ Slag coverage by chemical reactions in the arc

Common shielding gases:

Argon, helium, carbon dioxide and oxygen

- 100 % for certain applications
- Mixed together in different combinations

Properties:

Reactivity, ionization potential and thermal conductivity

So, apart from this characteristic power source we can find out that 2 different characteristic of the power source. And then we can find out that there is another important phenomenon which happens in the welding process that is the shielding gas. So, basic role of the shielding gas we use in this shielding gas in the welding process, but the main role is that to protect the molten metal from contamination of by the outside atmosphere. That is the main objective of using the shielding gas.

Now, this is the essence of part of the welding process until and unless the welding happens in vacuum. So, in if it happens the vacuum there is a no question of the contamination of the molten weld pool or with the atmosphere. So, in that sense is an almost every welding process, normally different way we can protect the molten pool from the outside atmosphere; either using the direct using of the shielding gas or in different way that means, we can create the slag coverage and that is by the chemical reaction of the arc that happens during the chemical reaction of the arc. So, these are the two way two different to apply the shielding gas or to protect the molten pool.

Now, what are the common shielding gas uses? We use we have observed that the different type of the shielding gases like argon, helium, carbon, carbon dioxide and oxygen. These are the typical shielding gas is used, but oxygen cannot be used alone, but always we use the oxygen mixing with the other shielding gases.

Now, the shielding gases either we can use is 100 percent. The, if we see the shielding gas is mostly the inert type of gas. So, that it will try to avoid the make the reaction with the molten pool; that is why argon, helium these are the typical type of shielding gas we use during the welding process.

First either the shielding individual shielding gas can be used all 100 percent of the, shielding gas can be used in the for certain application or sometimes we use the mixture of the 2 different or more different shielding gases for with different combination to get the certain advantage, but the basic role of the shielding as or basic principle of the shielding gas actually relates to the reactivity or shielding gas can be decided based on the reactivity of the shielding gas with the molten pool or maybe you know during that high temperature environment.

And what is the ionisation potential of this type of shielding gas; that means, how easily it can be organised or not. And what is the thermal conductivity of this type of gas or

thermal conductivity of the work piece materials. That also play important this factors also play important role to choose the shielding gas.

But basic point of choosing the shielding gas is that; based on the the whether it is very reactive with the at high temperature environment or not. Or if whether by reacting with the work piece materials subset material whether it can produce some defect in the welded joint or load. So; based on that we can choose, the different type of the shielding gas.

Now, these are the basic role of the shielding gas, now we will try to discuss the some overall idea, but in general different fusion welding processes.

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Fusion welding	
Fusion (Non-Pressure) Pressure (Non-Fusion)	
✓ Gas Welding ○ Oxy-Acetylene ○ Air-Acetylene ○ Oxy-Hydrogen	✓ Arc Welding ➤ Consumable Electrode ○ SMAW – Shielded Metal Arc Welding ○ GMAW – Gas Metal Arc Welding ○ SAW – Submerged Arc Welding ○ ESW – Electroslag Welding ➤ Non-Consumable Electrode ○ GTAW – Gas Tungsten Arc Welding ○ PAW – Plasma Arc Welding ○ Carbon Arc Welding
✓ High Energy Beam ○ Electron Beam Welding ○ Laser Beam Welding	
✓ Chemical Based ○ Thermit Welding	

So, this fusion welding processes we know; that it is a broadly categorized this welding processes that fusion welding processes non pressure; that means, without the application of the any pressure or pressure welding that non fusion. So, without using any with; that means, pressure welding there is no fusion of the substance material.

So, what we will we focus on the only on the fusion welding processes some general idea about the fusion welding processes. So, that fusion welding is basically we can categorize this way; that gas welding name of the different gas welding processes that is oxyacetylene here acetylene oxy hydrogen. So, basically chemical sources by burning this gases they are this can produce the heat. And that heat can be used to fuse to melt the

material. So, these are the typical gas welding processes we have used for joining of the metallic materials.

High energy beam see if we look into that high energy beam welding process normally the electron beam welding process and laser beam welding process are too widely used the high energy beam welding processes. Third is the chemical based the thermit welding so in that case some oxides are used. And during the reaction it generates the heat and that heat is basically try to fuse the material. So, that is call the welding process, that is chemical based welding process. The one example of this thing is the thermit welding process.

And apart from this other at the other typical usable welding processes that is arc welding process. So, arc welding process in this case the categories in the following way that using the consumable electrode or using non consumable electrode. So, consumable electrode the electrode can be consumed due to the welding process and it becomes the final part of the weld joint. So, consumable electrode we can find out that shielded metal arc welding process that is SMAW process mostly uses, GMAW gas metal arc welding process submerged arc welding process and electro slag welding process. These are the most general the consumable electrode arc welding processes.

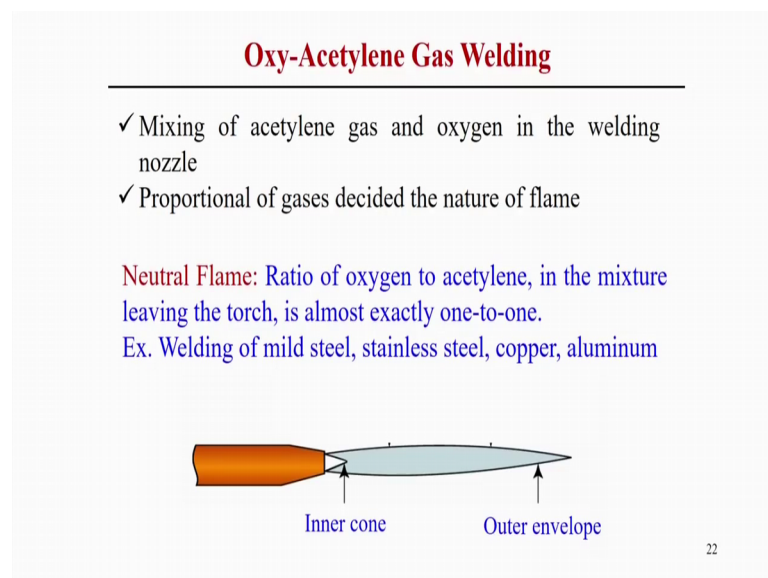
And if you look into that non consumable electrode, that is the gas tungsten arc welding process. Plasma arc welding process and carbon arc welding process these are the typical non consumable electrode process, but of course, which is a non-consumable electrode process; that means, in the sense that main electrode which creates the arc between the work piece and the electrode material.

So, in this case that electrode material is non-consumable, but it is possible to use some extra material that can be melt during the creation of the arc between the work piece and the non-consumable electrode. And that extra material becomes the final part of the weld joint. And in this way that using the filler metals the non-consumable electrode arc welding process can also be developed for example, in case of gas tungsten arc welding sometimes we use the extra filler material in this case, but the main electrode is not consumable in this case in that sense it is call the non-consumable electrode arc welding process.

So, with this fusion welding processes, we will try to give an overview of all this type of fusion welding processes; although it is the very conventional courses this is this already covered, but I am giving try to give some basic idea about this all these processes.

So, first we will start with the oxyacetylene gas welding process. So, oxyacetylene is a gas welding process. So, basically the mixing of the oxygen and acetylene in the different way different way means the in the different proportionate between oxygen and acetylene they can produce the varieties of the envelope of the varieties of the envelope of the flame.

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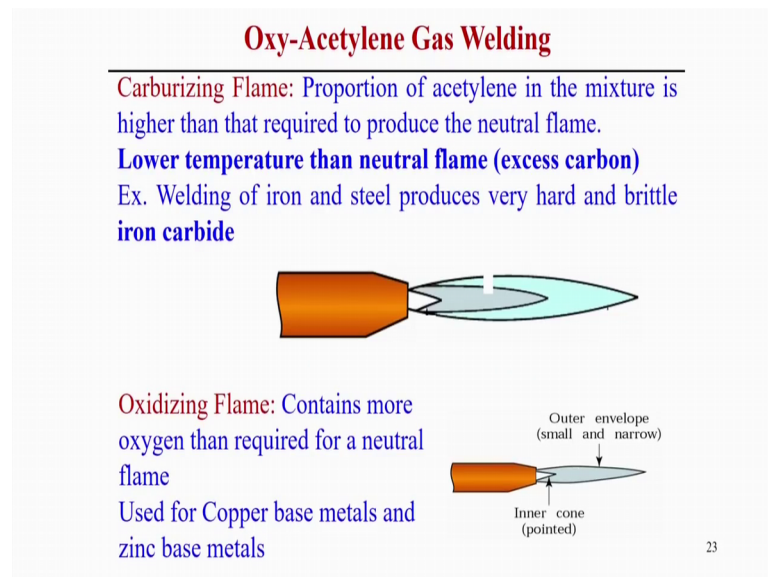
And that temperature actually depends temperature of this flame depends on what ratio where mixing between the acetylene and oxygen.

Let us see that the proportional of the gases; that actually decide the nature of the flame. First we will look into the natural flame. So, in this case oxygen and acetylene is mixed in such way that; almost one to one. And in this case if we see from the figure the typical nature of the flame that actually produces the some inner cone. And output envelope during the welding process.

So, that probably that outer envelope here actually tries to protect the heated zone from the little bit heated zone from the outside atmosphere, and inner cone actually supply the try to may melt the molten material.

So, in this case; if we see that welding of the mild steel, welding of the stainless steel, copper, aluminium all these type of materials can be welded using the simple gas welding processes. And here natural flame in that sense that we assume the copper mixing of the oxygen and acetylene can happens here can happens here also. Depending of the nature of the flame the applicability of the 2 different material processes actually can be decided.

(Refer Slide Time: 20:57)



Second one is that carburizing flame. In this case the proportion of the acetylene in the mixture is higher than that require to produce the with reference to the neutral flame so; that means, the acetylene part is more in this case and oxygen part is less in this case with reference to the neutral flame. So, definitely it can be assumed that the absence of oxygen that can be say that there may be some unborn acetylene in this case.

So, for this case sufficing sufficient bonding does not occur. So, it can produce the low temperature with respect to the neutral flame. And at the same time it can create some excess carbon can be created. So, typical applications of the neutral flame we can see that welding of the iron and steel and since excess carbon always produce the hard brittle iron carbide.

So, if there is a requirement of producing the iron carbide, in that case the use of the carburizing flame is more preferable, but the maximum temperature is lower than that of the neutral flame in this case and if you look into this figure the envelope of the flame is

like 3 different way it can creates the 3 different envelope. So, if you see the inner cone and outer envelope, but here if you see the apart from inner cone to outer envelope also created and that can be created due to the nature of the mixing ratio between the oxygen and acetylene.

So, third one is the oxidising flame. So, here if you see the oxidising flame means in this case the oxygen amount will be the more, and the with reference to the neutral flame. So, in this case definitely since oxygen amount is more. So, in this case the temperature will be the more with respect to the neutral flame.

And here you can see that from the picture we can see also that inner apart from the inner cone there is the outer envelope and the outer envelope is basically smaller and narrower as compared to the neutral flame. So, this type of flame is used when there is a high amount of the heat is required. For example, highly conductive material like copper base metals and can also be used in case of the zinc base metals.

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Shielded Metal Arc Welding

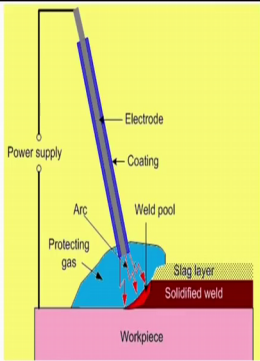
- Consumable electrode (coated with a shielding flux)
- Flux produces protective gas around weld pool
- Flux coated rod
- Slag keeps oxygen off weld bead during cooling

✓ **Advantages**

- Simple, portable and inexpensive equipment

✓ **Disadvantages**

- Process is discontinuous due to limited length of the electrodes
- Weld may contain slag inclusions
- Fumes make difficult the process control



The diagram illustrates the Shielded Metal Arc Welding (SMAW) process. It shows a power supply connected to an electrode holder, which holds a consumable electrode. The electrode is coated with a flux. As the electrode moves, an arc is formed between the electrode tip and the workpiece. The flux coating melts to form a protective gas shield around the weld pool. As the electrode moves away, the molten flux solidifies to form a slag layer over the solidified weld metal. Labels in the diagram include: Power supply, Electrode, Coating, Arc, Weld pool, Protecting gas, Slag layer, Solidified weld, and Workpiece.

24

So, this is the very basic types of the gas welding process. Now we will try to look into the other welding processes that are called the shield metal arc welding process. So, it is well known that shield metal arc welding process, but here we are try to focus on the some typical characteristics of this welding process.

First is that definitely shielding metal arc welding process is most commonly used and we can see this welding processes used in the definitely in the construction site also. So, first thing we can see that consumable electrode; can be used in this case, but if we see precisely look in to the electrode, electrode is coated with some flux. So, purpose of using this coated flux that actually tries to produce the protective gas around the weld. And then it actually helps to protect this molten pool from the atmosphere by creating the outside that creating the protective gas.

And finally, it becomes it creates the produce the slag layer of the one slag that is in weight that is lighter as compared to the molten material or may be as compared to the base material. So, that lighter metal becomes on the top surface and that creates the layer of the slag layer. So, that slag layer also other way until unless becomes cool down heat also heat also against protects this molten material during the solidification process.

So, in that case it is very most advantageous to use, the in the different way basically it is a electrode is basically supplying the extra material and the same time it is also protecting the weld zone during the welding process or as well as during the solidification process also. So, if you look into that figure there is a power supply and it is completes the electrical circuit and between the work piece and the electrode it creates the arc, and the arc is basically surrounded by the protective gas, and that protective gas actually creates from the coating of the coating over the flux coating over the electrode.

And then if we see the solidified metal, over the solidified metal there is a slag layer. So, after finishing welding process it is necessary to remove the slag layer. So, these are the very, very well-known and very stable welding process and we use most of the cases, but here the choice of the electrodes depends the because electrode material is also important factor here. The what type of material we are trying to weld and what is the that choice can be done according to the metallurgical compatibility of the electrode material to the base material based on that we can choose the different types of the electrode material.

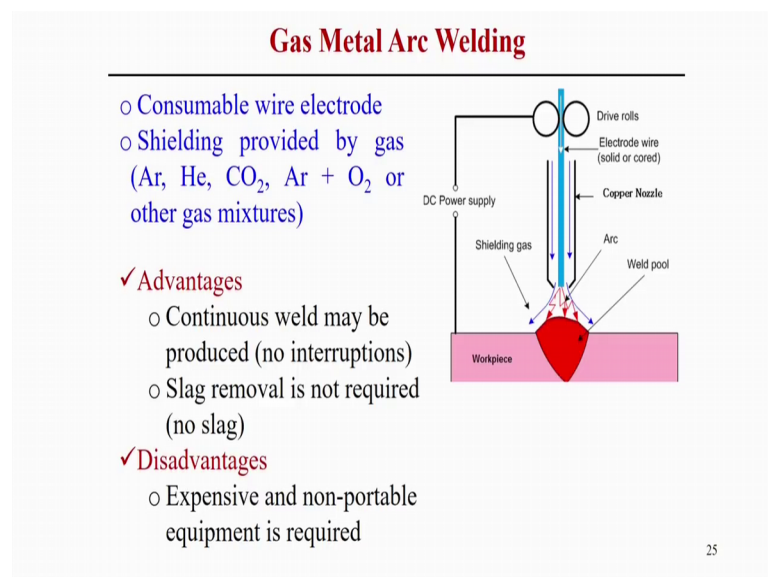
In simple way what are the advantage of this process? It is a very simple process and mostly this process is used manually, it is a very simple portable and portable, equipment and the not very costly equipment as compared to the other welding processes, but if you look in to the limitation of this process disadvantage of this process is that it is a discontinuous process because the length of the electrode is limited. So, there is a not

continuous supply of the electrode. So, once the electrode is length of electrode is over then process becomes discontinued again we have to next we need to fit another electrode. And then we can continue the process. So, that is the one limitation.

Second the weld metal content also the slag inclusion because it is the height this given this high temperature phenomena molten metal may contain some kind of the some amount of the slag, slag material may also remain within this zone. So, that is also another disadvantage and because during the welding process it creates the protective gets gas and that is very, that is why it is very difficult to make it as a make the process control. So, in that sense this process can it is not process this process is not converted to the alternating process that is why, mostly use for the manual process.

Second if we look into the other welding process that is gas metal arc welding process.

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So, with reference to that shielded metal arc welding process the in gas metal arc welding process here, apart from this we can use the continuous supply of the electrode material. So, that electrode is basically the electrode is used is a continuous weld and that that is wanted in the other places and it is externally or separately it is supplied to the process continuously. So, in that sense it is a very we can say it is a continuous process as compared to the shielded metal arc welding process.

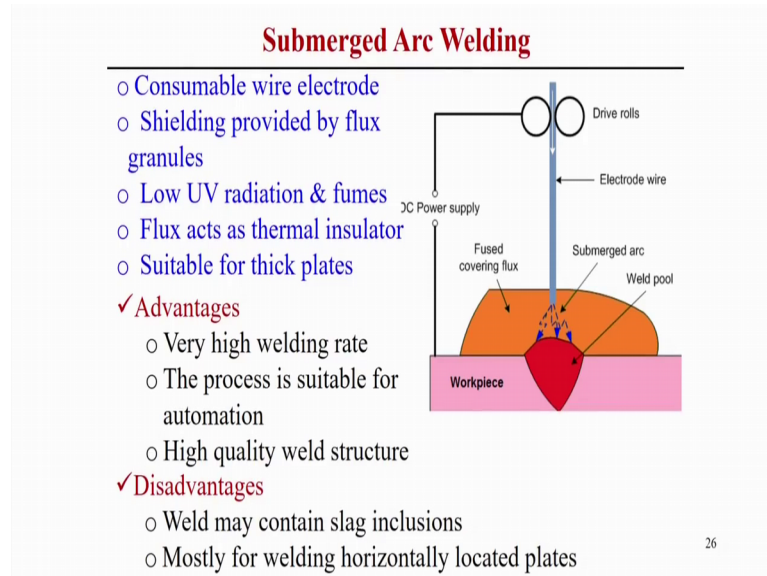
So, definitely gas metal arc welding process we use the consumable electrode. And in this case we generally not use the flux, but directly we can use the shielding gas here to protect the molten pool. So, shielding gas like argon, helium, carbon dioxide or mixing of argon oxygen or any other gas other gas mixture is normally used for gas metal arc welding process, but commercially we generally use in gas metal arc welding process for welding of the steels normally carbon dioxide can be used because carbon dioxide is cheaper as compared to the other inner type of shielding gas.

So, if we look into the process that it is also create the electrical circuit, that to the arc is created between the electrode and the work piece. And here if you see there is a apart this along with the supply of the consumable electrodes over some drive rolls the same times there is a supply of the shielding gas used to the same nozzle. So, that shielding gas actually protect the molten pool thing and normally copper nozzle is used here and this wire sometimes we use, either the electrode wire is either is the solid or solid wire definitely use and sometimes it is also used in the form of the some coating maybe d1 over the solid wire.

So, this process if we very precisely look into; what are the advantages of this process. We can find out that it is a very it is a continuous welding process no interaction, like shielded metal arc welding process. And of course, in another advantage is that it is not necessary to remove the slag. So, slag after the finishing of the welding process slag removal is not required. So, that is why in this way this gas metal arc welding process is possibly can be or can be automated as in the automated and in that sense it is advantageous as compared to the shielded metal arc welding process.

But if we look into the disadvantage in general that it is a definitely expensive as compared to the shielded metal arc welding process, because it is also necessary to drive the electrode material according to the consumption rate. That should be adjusted to the consumption rate during the welding process. So, in that way it the equipment is little bit expensive as compared to the shielded metal arc welding process.

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Then will one of the most widely used welding process that is submerge arc welding processes. In this case also we use the consumable wire electrode and, but the difference is that, that shielding is actually provided not by the shielding gas is a provided by the granules of the flux is used. In this case if we look into this picture though like gas metal arc welding process here also some drive roll is there and that actually supply the drive roll is basically control the consumable electrode and, but the shielding is happen using the flux granules.

And this low and it produce the low ultraviolet radiation and also fumes as compared to the shielded metal arc welding process. And flux actually acts as the thermal insulator and suitable for this process is mainly suitable for the very thick material. So, it is a large volume of the welding is required. So, in that case submerged arc welding is the good choice of that.

So, submerged arc welding process also developed that not only the single wire twin wire 2 wires can be used also so instead of single wire. So, it is a kind of taking the advantage of the submerged arc welding process combining these things that both shielded metal arc welding process. So, using the flux and takes the advantage from the gas metal arc welding process. So, here we use the consumable electrode, but in the form of the wire.

And here if you see similar electrical circuit is put between the consumable electrode on the work piece, but it is a huge flux actually cover the weld zone. So, that is since the flux granules cover the weld zone. So, in this case the efficiency of the process is, efficiency of the process is relatively higher as compared to the arc welding or shielded metal gas metal arc welding or shielded metal arc welding processes, but if you look into that typical advantages that it is a very high welding rate.

So, as compared to the shielded metal arc welding gas metal arc, welding or shielded metal arc, welding process. And this process is basically it is possible to do the suitable for the automation or it can be converted to the automatic system and high quality weld structure is can be produced. And main advantage is the efficiency of this process is very high as compared to the gas metal arc welding or shielded metal arc welding processes, or at the same time the very high welding rate can also be done using the twin wire also; that means, two wires can also be used in this process to get this to improve the rate of the welding process or material deposition process.

And of course, this process is designed or developed specifically for or suitable specifically for the very when there is a requirement of the very high thickness or large volume of the metal material, but also having some disadvantages, that weld may contents the as in as in general other processes also. That it content the slag inclusion within the weld zone also, and mostly used for or suitable for the horizontally located plate. So, these are the two typical at these advantages of this process.

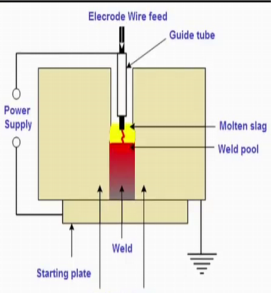
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Electroslag Welding

- Workpiece is filled with a welding flux
- At start, arc is created to melt the flux powder and forms molten slag
- Molten flux short circuits the arc
- Heat is generated due to ohmic heating of the slag
- Slag circulates and melt the consumable electrode and workpiece edges

✓ **Advantages**

- High deposition rate
- Welding of thick plates
- Low slag consumption
- Low distortion



The diagram illustrates the electroslag welding process. It shows a vertical assembly where an electrode wire is fed through a guide tube into a chamber filled with molten slag. A power supply is connected to the electrode wire and the workpiece. The workpiece consists of a starting plate and welded pieces. A weld pool is shown at the bottom of the slag chamber. Labels include: Electrode Wire feed, Guide tube, Molten slag, Weld pool, Power Supply, Starting plate, Weld, and Welded pieces.

✓ **Disadvantages**

- Coarse grain structure of the weld
- Low toughness of the weld
- Only vertical position is possible

27

And now we will look into that electro slag welding process. So, in this process the work piece is filled with the welding flux. If you see the welding flux and, but at the start the arc is created to melt the flux powder and that actually forms the molten pool. And then after that heat is generated the due to the molten flux become short circuit the arc and then heat is generated due to the ohmic heating of the slag.

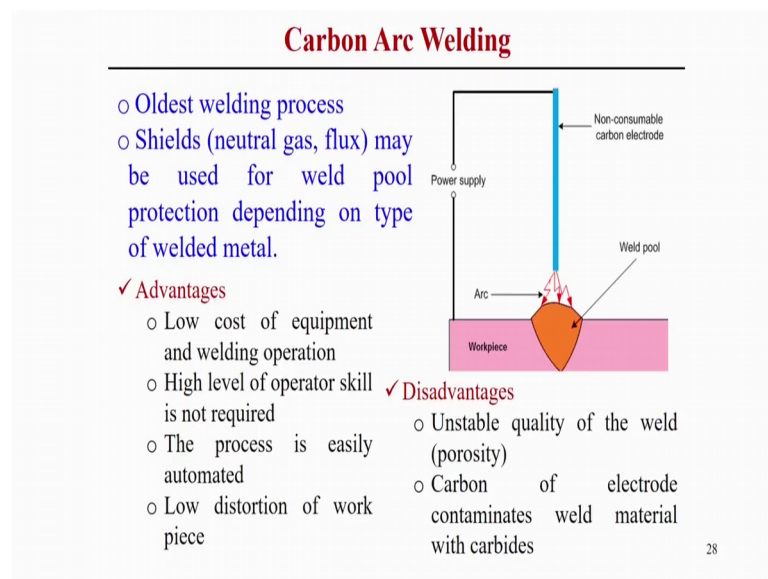
So, then slag circulates and the molten circulates within the zone and the melt the consumable electrode and basically finally, it is join the work piece edges. So, we look into this figure, that we use the electrode wire and the power supply; that means, to make is the electrical circuit. The guide tube also there and that actually wire electrode and guide tubes the flux making this thing and produce the molten. This in this the in this case the advantage is that it produce the molten slag and then indirectly that molten slag is actually produces the weld pool.

So, in this case if we look into the main advantage of this that that high deposition rate is possible, even also welding of the very thick plates also possible, that slag consumption rate is typically low and low distortion is possible in this processes; that means, the electro slag welding processes is almost the similar kind of advantage of the submerged arc welding process, but if you look into the other aspects this thing the distortion point of this thing.

First point is that this process can be done only over the in the design specifically for joining of the in the vertical position of the place, basically when keep the vertical position of the plate and then keeping two plates as a vertical position and then from the bottom plate we just keep on welding and the electrode is basically simply keeping upward direction and then upward direction and at the consequently it make the welding in the backside.

So, that this process is specifically advantages for joining of the vertical to vertical plate and in the large scale; that means, large volume of the molten pool is required in this case this process is more suitable. So, apart from the electro slag welding process also there are other welding processes. That is the more simple welding process that is called the carbon arc welding process.

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It is a very oldest welding process shields may be used for the weld pool, protection depending on type of the metal shielding can be use also; that means, either natural gas or flux can be used in this processes, but the basic principle of this process is that powers same as the other welding processes the work piece power supply, the work the arc is created between the work piece and the electrode using the non-consumable carbon electrode.

And it produces the weld pool and in this case if you see that non consumable carbon electrode is basically used and that this process has been developed long before than the other processes.

So, but if we typically look into the advantages of this process is the first is that; low cost of the equipment. So, simply we can use the non consumable carbon electrode and shielding can also be done either flux or maybe we can use the natural gas. So, in this process that is one of the advantages that, low cost of the equipment and therefore, not required very high operator skill is not required. And these processes can be easily automated, but because this process is not very complicated and low distortion work piece can also be achieve.

Since this is one of the one of the oldest welding process. So, that it is a very simplified way can be applied, but definitely if we look into the very precision of the welding process in the sense less defect and other way try to produce the less amount of the defects, probably then looking into that aspect the other welding processes has been better choice as compared to the carbon arc welding process.

But precisely looking into the disadvantage of this process that; is that mainly the quality of the weld joint. So, in terms of that it is not suitable for the when you try to expect the high quality welding joint processes has is already there, but one point of that, one point is that the carbon of the electrode actually contaminates the weld material with making formation of the carbides, because since carbon is acting as an electrode. So, at high temperature there may be the possibility of the transfer of the carbon atom and that creates the carbides in the work piece metal.

So, if it is the requirement of to produce the any carbide on the work piece metal probably in that sense this welding process is more suitable as compared to the other welding processes. Now, the most usable another one of the most usable welding process that; is gas tungsten arc welding process.

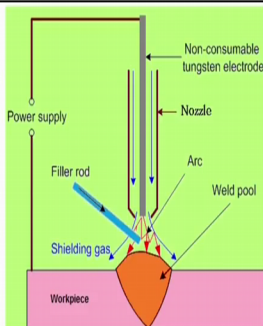
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Gas Tungsten Arc Welding

- Non-consumable electrode
- With or without filler metal
- Shielded by inert gas (Ar, He, N₂)
- Used for thin sections of Al, Mg, Ti

✓ **Advantages:**

- Weld composition is close to that of the parent metal
- Relatively high quality weld structure
- No slag formation
- Thermal distortions of work pieces are minimal due to concentration of heat in small zone



✓ **Disadvantages:**

- Low welding rate
- Relatively expensive
- Requires high level of operators skill

29

In this process we use that non consumable electrode and of course, non-consumable electrode, but with or without any extra filler material can be added in this process. And shielding is done generally argon helium and nitrogen that is one type of the inert type of the gas and specifically used for this process when it is a very thin section or very small weld join is required in this case the gas tungsten arc welding is a good solution.

Now, if you look into this from the figure that, power supply is similar to other welding processes between the arc can be created between the non consumable electrode and the work piece material shielding gas is required. And the filler roll may or may not be used depending upon the application. So, the non-consumable to the along with the non-consumable electrode that there is a passes through the nozzle and the also the shielding gas also passes through the nozzle.

So, this is the may be without using the any kind of using the non-consumable electrode this is one of the more simple a simplified welding process, but more power more usable welding process in the sense that it is having the typical advantages; that since there is no need of using some consumable electrode or if there is no need of use any filler material.

So, only by supplying the heat and fusing these two materials so, material composition is almost close to that of the parent material. But of course, the nature of the solidification behaviour of the specific material that may be bring some structurally different from the base material, but composition may be the same.

Relatively high quality welded structure can be possible. So, no slag formation as compared to the other welding process since we are using only in the shielding gas and it may not become part of the final weld joint. So, thermal distortion of the work piece can be minimised because the heat can be concentrated in a very small zone as compared to the consumable electrode like gas metal arc welding or shielded metal arc welding process.

So, in general the shielded metal arc welding or gas metal arc welding process definitely the concentration of heat depends on the size of the electrode, but in that sense the size of the electrode can be control is a in case of gas tungsten arc welding process, that can be done the different shape of the nozzle tip and accordingly heat can be concentrated and of course, in other way heat also depends of the shield gas product also.

So, in that point of view that; the gas tungsten arc welding process is one of the most widely used welding process specifically when you try to join is the very thin metal and there is no need of any filler material, but disadvantage is that low melting rate as compared to the other welding when there is uses of consumable electrode, relatively expensive as compared to the I can say that carbon arc welding processes and it is also requires high level of the operator skill; that means, to maintain the arc gap or to move the torch then high operating skill is required to get the successful weld joint from this processes.

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Gas Tungsten Arc Welding

- ✓ Workpiece in a protective inert gas atmosphere
- ✓ Any filler material supplied externally
- ✓ To increase melting point of electrode – thorium or zirconium is added to tungsten
- ✓ DCEN is normally used
- ✓ Welding Al and Mg – AC is used
- ✓ Ar is most commonly used shielding gas
- ✓ N₂ is used for welding copper

So, apart from gas tungsten arc welding process we can look into the other aspects of the gas tungsten arc welding process. One thing is that work piece in a protective inert gas work piece remains in the protective gas atmosphere. And next is the any filler material is used with which can be used externally. So, there may or may not be required any filler metal or may be filler metal may not be the part of the main welding system.

Sometimes to increase the melting rate melting point of the electrode. So, that since in this process we use the non-consumable electrode is objective maybe to increase the melting point of the electrode, and that can be done using the thorium or zirconium is added to the tungsten that actually that is basically useful or helpful to retain the high hot hardness even at very high temperature.

So, in that case we generally use 2 percent oriented tungsten electrode in gas tungsten arc welding process just because of that in for this material the melting point is very high. So, that it we will try to reduce the wire of the electrode, at the very high temperature or melting of the electrode.

But in the when we try to look into the that we use we can see there is a electrical circuit is there power supply. And then here work piece and that it is create the circuit. So, whether the electrode, what is will be the polarity of the electrode? Uh that can also be changed in gas tungsten arc welding process. Normally DCEN; that means, direct current electrode negative is used in this case, but of course, depending upon the application direct current electrode positive can also be used or ac current can be used instead of the only of the DC current.

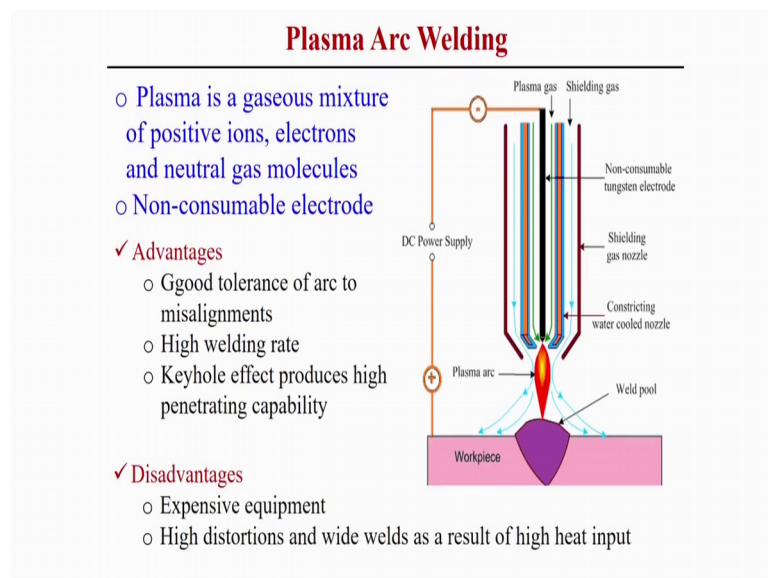
Normally welding of the aluminium and magnesium and their alloy normally ac current is preferred because alternative current is make the cleaning action in the half of the cycle during the welding of this material. So, there is a continuous change of the polarity positive and negative when we use the ac current, but typical point of this process is the most usually shielding gas is the argon material, but sometimes use the nitrogen for welding of the copper material. So, these are the typical characteristics or typical points that are related to the gas tungsten arc are welding process.

Now, we will look back to another arc welding process that is called the plasma arc welding process. Here if we see that plasma arc welding process it is always it is try to take the advantage of the gas metal arc welding process, almost similar configuration;

that means, they use the non-consumable electrode creates the electrical circuit, but here we can use that another extra shielding gas that is call the plasma gas basically that actually creates the arc and maintains the arc. And that actually helps to melt the work piece material.

So, with respect to the gas tungsten arc welding process and all the all the general components of the gas tungsten arc welding process here the addition of the extra plasma shielding gas, but let us look into this figure, how this process has been developed?

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The plasma arc welding process here you can use the DC power supply and create the positive and negative and here in non-consumable tungsten electrode we can use here and shielding gas also supply, but inside there is a plasma gas plasma gas also be supplied here.

So, basically passing through the electrode, there is a current when passes through the electrode it creates the pilot arc and then after that the it creates the arc due to the passing of the plasma gas and then high temperature has been created and finally, it creates the plasma arc between the nozzle tip and the work piece material.

So, what is the advantage of with respect to the gas tungsten arc welding process in case the plasma arc welding process. In general the position of the electrode or torch of this plasma arc welding process can be designed in such way that; it can produce the very

constricted arc as compared to the gas tungsten arc welding process, because gas tungsten arc welding process the arc is created between the work piece and the electrode tip of the electrode.

So, depending of the tip of the electrode the shape of the arc can be decided mainly, but in this case the apart from the electrode tip there is a the plasma gas is the main gas that actually creates the arc between the work piece. So, that plasma gas application of the plasma gas can be constricted in a very small zone. So, that is why very constricted arc can be created using the plasma arc welding process.

So, even from on the other welding on the arc welding process only in the plasma arc welding process it is possible to produce the keyhole mode; that means, high depth of penetration can be welded using the keyhole mode plasma welding process. So, here look in to that typical points of this arc welding process first is the, what is the plasma? Plasma is a basically gaseous mixture of positive ions electro and neutral gas molecules. And that plasma gas is actually create the arc between the work piece and electrode material.

And here also like GTAW here is the non-consumable electrode by specific advantage is that, it is a good tolerance of the arc to misalignment if there is a misalignment it can be adjusted by the creation of the arc. And high welding rate can also be done in plasma and keyhole effect can also be produced this is the only arc welding process, where keyhole mode effect can be produced. That produce that actually that actually penetrate is the high penetrate in the for high thickness material.

So, this is these are the typical advantage, but other advantage of this things plasma arc welding can also be, nowadays the plasma arc welding can also be developed in the micro plasma range in the sense that that is called micro plasma arc welding processes. So, such that the electrode current that welding current can also be reduced to less than 10 amperes and even it is can be controlled the even for the in the range of the milliampere.

So, it is controlled arc with this controlled current the arc can also be control in even in the model of the pulse or continuous mode; and that small amount of the application of the current here; that means, the indirectly heat is basically it can controls the heat input. And that input can be created in small way small amount, that may be are suitable for the

any kind of micro welding processes. So, that development has been done also in plasma arc welding processes. That is another advantage of this process can say.

But in terms of the disadvantage that expensive equipment as compared to the other welding process that of course, the expensive equipment it is a relative term here, probably this is expensive equipment as compared to the gas tungsten arc welding process, but high distortion and weld wide weld as a result of the high input if there is a requirement of the high input then it can produce the high distortion. And may be wider weld pool can also produce, but the width of the weld pool is more controllable in plasma arc welding process as compared to the gas tungsten arc welding process.

(Refer Slide Time: 54:20)

Modes of Plasma Arc Welding	
Transferred arc	Non-Transferred arc
✓ Workpiece being welded is part of the electrical circuit ✓ Plasma arc transfers from the electrode to the workpiece ✓ May be used for high speed welding	✓ Arc occurs between the electrode and the nozzle ✓ High temperature is carried to the workpiece by the plasma gas ✓ Thermal energy-transfer mechanism is similar to that for an oxy-fuel ✓ It is used for welding of various metals and for plasma spraying (coating)

32

Now, normally plasma arc welding process two modes of the plasma arc can be used in the arc welding process. One is the transfer arc another is the non-transfer arc. So, transfer arc means it is a simple way the creating the arc between the work piece and the electrode material. So, that work piece being welded that work piece being welded and it becomes the final part of the electrical circuit. Plasma arc transfers from the electrode arc basically arc creates or arc transfer from the electrode to the work piece material and that can be done is a very high speed of welding.

So, this is the normal mode of the plasma arc welding process that is that we say the transfer arc it is like a gas tungsten arc welding process it is a simple way the creating the arc between the work piece and the electrode, but other way also it can also be

developed, but it is developing the another mode of the electrode arc that is called the non-transfer arc.

So, non-transfer arc is basically arc can be created between the electrode and the nozzle. So, basically nozzles becomes the part of the electrical circuit here to complete; and that generate the heat that heat can be the heat can basically creates the molten of the work piece material. So, in this non transfer arc basically high temperature is carried out to the work piece by the plasma gas. And this is in this case the thermal energy transfer mechanism is basically like the almost similar to and oxy-fuel, where mode of in oxy-fuel welding process or may be oxy-fuel transfer of the in oxy-fuel welding process what way it transfer the or it is generates the heat.

So, basically the non-transfer arc is mainly used for the welding of the various metal, but it is can be used as a in for the thermal spring or making the coating of the surface. This non transfer arc is more preferable. So, that is way this is another development of the plasma arc welding process the using the non-transfer arc basically create the coating process then welding processes.

(Refer Slide Time: 56:39)

LASER Beam Welding

- Heat is generated by a high energy laser beam
- Can be conduction more or keyhole mode welding
- Shelding gas is used

✓ Advantages	✓ Disadvantages
- Very narrow weld may be obtained - Relatively high quality of the weld structure - Very small heat affected zone - Dissimilar materials may be welded - Micro and nano-scale welding - Vacuum is not required - Low distortion of work piece	- High cost equipment - Not completely free from contamination

33

So, laser beam welding process this is one of the most precisely controlled heat source process and use and when there is a requirement of the very precision; that means, limited amount of the molten zone heat affected zone, then this is one of the best solution; that means, using the laser beam welding process.

Let us see the laser beam welding process. So, generation of the laser all these things that the physics of the laser, that can be explained or in the different module, but knowing all this fact about the laser we can say that in this case the laser beam welding is mainly advantageous to produce the high depth of penetration.

And it can create the limited size of the heat affected zone and the limited size of the molten pool; that means, aspect ratio between the ratio between the width and depth of penetration is relatively more in case of laser welding process as compared to the other are welding processes. Other point of laser welding process that heat can be used either conduction mode or keyhole mode welding process both depending upon the requirement.

So, conduction mode welding process means relatively the aspect ratio; that means, width and depth of penetration is relatively low as compared to the keyhole mode welding process. So, conduction mode welding process we can get the not much depth of penetration, but high amount of the weld width, but just vice versa in the characteristic of the typical keyhole mode laser welding process, where high depth of penetration and very small amount of the welding is produce the keyhole mode welding process.

So, depending upon the application both conduction and keyhole mode laser will be process can also be used. In this of course, like other arc welding processes here also the laser beam welding also use the shielding gas to protect the molten pool of the material, but if you look in the typical advantages of all this process; that first is that very narrow weld zone can be obtained using this laser beam welding process because it is focused on the, it is focused on the very small zone, but at the same time the intensity is intensity of focus intensity is very high as compared to the arc welding processes.

Relatively high quality weld zone can be produced by simply making the usable of the keyhole mode laser welding process in this case; very small heat affected zone, dissimilar combination of the materials can be welded using the laser welding processes more easily as compared to the arc welding process. And of course, laser welding process is one of the most suitable. So, welding process specifically to design and development of different micro and nano welding process because laser source; can be controlled very precisely.

So, taking this advantage there are the several developments of the micro and nano scale welding process has been done, where other arc welding process may not be suitable for the micro welding processes.

Of course since we can use the shielding gas also there is no need of the vacuum in this case like electrode beam welding processes. And heat can produce the low distortion of the work piece. Since, heat is focused on the or in this very narrow zone that is, that way it can produce the relatively low distortion as other are welding processes.

But if we try to look into certain limitation of this welding process, the one limitation is that the cost of the equipment is very high and as compared to the any other arc welding processes. And of course, it is not completely free from the contamination of the outside atmosphere therefore; there is a requirement of the shielding gas even in laser welding processes. So, these are the two limitations of welding processes. And maybe we can we will try to focus discuss more about on this laser beam welding processes later on.

(Refer Slide Time: 60:53)

Electron Beam Welding

- Beam of high energy electrons
- Carried out in a vacuum chamber
- Formation of keyhole

✓ Advantages

- Deep penetration weld
- Narrow weld and narrow heat affected zone
- Low distortion
- Filler metal is not required

✓ Disadvantages

- Expensive equipment
- High production expenses
- X-ray irradiation

34

And next we can look into another high beam energy welding process that is call the electron beam welding process. So, in this case so it creates this is a high beam of the flow of electrons and this process definitely it carried out under the vacuum. So, that the flow of the beam cannot be affected by the atmosphere and definitely it also follow the keyhole in that sense; that means, the even the high depth of penetration welding process

can be achieved in using the laser beam electron beam welding process as compared to the laser beam welding process.

So, if very precisely look into the different advantages that deep penetration weld can be produced and even narrower zone and heat affected zone and narrow weld can be produce as compared to the laser welding process very small distortion is the another advantage of this process, filler material is not required and another advantage is that electron beam welding process that; the lot of combination of the dissimilar materials can be welded more easily as compared to the other welding processes.

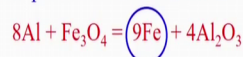
But of course, having some disadvantages in this case is the even more expensive equipment does that than laser welding process. And very high production cost is also very high; that means, when precision is the main requirement of any kind of welding process then it is better option; that means, electron beam welding can be used as compared to the other welding processes.

But another it during the electron beam welding process, the secondary scattering; that means, x ray irradiation also happens during the process. So, that needs to protect during the welding process. So, apart from this disadvantage in general the electron beam welding is normally preferred, when there is a requirement of the high precision by compromising the cost of this welding process.

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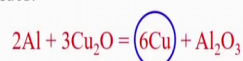
Thermit Welding

- o Utilizes heat generated by exothermic chemical reaction between the components of the thermit (a mixture of a metal oxide and aluminum powder)
- o The molten metal, produced by the reaction, acts as a filler material joining the work pieces after solidification



- o Reaction produces Al_2O_3 , free elemental iron and large amount of heat
- o The exothermic reaction occurs via reduction and oxidation
- o Al_2O_3 is much less dense

Other metal oxides:



Now, other welding processes we can see that the other type of welding process that is called the thermit welding process, where the chemical sources can be used as a source of the heat. So, basically the generation of heat is mainly control by the exothermic chemical reaction between the components of a thermit. Thermit can be defined as a mixture of the metal oxides and aluminium powder.

We can look into the example for example, if you look into this equation; that aluminium and Fe_3O_4 they react and forms the more Fe; that means, pure iron and that aluminium oxide that produce the oxide. So, during this reaction heat also heat also creates the heat. So, that heat generated is responsible to weld the two different materials, but at the same time that pure iron here becomes the part of the final weld joint.

So, therefore, the molten metal produce by the reactions acts as a basically filler material joining the work piece after solidification. And that reaction, since reaction produce the aluminium oxides and free elemental iron and large amount of the heat and that exothermic reaction occurs is basically reduction and oxidation.

So, here aluminium oxide is much less dense. So, that can be separated out from the molten zone, but it is also possible to include the welding process by sometimes by adding some kind of the other alloying elements. Since, the production of the pure iron becomes the final part of the weld joint. So, when you try to join the steel. So, that using some adding components can improve the composition of the steel along with the molten pure iron.

So, if you look into other type of reaction also in thermit welding that chemical reaction other metal oxides can also be used. Here to produce the copper, here also second equation we can see that there is a production of the copper. So, copper or copper based alloy can also be welded using a similar principle.

(Refer Slide Time: 65:24)

Thermit Welding

✓ Advantages

- heat of chemical reaction is utilized
- No external power source is required
- Large heavy section may be joined

✓ Disadvantages

- Only ferrous (steel, chromium, nickel) materials can be welded
- Relatively slow welding rate
- High temperature process may cause distortions and changes in Grain structure in the weld region
- Weld may contain gas (mainly H_2) and slag contaminations

36

Now, if you look into that advantage of this thermit welding process we can see that; heat of the chemical reaction is basically utilized in this process therefore, no need of the extra power source is required. And specifically these large heavy sections can be joined in this process. So, typical application we can see the thermit welding in realer track the joining of the component using this process.

But of course, having the disadvantage that one pointed out that only ferrous may be steel, aluminium, nickel materials can be welded and; that means, we need to chose choose the material. So, that the reaction may happens in such a way that; that produce the amount of the heat generate can produce the metal, but at the same time the production of the pure iron from the equation we have seen. That becomes a part of the actual welded join.

So, that is why it is having limitation limit combination of the material and the thermit; relatively slow welding rate. So, the welding rate is not as much as high as compared to the other arc welding processes, but high temperature passes may cause the distortion and that actually affect the grain structure in the weld zone, sometimes the weld metals may contain the hydrogen and the also the slag in slag inclusions or contamination is the another difficulties may be disadvantage of this welding process.

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Summary

- ✓ Heat generation in electrode depends on DC polarity
- ✓ Welding of aluminum AC is preferred
- ✓ Thermal conductivity of material is important parameter for FZ and HAZ dimensions
- ✓ Flat characteristic of V-I curve is suitable for semi-automatic arc welding
- ✓ Sharp dropping characteristic is suitable for manual arc welding
- ✓ Inert gas is most suitable shielding gas
- ✓ Non-transferred arc in PAW is suitable for thermal spraying or coating
- ✓ LBW or EBW is preferred for high depth of penetration is required (formation of keyhole)

37

So, in summary of all this welding processes we can see, we can see the few points that is most important points from overall idea of all the different types of the welding process and their basic structure first is that, heat generation is basically in the electrode that actually depends on the polarity. So, amount of the heat generated on the work piece or on the electrode that; depends on the whether we are using the direct current electrode positive or whether we are using the direct current electrode negative.

So, when use the direct current electrode negative in that case the maximum amount of the heat generated in the work piece material. So, welding of the highly oxidized material; that means, having aluminium oxides. So, where the cleaning action of is most important in that case ac current; that means, alternative current is more preferable.

Third point is that thermal conductivity of the material is very important parameter and that thermal conductivity actually decides that is the, that is the most in influencing properties of the material that actually influence the amount of the fusion zone as well as the more on the, what is the amount of the or size of the heat affected zone. So, this dimensional of these two heat affected zone; fusion zone is mainly depends apart from the other parameters the main parameter is the thermal conductivity of this specific material.

Now, if you when we discuss about the type or nature of the power source is required for different welding process, in general we can say the flat characteristic of voltage and

ampere current curve is suitable for the semiautomatic arc welding processes, but on other way the such drop characteristics type of the power source is more suitable for the manual arc welding process.

So, if you look into what is the nature of the shielding gas. So, inert type of gas is the most preferable choice for the shielding gas. And next is that in plasma arc welding process the non-transfer arc is specifically suitable for the thermal spray or the in the coating purpose rather than the welding processes welding of the different materials.

And laser beam welding or electron beam welding is mostly preferred when there is a requirement high depth of penetration, and the minimum heat affected zone and the minimum fusion zone. Definitely, this laser beam welding and electron beam welding they produce the high depth of penetration through keyhole mode formation of the keyhole mode welding processes.

So, thank you very much for your kind attention, next we will try to the next part of this module.

Thank you.