

Basics of Mechanical Engineering-2

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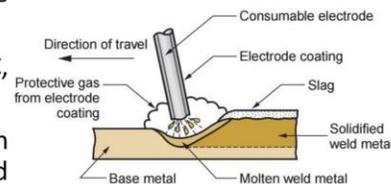
Lecture 27

Basics of Welding (Part 4 of 7)

Welcome to the lecture on the basics of the welding process.

Shielded Metal Arc Welding (SMAW)

- Shielded Metal Arc Welding (SMAW), also known as manual metal-arc welding or stick welding, is a widely used welding process for fabrication and maintenance.
- It involves generating an arc between a consumable coated metal electrode and the workpiece.
- The heat from the arc, which can reach up to 5000°C , melts both the base metal and the electrode.
- The molten metal from the electrode combines with the base metal to form a weld pool, which cools and solidifies.
- The burning flux coating creates a protective gas shield and forms slag that shields the weld from oxidation.
- After the weld cools, the slag is removed to reveal a clean weld.



M.P. Groover, Fundamental of modern manufacturing Materials, Processes and systems, 4ed

Now, let us get into the process. Until now, we have seen the fusion welding process. What are all the elements in welding? We have all seen that. Now, let us get into a process called shielded metal arc welding. So, SMAW. This is the short form that is used. Also known as manual metal arc welding or stick welding. It is widely used for fabrication and maintenance.

Typically in the construction industry. We use this welding process, which is called the manual metal arc welding process. So here, there is an electrode. This electrode melts,

and the material is deposited. It involves generating an arc between the electrode and the workpiece, melting it, and depositing it.

The temperatures reach as high as 5000 degrees Celsius. So, while melting, do you remember I talked about something in the past called wetting? Wetting is very important because this wetting allows the material to flow. So when you melt the alloy material from the electrode and the base, they should be miscible. Miscible means they should be able to enter inside.

If you take the unit cell, diffuse inside, and they form an alloy. And the rules for alloy we have seen in the basics of alloying in the lecture we saw that. So, Hume-Rothery rules have to be followed. So, that is very important and must be considered. So, the molten metal from the electrode combines with the base to form a weld pool, which cools and solidifies to form an alloy.

If you use immiscible materials, then what happens is there is always a crack. So there has to be a proper understanding of the base material. And the electrode material you use, a burning flux coating creates a protective shielding. This is what I said: protective shielding forms a slag around the weld. After the weld cools, the slag is chipped off with a hammer.

Shielded Metal Arc Welding (SMAW)



Arc initiation involves starting the arc between the electrode and the workpiece. Two methods are commonly used:

Touch Start

- The electrode is briefly touched to the workpiece, causing a short circuit that raises the current and temperature at the contact point.
- This leads to local melting and vaporization of the electrode and workpiece, generating free electrons that ionize the air, creating an ionized gas column and initiating the arc.

High Voltage Discharge

- A high-frequency unit introduces high voltage into the welding circuit, creating a strong electric field.
- This high-voltage pulse initiates the arc without contaminating the electrode.

So we have seen this in the beginning, touch start. So, the arc initiation involves starting the arc between the two electrodes. Two methods are commonly used. Touch start, as I told you—you touch it, it starts. So, you touch it and then you pull it up. The electrode is briefly touched to the workpiece.

Briefly—very briefly, a second—causing a short circuit. The first moment you touch, there is a short circuit. Once there is a short circuit, there is a heat phenomenon that raises the current and the temperature at the contact point. Why is that important? Because you want to initiate the melting.

So, you touch it, short circuit, heating happens, melting happens, and now you pull it up. So now you start doing it. This leads to local melting and vaporization of the electrode and workpiece, generating free electrons that ionize the air, create the plasma, and initiate the arc. So, friends, this is very important. There are two methods here.

This is a touch start. This is very commonly used. The other one is high voltage discharge. A high frequency unit introduces high voltage into the weld circuit, creating a short electric field, high frequency unit, AC unit, right. Wherein which you will have variable frequency drives are there.

And you can try to do it or high frequency you can try to take it in kilohertz. Create a high voltage into a weld circuit creating a strong electric field. This high voltage pulse initiates the arc, right. Without contaminating the electrode. So, this will try to create the heat phenomena and then later the current can flow through easily.

Shielded Metal Arc Welding (SMAW)



Important Term

Arc Crater



- A small depression forms in the parent metal due to arc penetration, with molten metal piled around it.
- The depth of the crater depends on the metal's thickness and is used to judge arc penetration.

Arc Length

- The distance from the electrode tip to the bottom of the arc crater is called arc length, typically 2 to 4 mm.
- It should be consistent for optimal results.



The other term is arc crater. This is a small depression formed in the parent metal due to arc penetration with molten metal piled around it. So this is arc crater which is there, a small depression formed. So in the parental metal, so what you do is you have a small depression, something like this. In the parent metal, due to the arc formation, right, and which molten metal piles around it, something like this.

So the depth of the crater depends upon the metal thickness and used for the judgment of the arc penetration. Arc penetration is also one important parameter which we do. Arc length we have already seen. The distance between the electrode tip should be generally between 2 mm to 4 mm. That is the distance, 2 mm.

You take your scale, 1 centimeter is this much. So 2 mm, 4 mm is too small. It should be consistent for optimum results. And where is the big difference coming in welding when you do manual arc welding is here. Consistently maintaining 2 millimeter and 4 millimeter while doing one electrode itself is a challenge.

That's why we go for automation. Arc stability. So this shorter length will lead to arc stability. A stable arc uniform and steady produces a good weld bead and defect free welding. To maintain the stability minimum arc variation length is essential.

So adding arc stability elements in flux can also help. As I told you we have seen the example in the flux. One is to oxide and the other one is arc stability. You can do that but predominantly it comes by arc length. So when we talk about polarity.

There are two types of polarities, when you use a dc welding. There is straight polarity and reverse polarity in straight polarity. The electrode is negative the electrode wire which you use is negative the workpiece is positive. When in the reverse it is reverse workpiece becomes negative and the electrode becomes positive in ac. Polarity changes periodically while within each cycle.

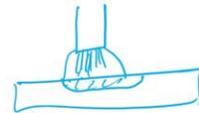
In AC, it is alternating current because here it swings. Positive, negative, positive, negative, it swings. This is alternating current, right. So, it swings. Periodically, it changes.

You can use straight polarity or reverse polarity. Straight polarity has the advantage of deeper penetration. Reverse polarity has the advantage of smearing and spreading without deeper penetration.

Shielded Metal Arc Welding (SMAW)

Direct Current Straight Polarity (DCSP)

- About 67% of heat is generated at the workpiece (+ terminal) while rest of total heat is generated at the electrode (-terminal). $\Rightarrow S.A \Rightarrow \text{more volume}$
- Hence, bare and medium coated electrodes are used.
- Deep penetration
- Mostly used for welding thicker sections.



Direct Current Reverse Polarity (DCRP)

- About 67% of heat is generated at the electrode (+ terminal) while the rest of the total heat is generated at the workpiece (- terminal).
- Hence, heavily coated electrodes are used to prevent overheating and melting of the electrodes.
- Shallow penetration
- Mostly used for welding thin sections.



Direct current straight polarity, which is called DCSP, generates about 67% of the heat at the workpiece. While the rest of the heat is generated at the electrode.

Because the heating mainly happens here, a pool will form, right? So, the electrode does not need a very high temperature because the substrate is heavier and has more surface area. More surface area leads to more volume. So, you need a lot of heat on the base. That is why we say 67% of the heat goes into the workpiece, while 33% goes into the electrode.

Hence, bare and medium-coated electrodes are used. Deep penetration occurs in direct current straight polarity, as I mentioned. It is mostly used for thicker welding joints. The other way around is direct current reverse polarity. Here, 67% of the heat is generated at the electrode.

While 33 percentage is given to the workpiece. So, when you give it to the workpiece, what happens is, so now instead your electrode is like this, the workpiece is like this. So, now more amount of melting will happen from here and this will try to create shallow welding. Large surface area welding will happen which need not give you a good strength but will give you primarily joining only. So, hence heavily coated electrodes are used to prevent overheating and melting of electrodes.

Shallow penetration, deep penetration, shallow penetration. So, on the surface you can try to do it. Mostly used for welding thin joints, we use reverse polarity. Because in thin joints, what happens? If you try to put a very high current, the workpiece itself will melt.

Joule heating effect, $I^2 R T$, right? It will itself melt. So, in that case, what we do is, we try to give maximum to the electrode. So, that is what is used here. So, DCSP, DCRP, very important. You should try to make a judgment whether to go deeper or shallow.

Shielded Metal Arc Welding (SMAW)



Important Term

Arc Blow



- In DC welding, arc blow refers to the wandering of the arc due to the magnetic field created by current flowing through the electrode, workpiece, and ground clamps.
- This magnetic field bends the arc from its intended path, especially at the beginning and end of the weld where the magnetic field concentration is higher.
- Unlike DC welding, AC welding does not experience arc blow because the polarity changes alternately.

Effects

Arc blow can cause porosity and other defects, as atmospheric gases may be drawn into the arc.



Arc blow. In DC welding, arc blow refers to the wandering of the arc due to the magnetic field created by the current flowing through the electrode, workpiece, and the ground

clamp. What we are trying to say is when there is an electric field with very high current flowing there. So what happens is, when the current flows, it leads to a magnetic field.

So this magnetic field, which is created because of the current flow, will sometimes try to disturb the arc that is forming there. The moment it is disturbed, the arc—which is a very small thing between the electrode—gets affected. Now there is a magnetic field present. This magnetic field will not allow the arc to stabilize. It will disturb it.

So that is what is called wandering. Like a blind man wandering in space. Arc blow refers to the wandering of the arc due to the magnetic field. This magnetic field is not created by you. It happens because of the current.

Current magnetic field are linked. The magnetic field bends the arc from its intended path. Especially at the beginning and the end of the weld where the magnetic field concentration is very high. So, unlike in DC welding, AC welding does not experience arc flow because the polarity changes alternatively. So, it is a phenomenon more common in DC welding.

DC supply. So we have to be careful. So arc blow can cause porosity and other defects whatever. It is because moment the heat swings and heat swings is not so much. It will swing in a very very small millimeter so that you get it. So, now we have seen the submerged arc welding process and all the phenomenas.

Shielded Metal Arc Welding (SMAW)



Advantages:

- Simple, low-cost, and portable equipment.
- Can weld in any position with high weld quality.
- Wide variety of electrodes available for different metals.

Disadvantages:

- Limited electrode length; requires cleaning when a new electrode is used, reducing welding speed.
- Difficult to control welding compared to MIG welding.

Applications: Fabrication, maintenance, repair jobs, shipbuilding, pipelines, construction, buildings, bridges, tanks, boilers, automotive, aircraft industries.

So, we will try to now look at the advantage and disadvantage. It is simple, low cost, portable. That is why you use it at any place. It can be used in any position where you want to have very high weld quality.

A variety of electrodes and different materials can be tried. What is the limitation? The electrode length is a limitation because it depends on the electrode length. At the end, suppose you are halfway through welding and the electrode ends. So at that point in time, what will happen is there will be a discontinuity in the flow of material and solidification.

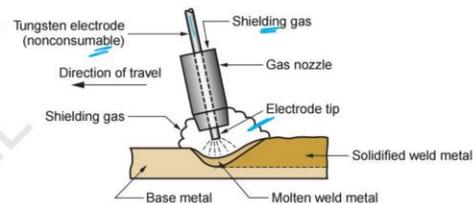
So, this part would have solidified, and this part is yet to solidify because you are manually changing the electrode. So, because of that, there can be discontinuity in the material form that leads to cracks. Then, cleaning is required when the new electrode is used, reducing weld speed. So, the other difficulty is that controlling is a little difficult compared to that of the manual inert gas welding process, which we will see later. So, where is it used? Fabrication, maintenance, repair jobs, shipbuilding, construction industry, gas pipelines—they use manual arc welding, sir.

Then, buildings, bridges, tanks, boilers, automotive, aircraft—everywhere they use this process, so that it is easy. If you want to automate it, replace a man with a robot, then you can go with a wire feed.

Tungsten Inert Gas Welding (TIG)



- Tungsten Inert Gas (TIG) welding, also known as Gas Tungsten Arc Welding (GTAW), is an arc welding process where heat is generated from an electric arc between a tungsten (non-consumable) electrode and the workpiece.
- The electrodes often contain thorium oxide or zirconium oxide to improve electron emission, arc stability, and easy restart at low currents.
- Filler metal is added separately if needed.
- The process is conducted in an inert gas atmosphere (argon, helium, nitrogen) to prevent contamination of the molten weld pool, with argon being the most commonly used gas due to its cost-effectiveness and smooth arc action.
- Both DC and AC power sources can be used, making it suitable for welding thin materials up to 6mm.



Tungsten Inert Gas welding (TIG) is also called the gas tungsten arc welding process. So here also, there is an arc which is created between the electrode and the workpiece. And here, the tungsten, which is used as the electrode, is not consumable.

So we have this. This is a base electrode. This is the circuit what you hold, so there is a shielding gas which is there. There is a tungsten electrode which is this one which is not melting non-consumable. So this tungsten does not melt and get deposited second thing tungsten is too heavy.

So when it gets mixed it will it will create lot of defects in the welding. So the electrodes often contain thorium oxide or zirconium oxide to improve the electron emission and arc stability and easy restart at low currents, the electrode. So electrode is this. The filler material is added separately if it is needed. So you can try to heat the base material and join possible or you can try to have a filler material which is there in the heated zone, it melts and deposits.

The filler metal is added separately if needed. The process is conducted in an inert gas atmosphere, so that what happens. You do not get any defects on the weld joints, argon, helium, nitrogen, to prevent contamination of the molten ventral pool, with argon. Being the most commonly used gas due to cost effectiveness and smooth arc action. Both AC and DC source can be used for TIG process.

So here, if you look at it, this is how it is. So you have an electrode which is used to create an arc, and then there is a filler rod which is there where it flows into the material. So in tungsten inert gas welding, a non-consumable tungsten electrode is mounted in the holder. So here, it need not be heavy; it will be one rod, and this rod is not consumed. So you do not have to worry every time. What you do is you have to use both this one to hold the arc and this one to feed the filler.

Or you can automate the process. The welding process begins by striking an arc. Again, the same thing: to generate an arc, you have to touch. And then strike an arc between the workpiece and the tungsten electrode in the inert atmosphere. So you can see here, there is an inert gas also flowing. So you can see a weld gun, and then there is an inert gas also flowing along with it.

So the arc can be initiated either by touching the electrode to a scrap metal piece or by using a high-frequency unit, which we saw. Once the arc is initiated, then the process continues. The welding torch is inclined at an angle of 70 to 80 degrees—normal is 90,

but here it's 70 to 80. Why? Because the filler has to come in at an angle. So, the filler material, if needed, is added by dripping the filler into the weld pool.

Tungsten Inert Gas Welding (TIG)



Polarities :

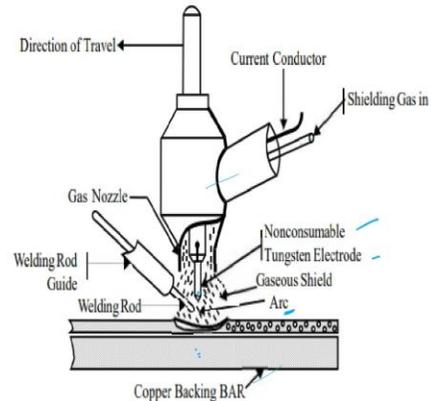
DCSP (Direct Current Straight Polarity):

Tungsten electrode (-ve), work (+ve). Used for welding mild steel, stainless steel, copper and titanium.

DCRP (Direct Current Reverse Polarity):

Tungsten electrode (+ve), work (-ve). Used for welding aluminum and heavily oxidized aluminum castings.

ACHF (Alternating Current High Frequency): It is used for Al and Mg. High frequency also helps in oxide cleaning actions.



<https://tristatefabricators.com/types-of-welding/>

So, as I told you in submerged arc welding, here also you have DCSP and DCRP. So, this is the same; we do not have to worry about it. And then we will only see a new thing, which is called ACHF, or alternating current high frequency. It is used for aluminium and magnesium, where high frequency is used to help prevent oxide formation or for oxide cleaning action.

So, if you look at it in a close microscopic view, you will see here the direction of travel, which is happening this way. And you see a current conductor coming. A shielding gas is coming through. So, this shielding gas protects. This is the inert atmosphere that protects.

There is an electrode that comes. This tries to come in contact with the workpiece to create an arc. There is a filler material. This filler material can have a coating or can come as bare. So, this is the microscopic view of the process.

So, the non-consumable tungsten electrode you can see here. Gas shielding—the gas is fed around it, and then you can see there is an arc filler material.

Tungsten Inert Gas Welding (TIG)



Advantages of TIG Welding:

- Ideal for high-quality welding of thin materials and nonferrous metals like aluminum and stainless steel.
- Provides better control with clear visibility of the arc and workpiece.
- Suitable for welding dissimilar metals, such as mild steel to stainless steel.
- Smaller heat-affected zone (HAZ) and no flux, reducing the risk of flux entrapment.

Disadvantages:

- TIG is slower than MIG and prone to contamination.
- Tungsten contamination can cause brittle welds & equipment costs are higher than SMAW.

Applications: Welding of aluminium, magnesium, copper, nickel, titanium, zirconium, and hard surfacing alloys, Welding of expansion bellows, transistor cases, instrument diaphragms, and can seal joints, Welding sheet metal, and thinner sections



So, the advantages and disadvantages are straightforward. It can be used for thin materials. Both ferrous and non-ferrous materials can be done.

It can provide very clear visibility of the arc and the workpiece. Stainless steel, mild steel to stainless steel can be welded. Dissimilar materials also can be done. Since it is precisely focused, the heat-affected zone is less compared to that of manual arc welding. So, TIG is slower than MIG.

TIG is tungsten inert gas. MIG is metal inert gas and prone to contamination. The tungsten is the same thing. Tungsten is used, which is replaced by metal. So, tungsten contamination can cause brittleness.

Suppose, in case tungsten melts, it is very heavy. So, it will fall down and create brittle welding. So, it is costly. So, in application, you can see non-ferrous materials; the majority of them use the TIG process. Weld aluminium, magnesium, copper, nickel, titanium.

See, all aerospace and automobile uses of magnesium and titanium require the TIG process, right? Zirconium and hard surface alloying are used. The welding of expansion bellows. Expansion bellows are components that provide a cushioning effect. Bellows, transistor casing, TIG.

Instrument diaphragm, thin instrument diaphragm joining, TIG. Then joints, seal joints, TIG. Welded shield plates and thin sections, TIG. So, you should now understand non-ferrous materials, which are thin, use TIG. When it is a heavy structure, it will be an arc welding process.

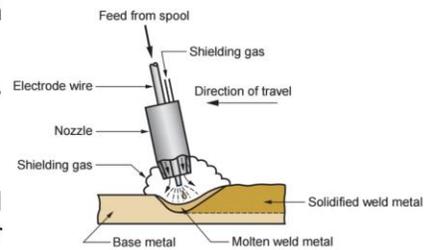
Metal Inert Gas Welding (MIG)



- Gas Metal Arc Welding (GMAW), or MIG welding, uses an electric arc to create coalescence between a continuously fed metal electrode and the job.
- The process is shielded by an inert gas, such as argon, helium, or carbon dioxide, and does not require flux.

Principle of Operation

- In MIG welding, a consumable wire electrode is fed through rollers, using DC reverse polarity (DCRP) for stable arc and efficient metal deposition.
- The process is shielded by inert gas, and the torch remains 10 ± 2 mm from the workpiece with an arc length of 1.5 to 4 mm.
- Arc length is maintained constant by using the principles of self-adjusted arc or self-controlled arc in semi-automatic and automatic welding sets.



So, a small difference between TIG and MIG: MIG is metal inert gas. So, the gas metal arc welding or MIG welding uses an arc to create a coalescence between a continuously fed metal electrode and the job. So now you see the difference: a continuously fed metal electrode. In TIG, a tungsten electrode comes, and filler comes, which you try to melt. But in MIG, the metal itself comes from the spool as the shield.

So you have this nozzle where the unshielded gas is. So you can try to have this gain metal. The process is shielded by inert gas such as argon, helium, or carbon dioxide, and it does not require flux. So this is very important. The process is shielded by inert gas, which does not do it.

So here, the metal melts and drops down. So in MIG, a consumable metal wire is used. So we can try to use either DCSP or DCRP. Generally, we use RP for a stable arc and efficient metal deposition. The arc length gap is between 1.5 to 4 mm, and the torch remains at 10 mm to 12.

From the workpiece with an arc length of this much. So, the arc length is maintained as constant such that you can get the best welding joints.

Metal Inert Gas Welding (MIG)



Self-adjusted arc:

- Electrode feed adjusts automatically.
- Decreased arc length increases current; increased arc length decreases current.
- Requires power source with flat characteristics.

Self-controlled arc:

- Electrode feed rate adjusts with motor speed.
- Decreased arc length decreases motor speed; increased arc length increases motor speed.
- Requires power source with drooping characteristics.



<https://www.tecweld.cn/pages/mig-welding-everything-you-need-to-know-from-setup-and-settings-to-technique>

So, there are self adjusting arc, there are self controlled arc. There are two types of arc which is possible in the metal inert gas welding process. So the electrode feed adjusts automatically, which is called as self-adjusted arc.

So if you look into it, friends, it is almost everything comes and falls as arc length, arc. So if you see what is arc, arc is nothing but flow of current. So if you can control the current flowing or if you can control the voltage flowing and if you can sense it properly. Then accordingly, you can help in feeding the electrode also. Suppose if the arc length is too short, then what happens?

You have to feed faster. So you can do it. So in welding, it is interestingly that you can control the process very nicely. So the electrode feed adjusts automatically. Decreased arc length increases current.

Increased arc length decreases current. Now you can see how beautifully it is doing. So you closely watch the animation which is here, you will understand. Requires power source with flat characteristics. As I told you, constant voltage, constant current, you can also do it.

Self-controlled arc. The electrode feed rate adjusts with motor speed. Decreased arc length decreases the motor speed. So, it is vice versa. It requires power source with drooping characteristics.

So, we will try to see flat characteristics and drooping characteristics later. So, is that clear? So, you can have two of this. So, this tries to automate the metal inert gas welding process.

Metal Inert Gas Welding (MIG)

Advantages

- Deep penetration and effective for both thick and thin workpieces.
- Fast with high deposition rates due to continuous electrode feed.
- Easily automated, flux-free, clean, and spatter-free.
- Reduces distortion, and requires less operator skill.

Disadvantages

- More complex and costly equipment, less portable.
- Shielding gas may disperse outdoors, affecting weld quality.
- Higher cooling rates may affect metallurgical and mechanical properties.

Applications: Welding carbon, silicon, low alloy steels, stainless steels, heat-resistant alloys, aluminum, copper, magnesium, and their alloys. Welding tool steels and dies. Manufacture of refrigerator parts. Used in industries like aircraft, automobiles, pressure vessels, and shipbuilding, etc.



Advantages, deep penetration and effective for both thin and thick. TIG is extensively used for thin materials. Metal is used for both thin and thick materials. It is fast with a higher deposition rate. It can be automatic, flux-free, clean, and spatter-free metal. So we prefer metal when we perform many welding processes.

It reduces distortion and requires less operating skill because most of them can be controlled by these two processes. One is a self-adjusting arc, the other is a self-controlled arc. The disadvantages are straightforward. Applications include welding carbon, silicon, low alloy, stainless steel, heat-resistant alloy—all these are possible with MIG. So if you compare it to manual arc, MIG can be chosen, but manual arc still has its own advantages.

Comparison: TIG vs MIG



TIG Welding	MIG Welding
1. Permanent non-consumable tungsten electrode is used in this process.	1. Consumable metallic electrode is used in this process.
2. Filler metal may or may not be used in TIG welding.	2. Filler metal in the form of wire is used in MIG welding.
3. Penetration is not so much deeper as compared to MIG.	3. Deeper penetration can be obtained as compared to TIG.
4. Both AC and DC power source can be used.	4. DC power source with reverse polarity is generally used.
5. Metal thickness which can be welded is limited to about 6 mm.	5. Suitable for thickness more than 6 mm. Thickness can go upto 40 mm.
6. Electrode feed not required in case of TIG welding.	6. Electrode need to be fed at a constant speed from a wire reel.
7. Welding speed is slow.	7. Welding is faster.
8. TIG welding torch is water cooled.	8. No cooling is necessary.
9. Additional fixtures required to hold the work piece.	9. No fixturing required. process can be easily automated.
10. Requires skilled operator.	10. Less skilled operator can perform.



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I am comparing MIG and TIG so that you can appreciate the differences. TIG uses a permanent, non-consumable electrode. Here we use metal, which is a copper wire, stainless steel wire, or mild steel wire. Consumable metallic electrodes are used in this process. Filler metal may or may not be used in TIG because you heat it and join.

So you do not need a filler. Then here in metal, a wire is used in the MIG welding process. The penetration is not as deep as compared to that of MIG. Here both AC and DC can be used. In MIG, only DC can be used.

TIG thickness can be limited only to 6. So here, thick and thin can be done. It can go up to 40. The electrode feed is not required in the case of MIG. But here it is required, which is why you saw these two here: self-adjusting arc and self-controlled arc. These two are there, right?

So the electrode speed can be adjusted with the motor speed and the arc speed. So next, the weld speed is slightly lower. Here it is higher. The TIG welding torch is water-cooled. Here, no cooling is required.

The additional fixtures are required to hold the workpiece. Here, fixtures are required for holding because heat will cause distortion. TIG requires high skill. MIG does not require as much high skill. This clearly distinguishes when to use MIG and when to use TIG. But here, the commonality is the inert gas flowing around it.

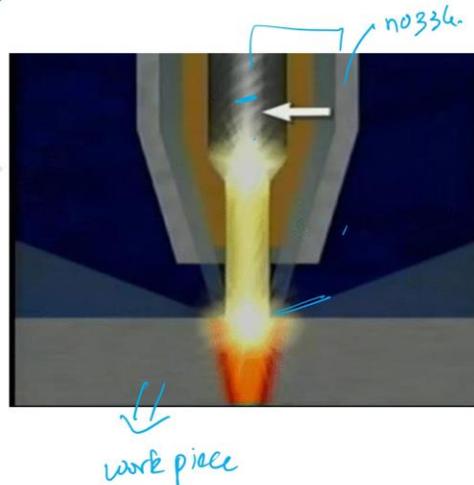
Plasma Arc Welding (PAW)



- Plasma arc welding uses a constricted arc between a tungsten electrode and a nozzle or work piece.
- It employs two inert gases, one for forming the arc plasma and the other for shielding it. Filler metal may or may not be added, and pressure is typically not used.

Principle of Operation Plasma arc welding is a constricted arc process.

The arc is constricted with the help of a water cooled small diameter, nozzle which squeezes the arc, increases its pressure, temperature and heat intensively and thus improves arc stability, arc shape, and heat transfer characteristics.



<https://makeagif.com/gif/plasma-arc-welding-50Erh7>

Next, let us look into the plasma arc welding process. Plasma arc welding uses a constricted arc between a tungsten electrode and a nozzle or the workpiece. So, what they are trying to say is between the tungsten electrode—this is tungsten—and this is the nozzle. The circuit can be closed by connecting these two and creating a plasma.

Or this is the workpiece. You can try to close the circuit between the tungsten and the workpiece. It employs two inert gases. One for forming the arc plasma. The other is for shielding it.

Two separate entities are used in plasma. First to create, then to shield. The filler metal may or may not be added, and the pressures are typically not used. It is almost like your TIG. If you want, you can try to add a filler if necessary.

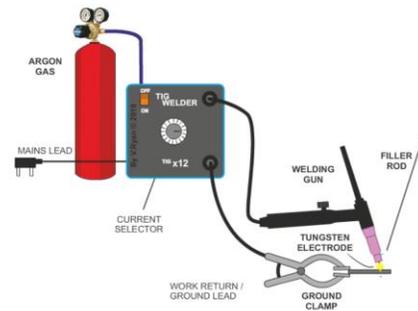
So here, you can see the arc is created and then The heat is gone, so now in the heat zone, you can keep a filler if you want. Otherwise, you can melt the material and then join.

Tungsten Inert Gas Welding (TIG)



Principle of Operation

- In Tungsten Inert Gas (TIG) welding, a non-consumable tungsten electrode is mounted in a special holder designed to allow inert gas to flow around the electrode and the arc.
- The welding process begins by striking an arc between the workpiece and the tungsten electrode in an inert gas atmosphere.
- The arc can be initiated by either touching the electrode to a scrap metal piece or using a high-frequency unit.
- Once initiated, the arc creates a molten weld pool on the workpiece.
- The welding torch is typically inclined at angles of 70° - 80° , and the filler metal, if needed, is added by dipping the filler rod into the weld pool.



<https://technologystudent.com/despro2/tigweld1.html>

The principle of operation: plasma arc welding is a constricted arc process. The arc is constricted with the help of a water-cooled, small-diameter nozzle, which sequences the arc, increases its pressure, temperature, and heat intensity.

Thus, it improves arc stability, arc shape, and heat transfer characteristics. It improves arc stability compared to that of TIG, MIG, and submerged arc welding. Arc stability is very high, arc shape is good, and heat transfer is also highly efficient.

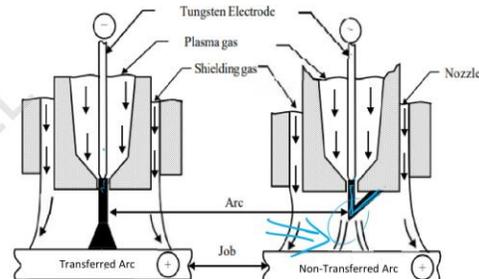
Plasma Arc Welding (PAW)

(i) Non-Transferred Arc Process :

- Arc forms between electrode and water-cooled nozzle.
- Plasma exits as a flame, independent of the workpiece.
- Used for ceramics and metal plating, with lower energy density.

(ii) Transferred Arc Process :

- Arc forms between electrode and workpiece.
- High energy density and plasma jet velocity.
- Used for applications requiring intense heat.



So in plasma, there are two types of arc processes. One is non-transferable; the other one is transferable. If you see a transferable arc, it is between the electrode and the workpiece. There is a flame, a heat flame, which is a plasma that is created. An arc forms between the electrode and the workpiece. It has a very high density, and the plasma jet velocity is also very high. It is used for high-heat applications. The same thing happens when you have a non-transferable arc; it is between the electrode and the nozzle itself.

So the plasma is created between these two, right? And this is the arc that is getting created. So now the arc is formed between the electrode and the water-cooled nozzle, right? So plasma exits as a flame, independent of the workpiece. So the workpiece can be conducting, or the workpiece can be non-conducting.

So for ceramic and metal paints with low energy densities, you can use a non-transferable arc. If you use a highly insulating material and want to join it, how do you do it? You can do it with plasma. So here again, you can have a filler, or you don't have a filler. So, a transferable arc has higher energy and high velocity when it comes and hits.

Plasma Arc Welding (PAW)

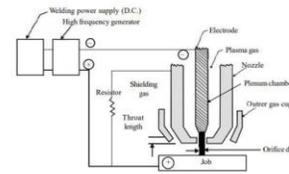
The plasma arc welding system consists of the following equipment.

Power Supply: A direct current power source (generator or rectifier) having dropping characteristics and open circuit voltage of 70 volts or above is suitable for plasma arc welding.

High frequency generator and current limiting resistors are used for arc ignition. Arc starting system may be separate or built in the system.

Plasma torch: It is either transferred arc or non-transferred arc type. It is hand operated or mechanised.

Shielding gas: Two inert gases or gas mixtures are used. The orifice gas at lower pressure and flow rates forms the arc plasma. Most of the materials can be welded with argon, helium, argon + hydrogen and argon + helium with inert gases or gas mixtures



So, again we should know little bit about the power supply. So, plasma arc welding PAW welding system consists of the following equipments power A DC power supply is used with a drooping characteristics and open circuit voltage of 70 volts and above. So we will see about the drooping characteristics in the next lecture. High frequency generators and current limiting resistor arc are used in the arc initiation.

The plasma torques can be transferable and non-transferable. We try to use for creating plasma and we try to use shielding gas. So two inert gas or a gas mixture is used. The orifice gas at the lower pressure and flow rate forms the arc plasma and the protection will be at a higher plasma. So you play with the flow velocity and then you try to do it.

Plasma Arc Welding (PAW)



Advantages

- Stable arc and high weld quality.
- Uniform penetration with simplified fixtures.
- Fully penetrated keyhole welds on pieces up to 6 mm thick.
- Root rewelding for cost-effective joints.
- Suitable for square butt joints.

Disadvantages

- Limited to metal thickness of 25 mm for butt welds.
- High inert gas consumption.
- Increased electrical hazards
- Welder may need ear protection due to damaging noise.

Applications:

- Welding high-performance alloys (cryogenic, aerospace, corrosion-resistant).
- Welding stainless steel tubes (2.6–6.3 mm) and titanium plates (up to 8 mm)
- Plasma torch for spraying, welding, and cutting hard-to-weld metals



So, again the advantages and disadvantages are here. So, now we will only look at the applications here. So, it is used for welding high performance alloy. For example, cryogenic aerospace and corrosion resistance welding process, corrosion resistance material it can do for cryogenic also material. It is used where we operate, talk about -30, -40, it is used.

So it is used for stainless steel, the plasma torch for spraying, welding, cutting, and it can also be used. So the moment you transform this, you try to use this alone, right? It can be used for cutting because you have high heat. You can use it for joining. And here, in between this non-transferable part, I fill a powder. So then this powder can be used for spraying.

So plasma spraying is possible. That's what I have told you. So the plasma torch for spraying is when you feed a powder. Then for welding, you keep a rod. Then if you don't put this and that, you just use it as a flame heat source. It can be used for cutting. So all are possible with the plasma welding process.

Submerged Arc Welding (PAW)



- In submerged arc welding, an arc is formed between a metal electrode and the workpiece, submerged under flux.
- The continuously fed electrode melts, acting as a filler rod.
- Large electrodes (12 mm), multiple electrodes, and high currents (4000 A) allow for high deposition rates (20 kg/hr), fast welding speeds (5 m/min), and welding of thick plates (up to 75 mm) in a single pass.

Principle of Operation

In submerged arc welding, the arc is struck by touching the electrode to the workpiece or using steel wool/high-frequency.



<https://makeagif.com/gif/submerged-arc-welding-4sJEJO>

Next, let us look into the submerged arc welding process. This is used extensively in heavy engineering applications. In the submerged arc welding process, an arc is formed between the metal electrode and the workpiece submerged under flux.

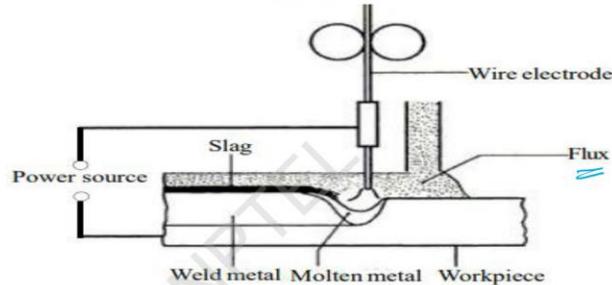
So you see here, there is a flux pouring hopper. So this is a flux hopper, a pouring hopper. They go first. They keep feeding, and they go, and then you have an electrode which is there. So now the electrode is submerged into the flux, and it does joining.

So the continuous feed electrode melts and acts as a filler rod. So you can see here, this portion is here; whatever gets created is the arc, where it is created by the continuous feeding of the electrode. So, large electrodes up to 12 millimeters can be used, and currents like 4000 amps can be used. So, the rate of deposition can go up to 20 kg per hour. So the speed can go up to 5 meters per minute; it can reach that speed.

The thickness which can be welded can be up to 75 millimeters in one pass, right. So this is the submerged arc welding process most of the time. We use a robot or a machine where it is continuously feeding. So it can be done, for example, if you try to take two thick rings, you put the two thick rings which are used for the sewage system. The heat exchangers, very big heat exchangers, the diameter can be 6 meters, 5 meters, or 3 meters.

So you take these two rings and then we use the submerged arc welding process; it goes around and then joins. So the principle is the submerged arc welding; the arc is struck by touching. And then the electrode touches the workpiece, the spool is fed, and then you start the process.

Submerged Arc Welding (PAW)



The flux melts, becomes conductive, and allows current flow. No pressure is applied, and the solidified flux can be reused.

Advantages:

- No sparks, spatter, or smoke, eliminating the need for safety equipment.
- High deposition rates and deep penetration reduce the number of passes required.
- Faster process with neat, smooth welds and minimal distortion.



<https://tristatefabricators.com/types-of-welding/>

So this gives more clarity: the flux is fed first, then there is an electrode which is continuously fed. So you can try to go through it. So once the weld is done, then you will have slag. So after the weld is over, we try to use the chipping hammer to remove the unwanted slag, and the weld zone forms, right. So this is the weld metal or the molten metal formed here. This is the workpiece. So the flux melts, becomes conductive, and also allows current to flow.

No pressure is applied. The solidified flux is used for joining. So, advantages: this pattern and all will not be there; it will be a clean joint, and you get heavy thick metal welding happening.

Submerged Arc Welding (PAW)



Disadvantages:

- Requires jigs, fixtures, and accessories for proper positioning.
- High flux consumption and frequent replacement.
- Limited to flat position welding.
- Not economical for small or thin welds; unsuitable for Cl, Al, and Mg alloys.

Applications:

- Bridge girders, railroads, pressure vessels, pipes, and railway structures.
- Shipbuilding, automotive, nuclear industries.
- Ideal for mass production of steel sections and long welds.



So, these are some of the advantages and disadvantages. You can see applications: bridge girders can be used, water pipelines, railway structures can be done, nuclear industry. They also use the submerged arc welding process, ideal for mass production in steel sections.

Electroslag Welding (ESW)



- Electroslag welding (ESW) is similar to submerged arc welding but performed in the vertical position.
- It involves casting filler metal between workpieces in a single pass.
- Heat is generated by molten slag, which melts both the filler metal and workpiece surfaces, enabling the welding of large and long plates.

Principle of Operation:

- Electroslag welding starts with an arc that melts flux to form slag.
- The arc is extinguished, and the molten slag, heated by resistance, reaches temperatures of 1650°C to 1950°C, enabling welding of thick sections.
- Multiple electrodes distribute heat for longer welds, while water-cooled copper shoes prevent metal runoff and aid solidification.
- The flux shields and purifies the molten metal.



So, we have the electroslag welding process. The electro slag welding process is very similar to the submerged arc welding process but performed in a vertical position. It involves casting filler metal between the workpieces in a single pass. Electro slag welding (ESW).

The heat is generated in the same way; the rest of the things are the same. The electro slag welding starts with an arc, same. The temperatures go up to 1500 or 1600 to 1900. Multiple electrodes distribute heat for longer weldings. Water cooling is used, and the flux shielding is also tried.

So, this is how the electro slag welding process works. In the electro slag welding process, what happens is you have to go from bottom to top. A very thick joint has to be formed. So, we continuously feed it. So, there I said a ring will be rotated.

Here, it will go vertically to the top. So, it is economical for thicker, long plates with high deposition rates. Then, low flux consumption occurs, and the weld speed can go very high. The disadvantages are this: the fabrication of high-pressure vessels requires a frame of heavy mechanical and hydraulic equipment, and then you try to achieve it. So, the other one is electro-slag welding.

Electro Gas Welding (EGW)



- Electro gas welding is an arc welding process where an arc forms between a continuous filler metal electrode and the weld pool in a vertical position.
- The molten weld metal is confined by a backing, with or without shielding gas.
- The joint (square or V) remains vertical during welding, which is done in a single pass without repositioning.
- It is a machine-based process.

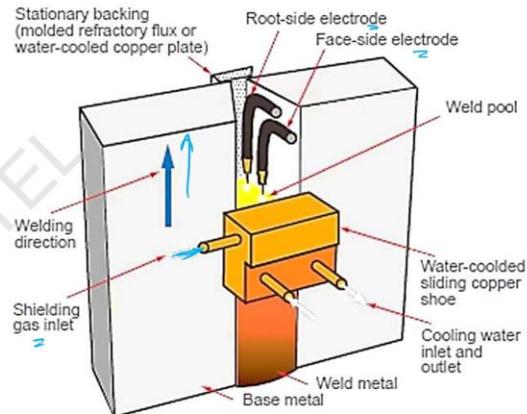
Principle of Operation:

- The consumable electrode, either solid or flux-cored, is fed into a cavity formed by the base metals and retaining shoes.
- An arc is initiated between the electrode and the starting tab, melting both the electrode and groove faces.
- The molten metal forms a weld pool and solidifies.

Now, we will see electro-gas welding. So, electro-gas welding is an arc welding process where the arc forms between continuously fed filler metal electrodes and the weld pool in the vertical position.

Electro Gas Welding (EGW)

- Flux-cored electrodes provide protection from atmospheric contamination, or shielding gas (typically CO₂) can be used.
- The electrode may oscillate horizontally for uniform heat and weld metal distribution.
- The weld is deposited in the flat position, and the welding uses a constant voltage DC power supply with a range of 100-800 A and 30-50 V.



<https://weldingofwelders.com/electrogas-welding/>

Again, the rest of the process is the same. So, you have it like this, which is called the electro-gas welding process. So, here you see that.

There will be water cooling so that the heat, whatever is generated, is removed. This is the vertical direction in which it is moving, and then you have electrodes, right? One is the face-side electrode, the other is the root-side electrode; two electrodes can be used, and then you can try to join. So, this is where the shielding gas is fed, right? So, it can go like this to the top, and then you can fill it up. So, gas electrode welding. So, if you look into it, electro slag welding can also do the same, and it is almost identical with a very minor difference.

Electro Gas Welding (EGW)



Advantages:

- Ideal for welding thick steels in vertical position.
- Saves time and cost by eliminating joint preparation, preheating, and inter-pass control.
- Minimal angular distortion of the base metal
- Quiet welding action with little spatter.

Disadvantages:

- Interruptions can cause major discontinuities, hard to repair.
- High heat input causes large grain size, reducing toughness.
- Requires protection from wind over 8 km/h.
- Additional safety measures needed when welding at heights.

- [① Reverse polarity
+
② Forward =]
- Steel → AC welding
- magnetic field +
Electric field =



So, the advantages and disadvantages are clearly given. So, it can go up to 8 kilometers per hour. So, in this lecture, we saw various fusion welding processes: metal arc welding, submerged arc welding, tungsten inert gas welding, and metal inert gas welding.

We also saw that welding can happen in horizontal and vertical directions. We saw electro slag and electro gas welding processes. So, I have one question left for you. Throughout my lecture, I mentioned reverse polarity and forward polarity. I have also explained the difference.

So now, consider where reverse polarity and forward polarity can be applied in real-time scenarios. This will be one assignment. The second assignment is: why is mild steel always used in AC welding, whereas non-ferrous materials always use DC? A second question for you to ponder. The third question is: what is the influence of magnetic and electric fields?

Can I control the electric field by using the magnetic field that is being generated? Or can I use the magnetic field that is generated to control the electric field? See what the relationship is and how you can do it. These are three things you can always look into, read, and examine from the many references available. Then, try to educate yourself.

Please take a look at this, and then we will continue in the next lecture. I will also try to discuss the drooping curve and other characteristics in the next lecture.

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These are the references we used in preparing the lecture.

Thank you very much.