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SAM – SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

2023-02-13

CU 01: DED-Arc Process. Fundamentals

Project No. 601217-EPP-1-2018-1-BE-EPPKA2-SSA-B

SECTOR SKILLS STRATEGY IN ADDITIVE MANUFACTURING

Co-funded by the Erasmus+ Programme of the European Union

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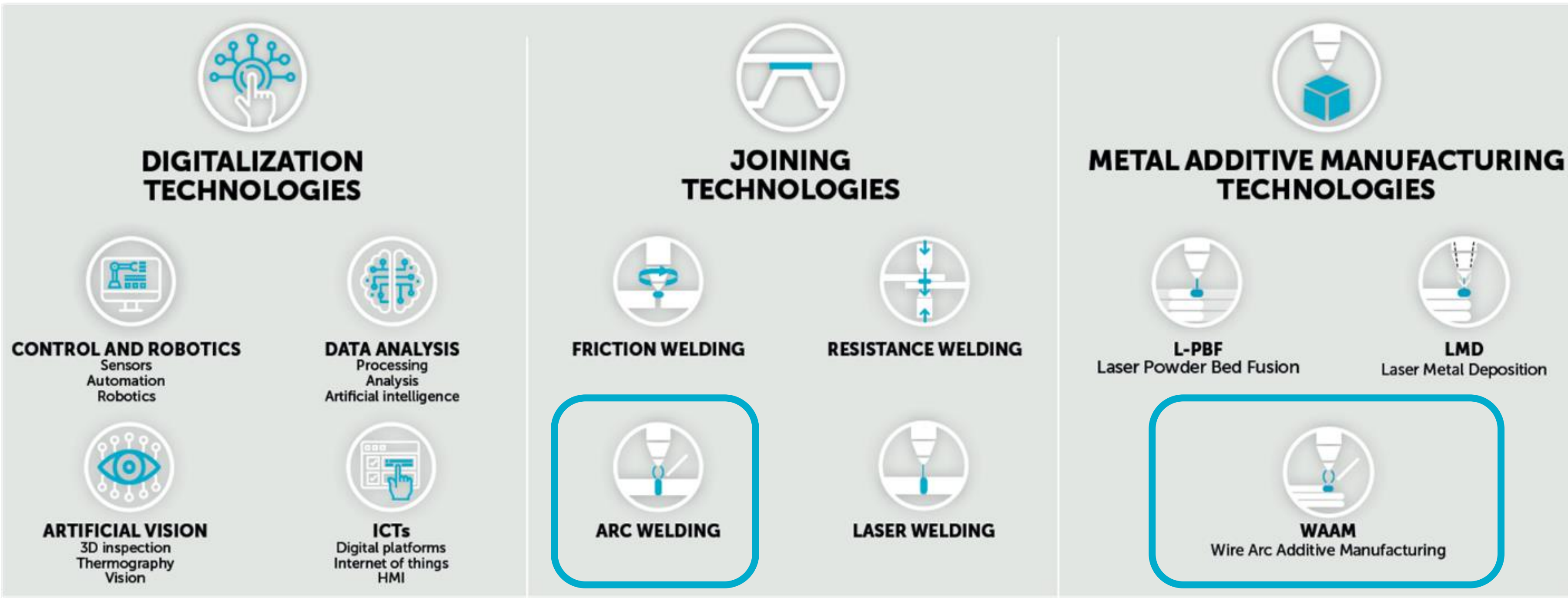
Mission

LORTEK S.COOP. is a private Technology Centre that generates excellent knowledge in the digitalization of manufacturing processes to transfer it to the industrial sector and hence, increase its competitiveness and sustainability.

- ✓ Accredited as an agent of the RVCTI
- ✓ Member of the BRTA consortium (Basque Research & Technology Alliance)
- ✓ Cooperative integrated in the Mondragon Corporation


DIGITALIZATION TECHNOLOGIES
CONTROL AND ROBOTICS
Sensors
Automation
Robotics
DATA ANALYSIS
Processing
Analysis
Artificial intelligence
ARTIFICIAL VISION
3D inspection
Thermography
Vision
ICTs
Digital platforms
Internet of things
HMI
JOINING TECHNOLOGIES
FRICTION WELDING
RESISTANCE WELDING
ARC WELDING
LASER WELDING
METAL ADDITIVE MANUFACTURING TECHNOLOGIES
L-PBF
Laser Powder Bed Fusion
LMD
Laser Metal Deposition
WAAM
Wire Arc Additive Manufacturing

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Session 1.3 – Fundamentals of DED Arc

Outline

- Introduction to arc welding processes
- Basics of electricity
- Nature of the electric arc
- Types of current & polarity
- The arc as a heat source
- Interaction of the heat source and the feed-stock
- Formation of the weld pool
- Lunch break
- Shielding gases
- Methods for arc ignition
- Metal transfer modes
- Process principles for common arc welding processes;
    - TIG
    - MIG/MAG
    - PAW

Quizes

Part 1: https://app.sli.do/event/heo2ern7Zor4y6EzNybofF

Part 2: https://app.sli.do/event/74nmF4YBcGvjs2TnR7jH1i

https://www.slido.com/ → Participation code part 1: 3430125
Participation code part 1: 1121115

Question time

What is your knowledge in arc processes?

5 minutes

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Introduction to arc welding processes

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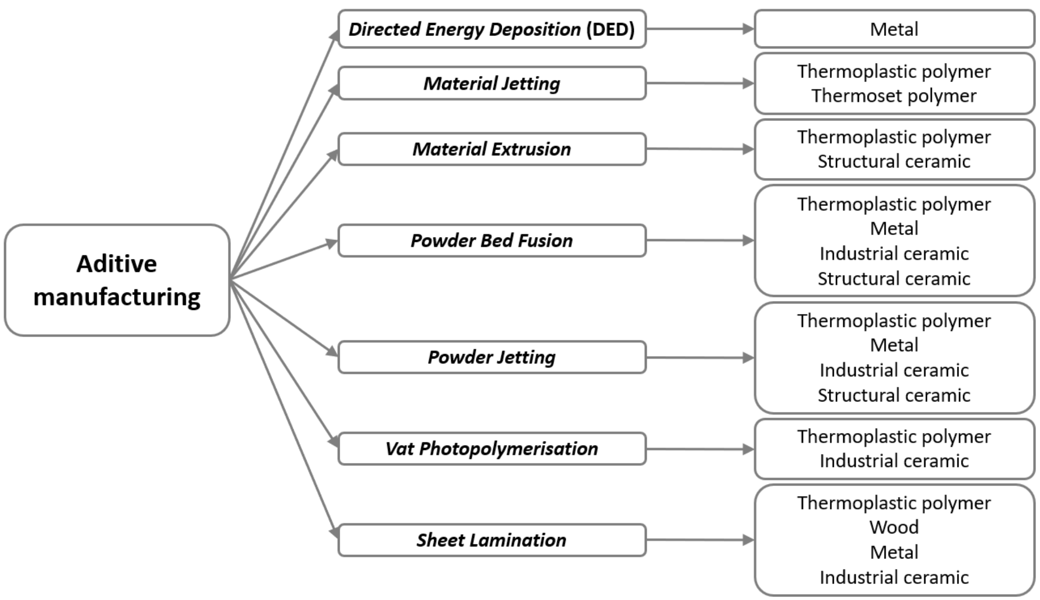
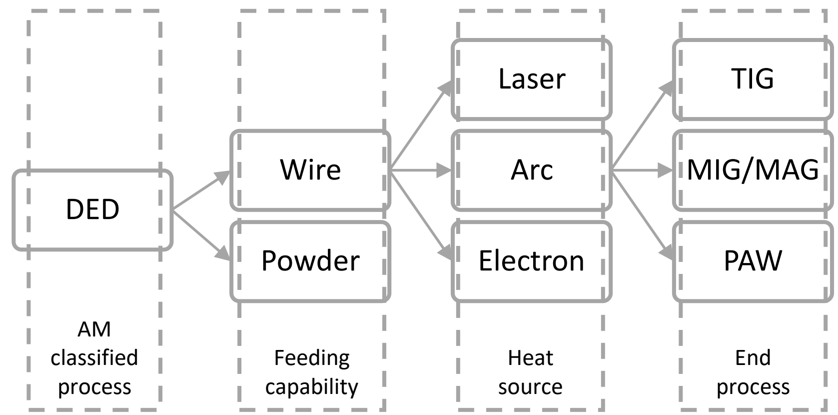
Introduction to arc welding processes

Classification of AM



Classification of DED



Introduction to arc welding processes

	Laser-DED	Arc-DED	EB-DED
Manufacturing speed	-	++	+++
Complexity	+	-	--
Accuracy	+	--	---
Part size	-	+++	+++
Cost saving in small parts	++	---	---
Cost savings in large parts	-	+++	++
Surface quality (without postprocess)	-	---	---

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Question time

List the main components in arc welding processes

5 minutes

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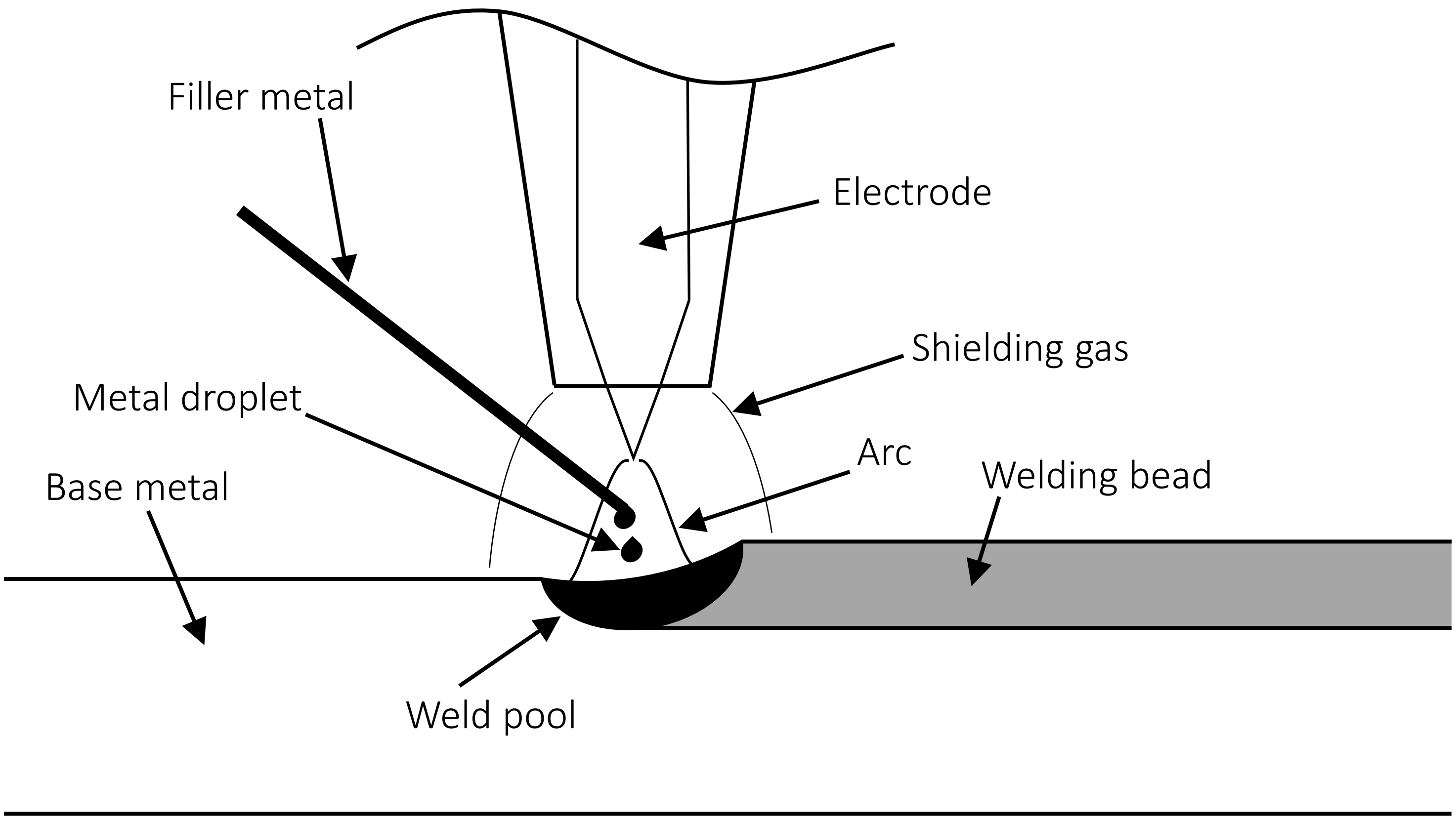
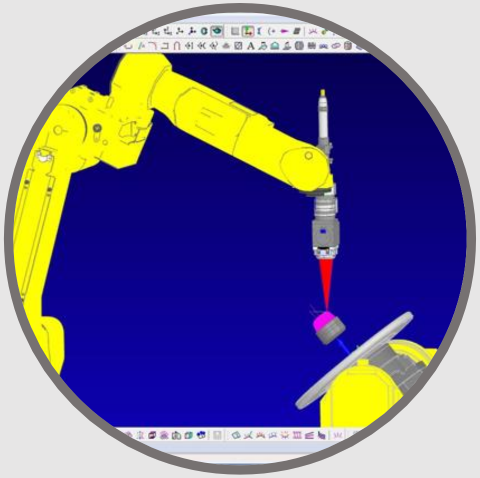
Introduction to arc welding processes



Introduction to arc welding processes

ENERGY SOURCE (POWER SOURCE AND TORCH) + SHIELDING

BUILD PLATFORM (ROBOT / CNC SYSTEM)



CAM SOFTWARE

PRACTICAL PROCESS KNOWLEDGE

DIGITAL TOOLS

MULTIPLE PROCESS INTEGRATION

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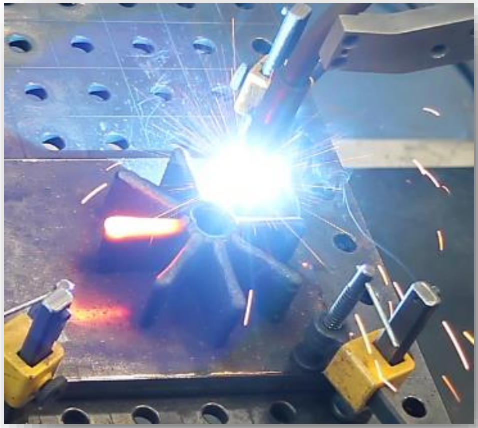
Introduction to arc welding processes

WAAM (Wire and Arc Additive Manufacturing)

- 3D part manufacturing by superimposing molten weld beads
- Electric arc as a heat source: TIG, MIG/MAG, PAW.
- Metallic wire as feedstock
- Large to medium parts with low to medium complex geometry



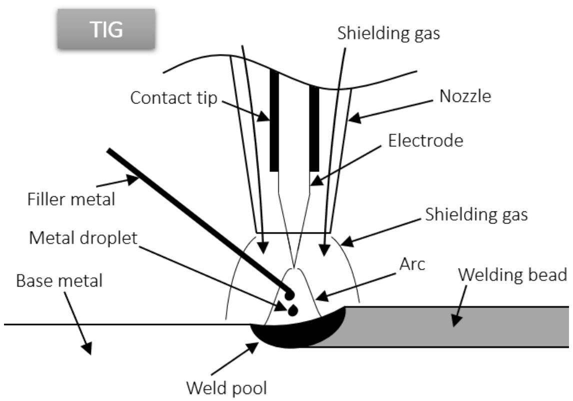
Advantages:

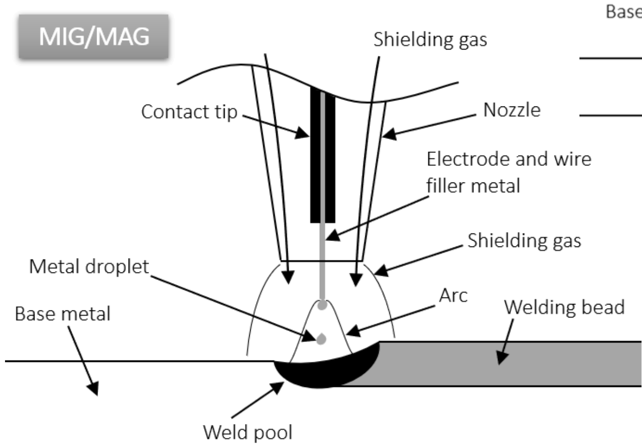
- Low BTF → sustainability
- Minimum human intervention and setup times
- Low capital cost
- Available welding equipment, manipulators, filler metals
- Unlimited build envelope
- High deposition rates
- Personalisation
- Repairing
- Functionalisation

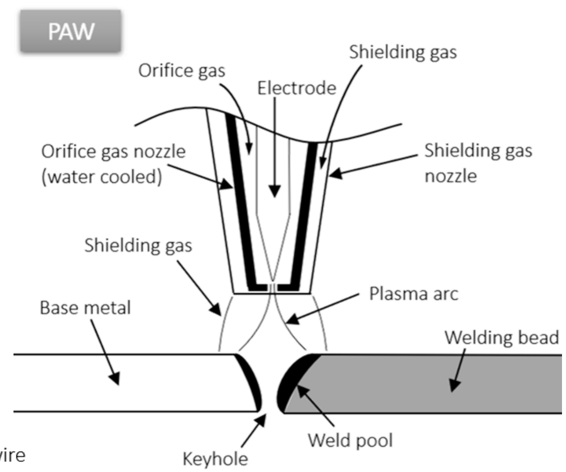
Limitations:

- Residual stresses and distortion
- Poor part accuracy
- Poor surface (waviness: 0,5 mm) → Milling post process

Introduction to arc welding processes



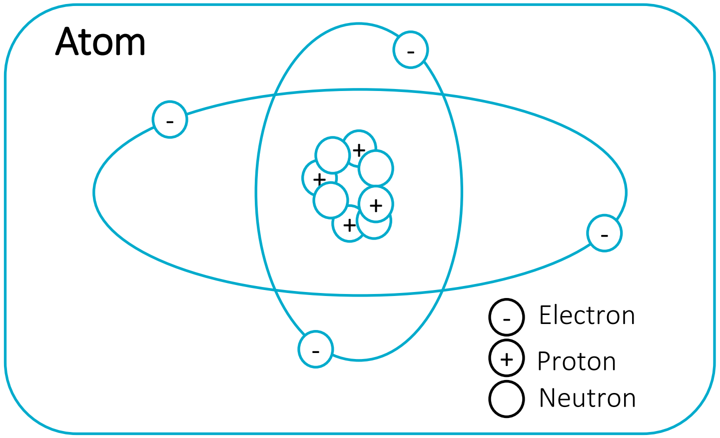




Process	Characteristics	Main Limitation
GMAW Gas Metal Arc Welding	• Consumable wire electrode • Typical deposition rate 3-4 kg/h	• Poor arc stability, spatter
GTAW Gas Tungsten Arc Welding	• Non consumable electrode • Separate wire feed process • Typical deposition rate 1-2 kg/h	• Low deposition rate • Wire and torch rotation needed (non-coaxial process)
PAW Plasma Arc Welding	• Non consumable electrode • Separate wire feed process • Typical deposition rate 2-4 kg/h	• Wire and torch rotation needed (non-coaxial process)

Basics of electricity

Basics of electricity



Electrical current: Stream of charged particles, such as electrons or ions, moving through an electrical conductor space.

- **Intensity:** the power transferred per unit area
- **Tension:** the pulling force transmitted axially by the means of a string
- **Resistance:** measure of its opposition to the flow

Think of water!

Intensity ≈ water flow rate in a section of the pipes
Tension ≈ pressure difference that moves the water
Resistance ≈ friction between the water and the walls of the pipes

Ohm's law

The current through a conductor between two points is directly proportional to the voltage across the two points and inversely proportional to resistance

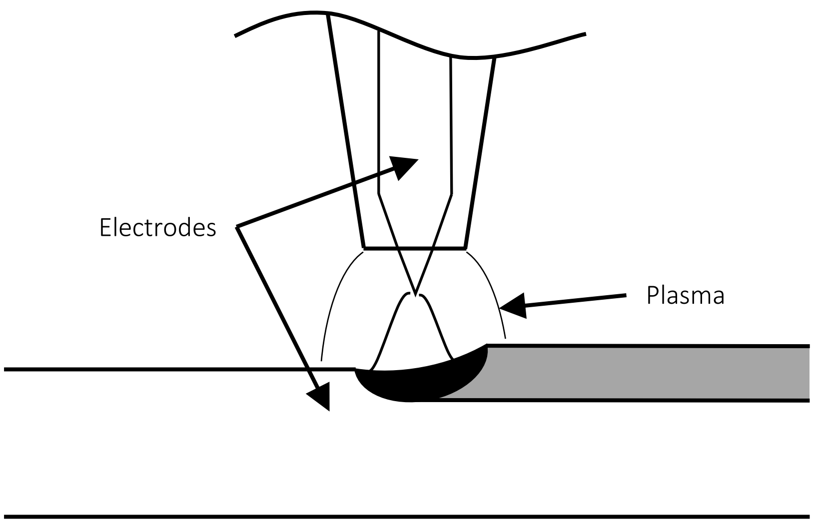
$$I = \frac{V}{R}$$

Nature of the electric arc

Nature of the electric arc

The **electric arc** is a continuous discharge between two slightly separated conductors, through which travels the current when the air or gas between them becomes conductor.

That arc is heat input many welding processes use.



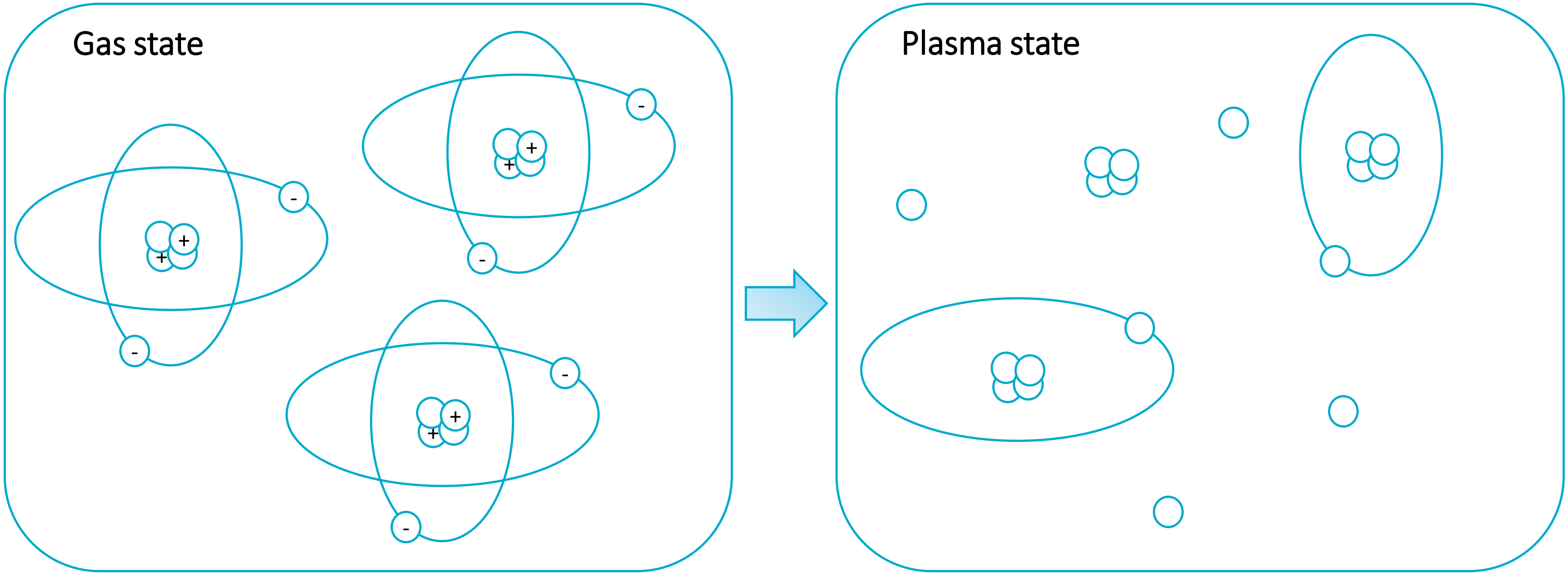
Two main components:

- **Electrodes**: two slightly separated conductors
- **Plasma**: conductor gas

Nature of the electric arc

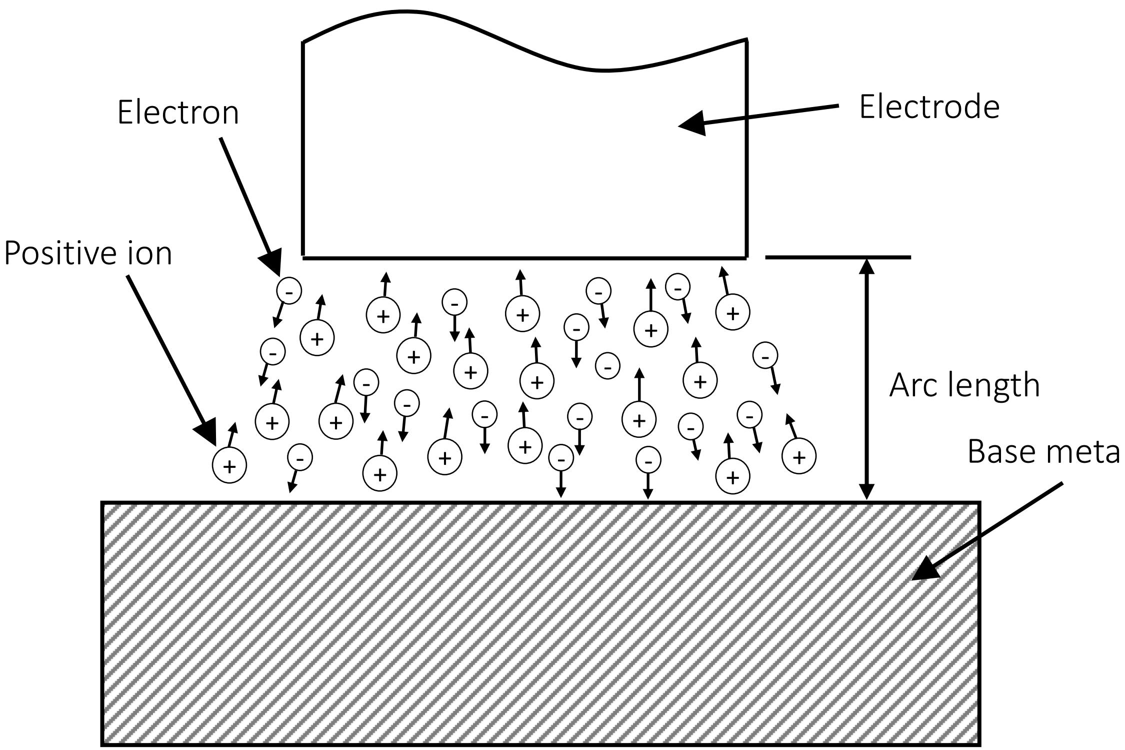
The gas between the two conductor is has to be transformed into a conductor material. That is achieved by separating the atoms into ions and electrons → ***ionization***

The ionization is obtained by clashing electrons coming from the electrode with the gas.



Nature of the electric arc

Electrodes have to be heated in order for the electrons of the electrode to separate and bombard the gas.

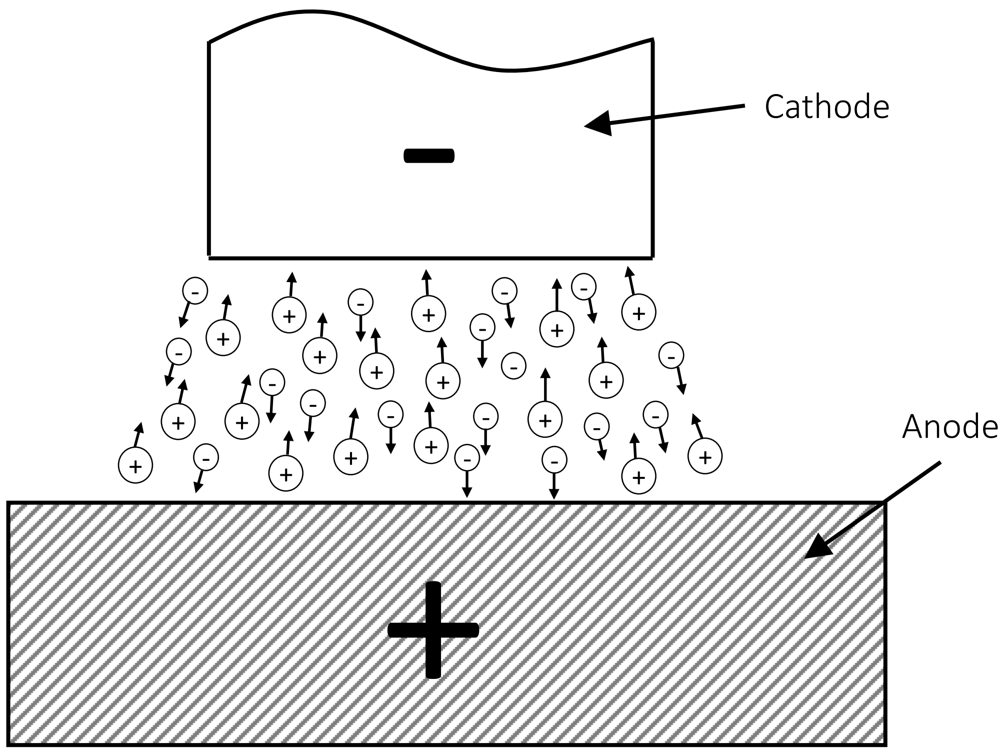


The simplest way to add the energy necessary to move the electrons is to heat the electrode at a high temperature, and the easiest way to heat the electrode is by short-circuiting both conductors.

When a high current travels through the electrode due to the short-circuit, the electrons detached from the cathode ionise the gas by colliding with its atoms.

Nature of the electric arc

The plasma ions travel to the cathode and the electrons travel to the anode, to which they transfer their kinetic energy (movement), that transforms into heat, keeping the high temperature on the anode.



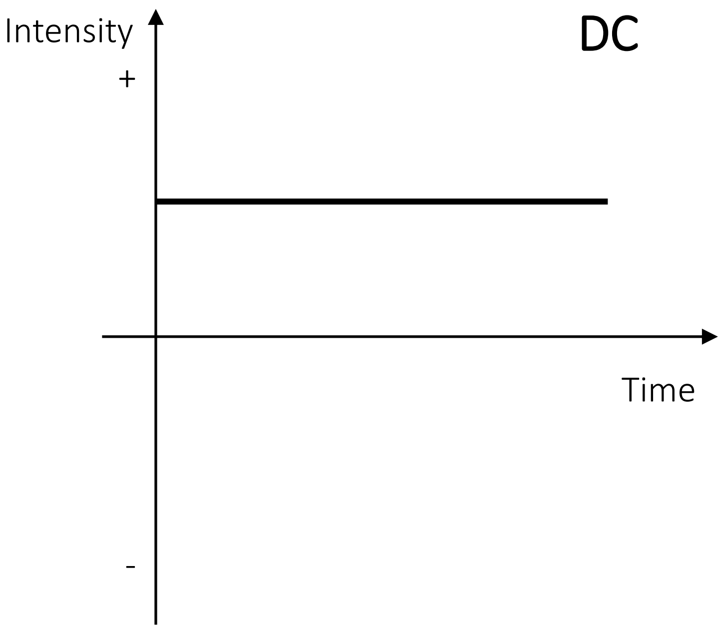
Elements in the arc:

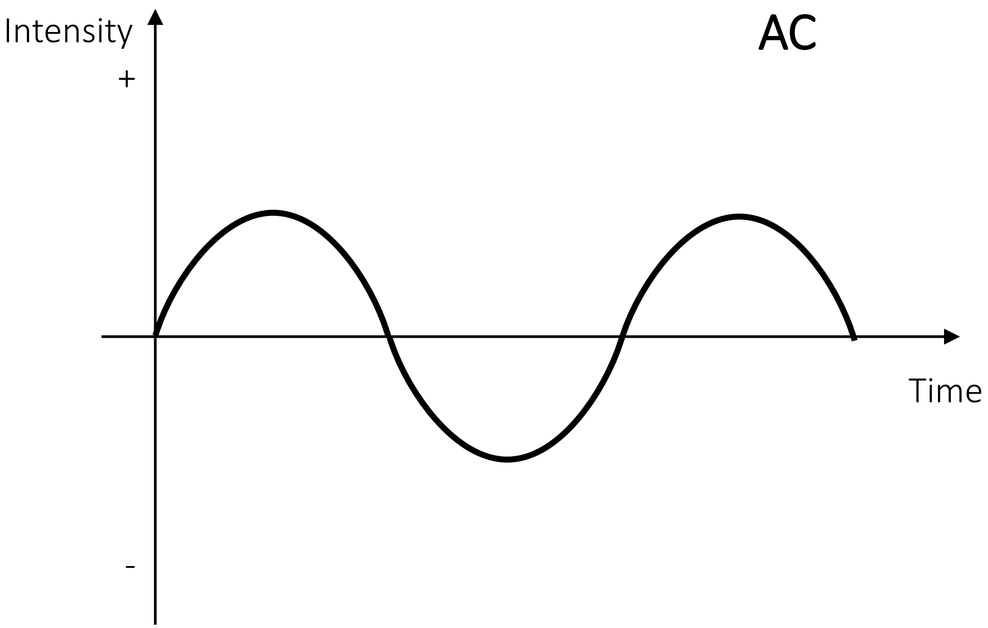
- **Cathode**: Electron emission. Self-cleaning effect (electron collision).
- **Plasma**: Heated gas to a partially ionised state, becoming conductor (~3000ºC)
- **Anode**: Electrons are attracted by the positive charge.

Types of current & polarity

Types of current & polarity

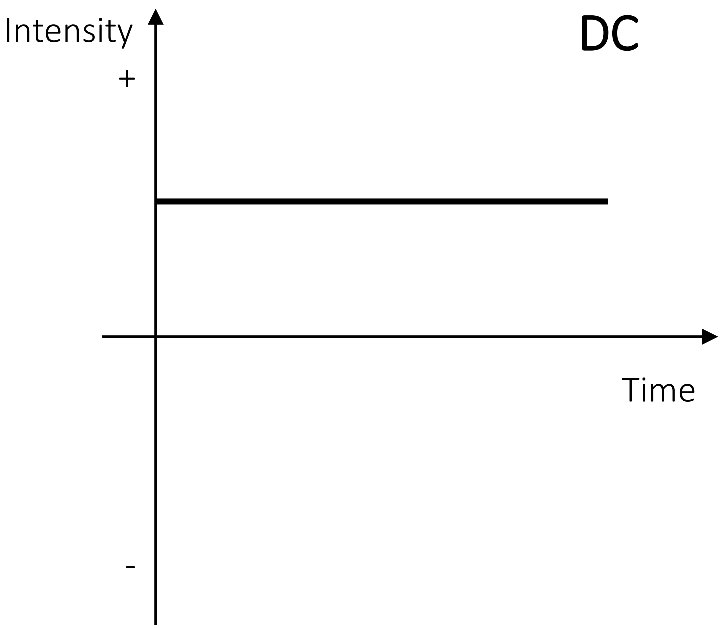
Two types of current: **direct** (DC) and **alternating** (AC).





Types of current & polarity

Direct Current

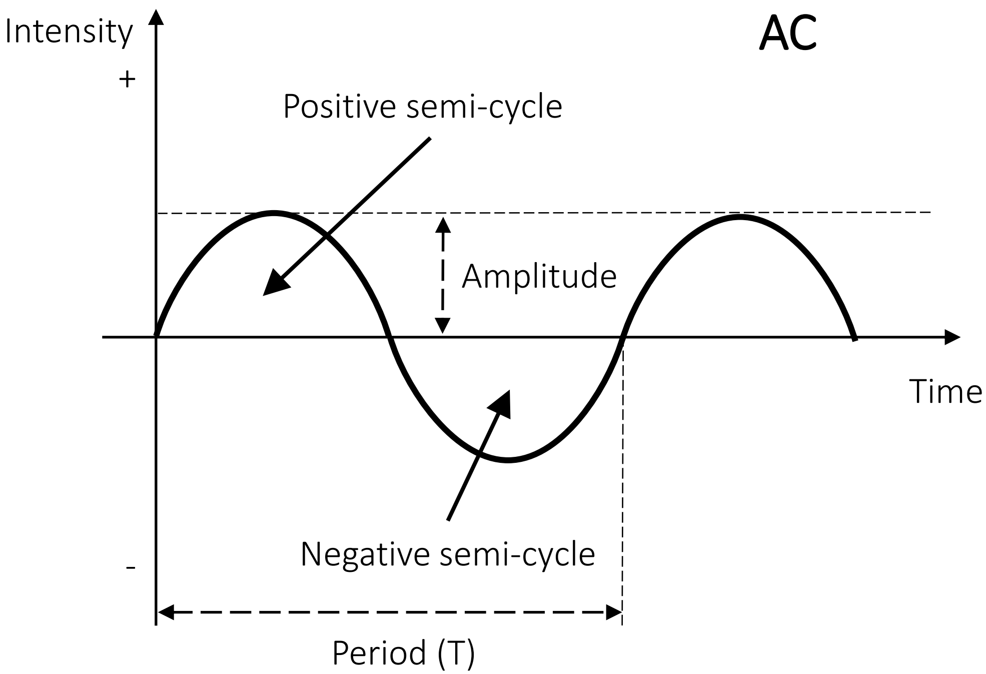


The current circulates in a determined direction constantly.

There is one terminal with the positive pole and the other one with the negative.

Types of current & polarity

Alternating Current



The current changes through time (not constant).

Sinusoidal wave shape that changes direction periodically.

Cycle: a complete wave
Period (T): time to complete a cycle
Frequency: number of cycles per second (f=1/T)
Amplitude: maximum value of the cycle

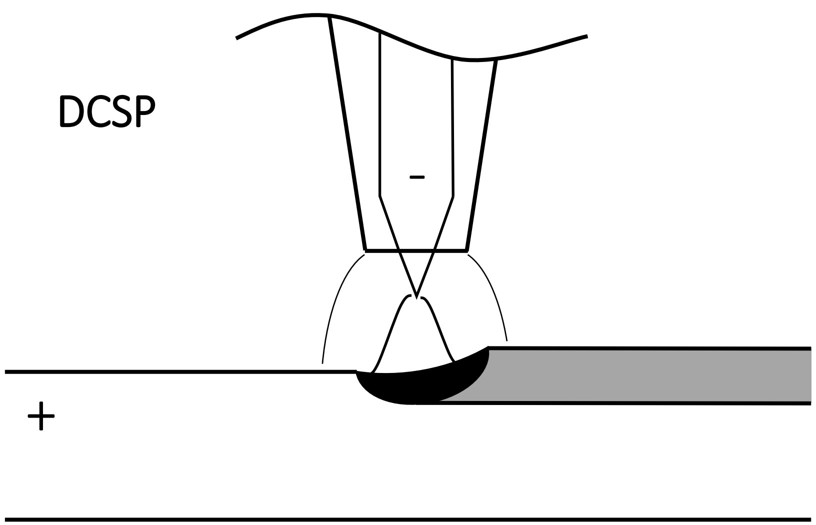
Types of current & polarity

To ignite the arc, AC or DC can be used.

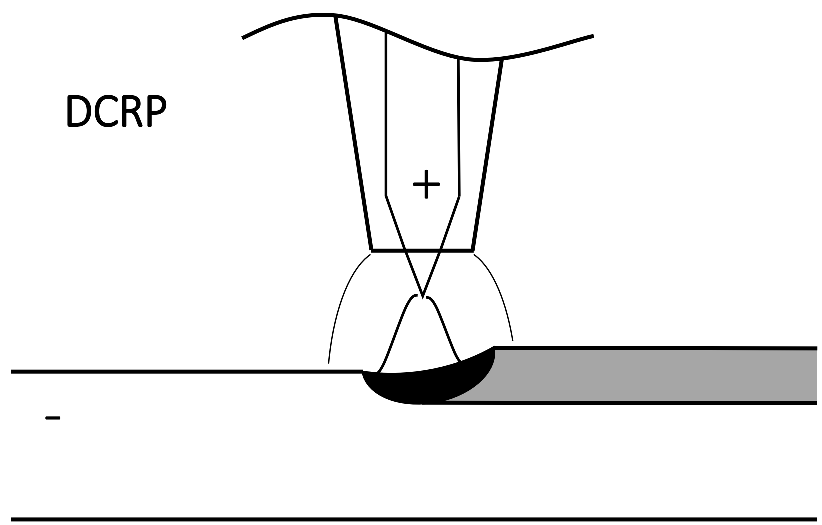
If DC is used, there is a difference between connecting the negative pole to the electrode and the positive to the metal base or the other way around → **Polarity**

AC does not have polarity variation, because the process itself changes polarity periodically.

DCSP



DCRP

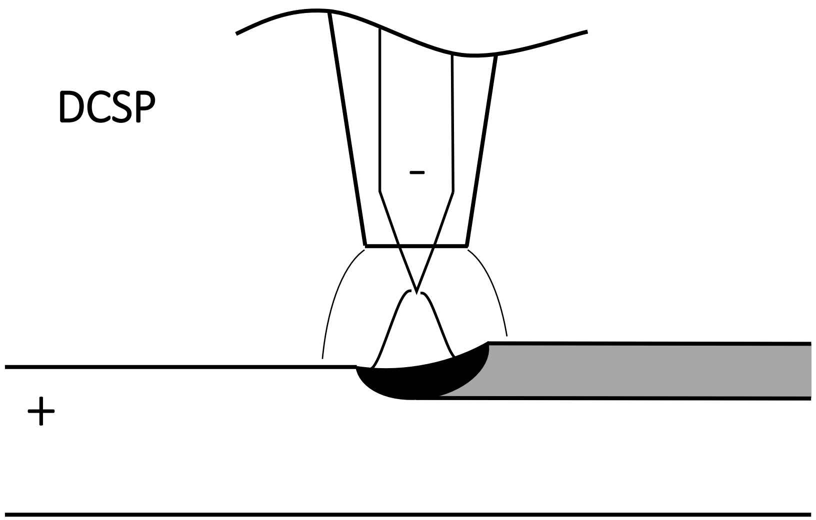


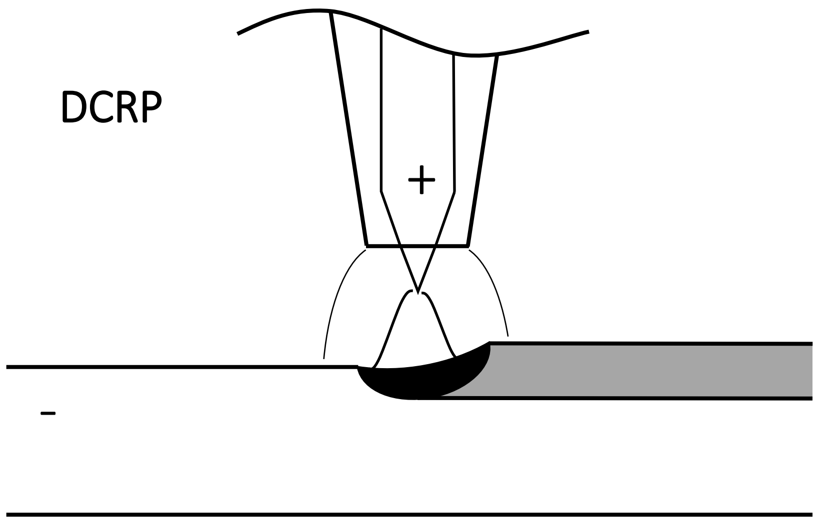
Types of current & polarity

DCSP (Direct Current Straight Polarity) or *negative polarity.*

DCRP (Direct Current Reverse Polarity) or *positive polarity.*

Selection will depend on the welding process and material used





Types of current & polarity

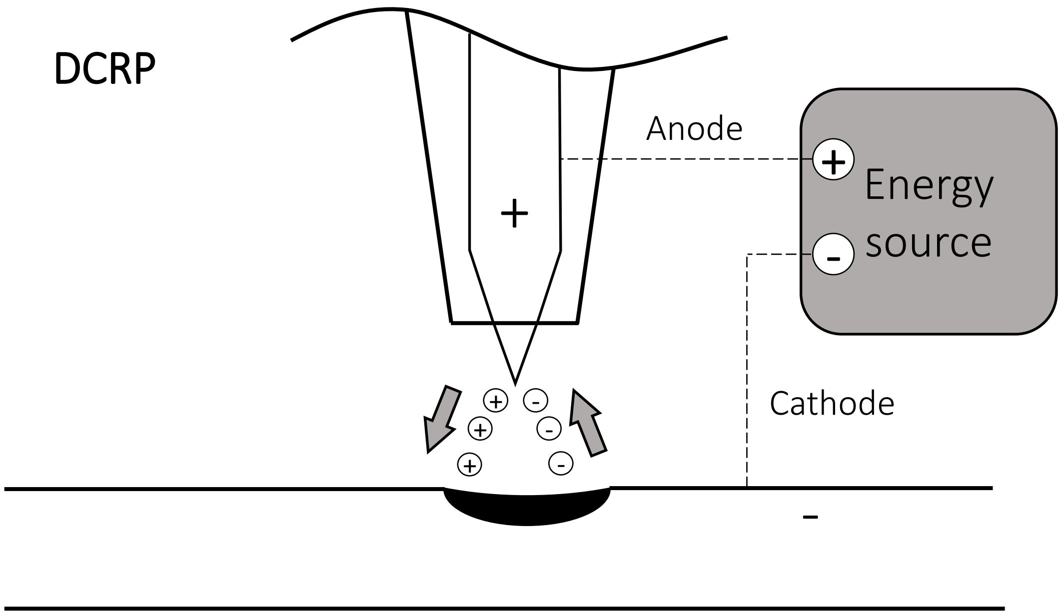
DCRP (Direct Current Reverse Polarity) or *positive polarity.*

Anode is the electrode, the most heated element. The positive ions, when colliding with the cathode have a stripping effect.

This is very important effect to weld aluminium and magnesium alloys, in order to remove the heat-resistant oxide layer from the surface.

Main characteristics:

- Wide welding bead, low penetration
- Fast deterioration of the electrode due to heat accumulation
- Stripping effect



Types of current & polarity

DCSP (Direct Current Straight Polarity) or *negative polarity.*

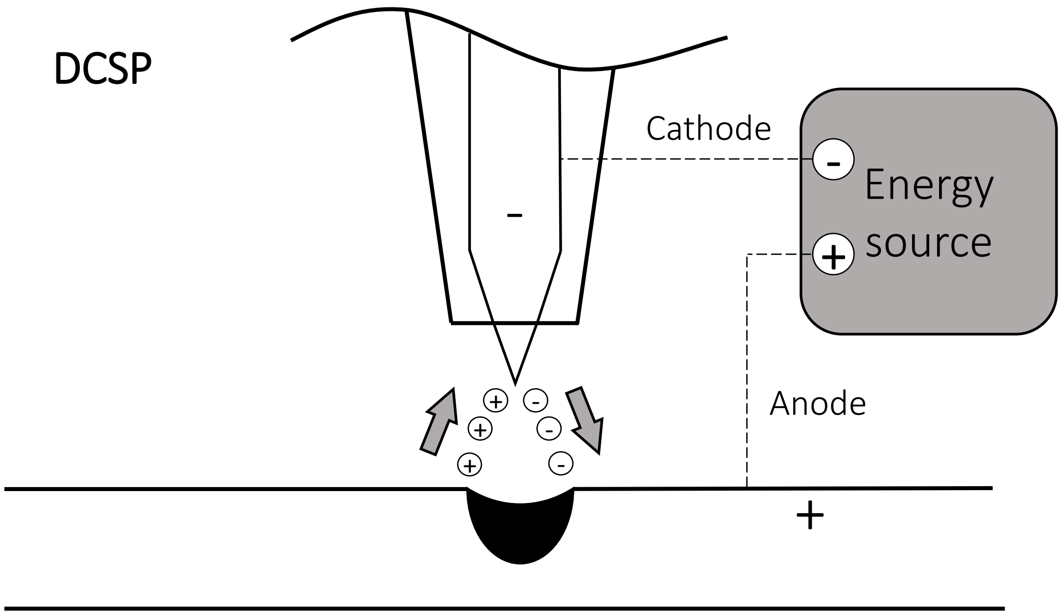
Anode is the metal base, the most heated element.

Main characteristics:

- Thin welding bead, high penetration
- Electrode is capable of enduring eight times more intensity than in DCRP

Not commonly used

DCSP



Types of current & polarity

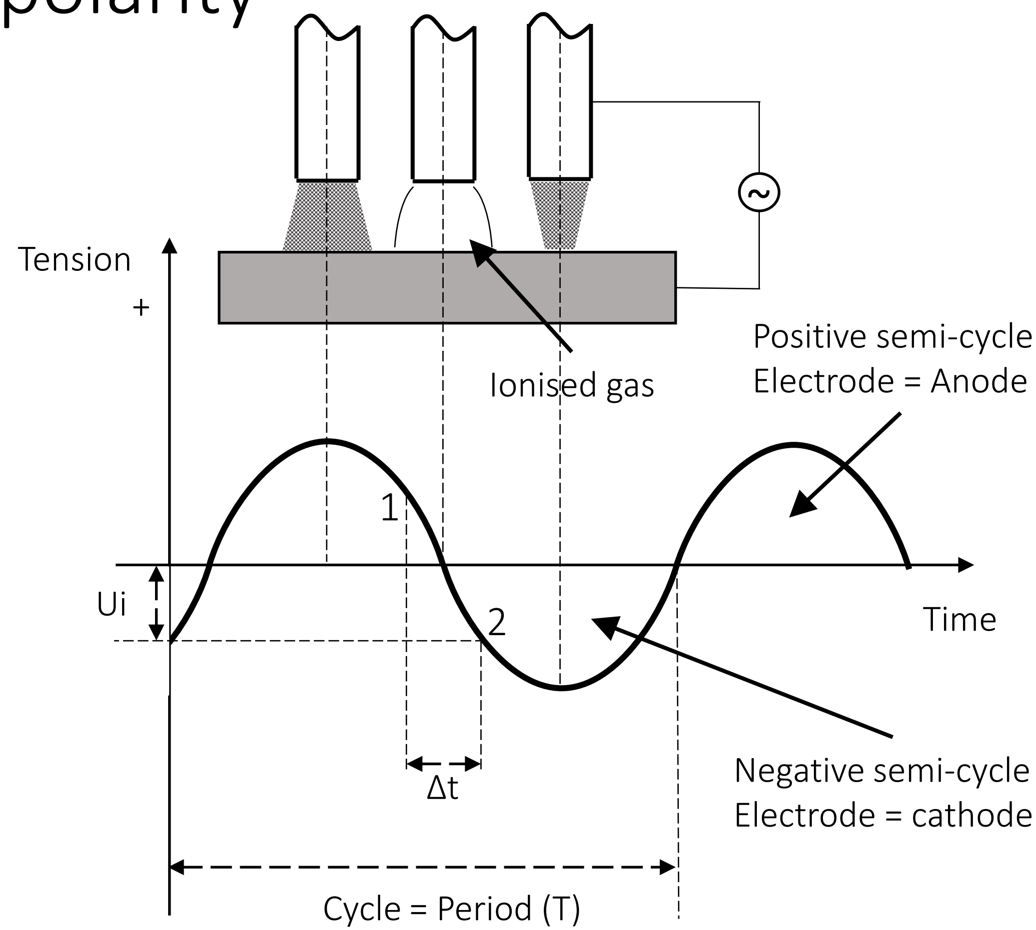
Alternating Current

Electrode periodically changes between cathode and anode.

Because of it, the AC “combines” the advantages of both polarities in DC.

Arc is not stable due to continuous change in tension.

1 – Arc extinguishing point
2 – Arc ignition point
Δt – Time period in which arc is extinct
Ui – Arc igniting tension



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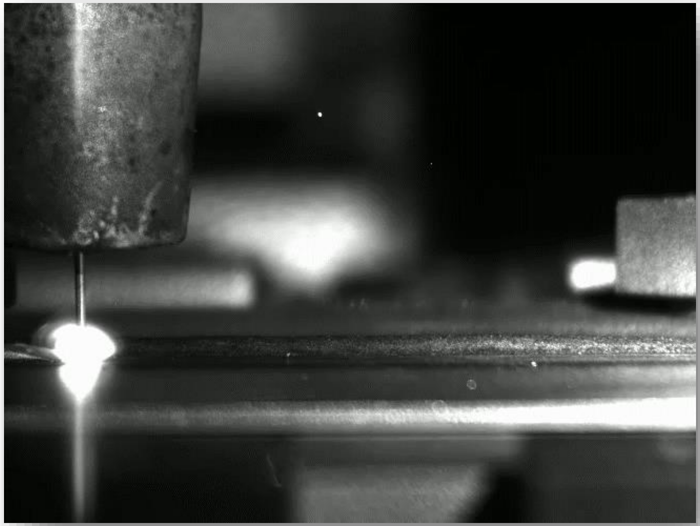
The arc as a heat source

The arc as a heat source

The arc is generated by the energy source, and it has to adapt the current and voltage to suitable values for the welding process.

A key factor is the CTWD (Contact Tip to Work Distance), the longer it is, the higher the resistance. It needs to be kept as constant as possible.

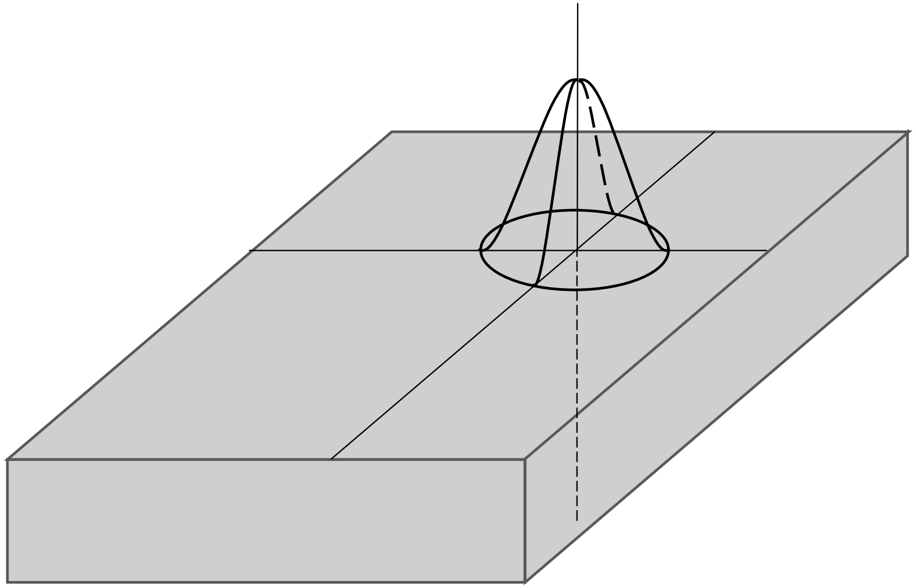
There are some systems that adapt this distance to maintain the welding parameters as stable as possible.

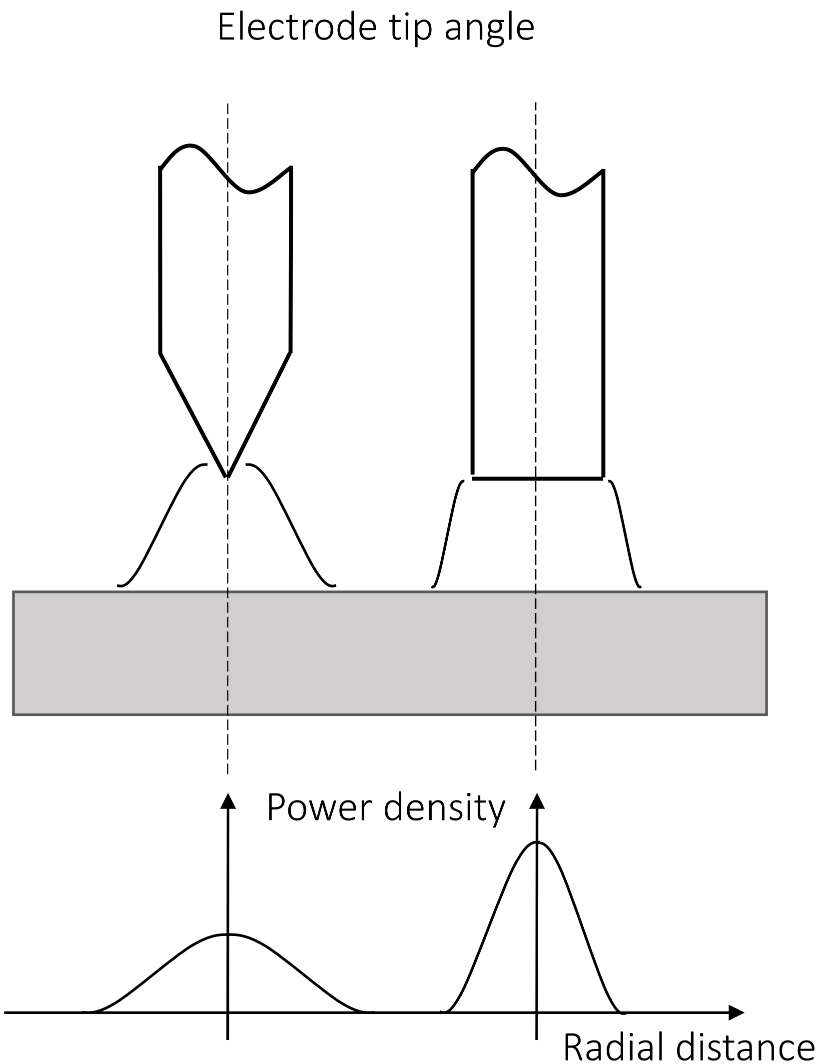


The arc as a heat source

The arc does not distribute the heat uniformly → Gaussian distribution

Temperature ≈ 11.000 ºC

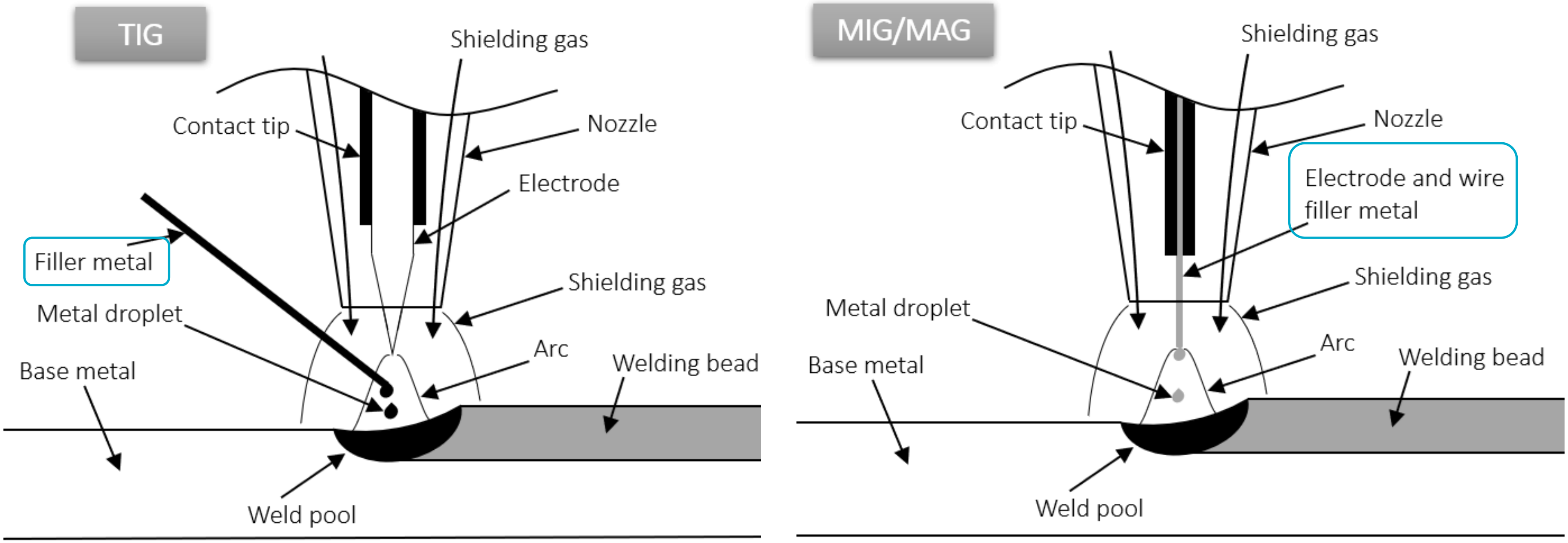




Interaction of the heat source and the feedstock

Interaction of the heat source and the feedstock

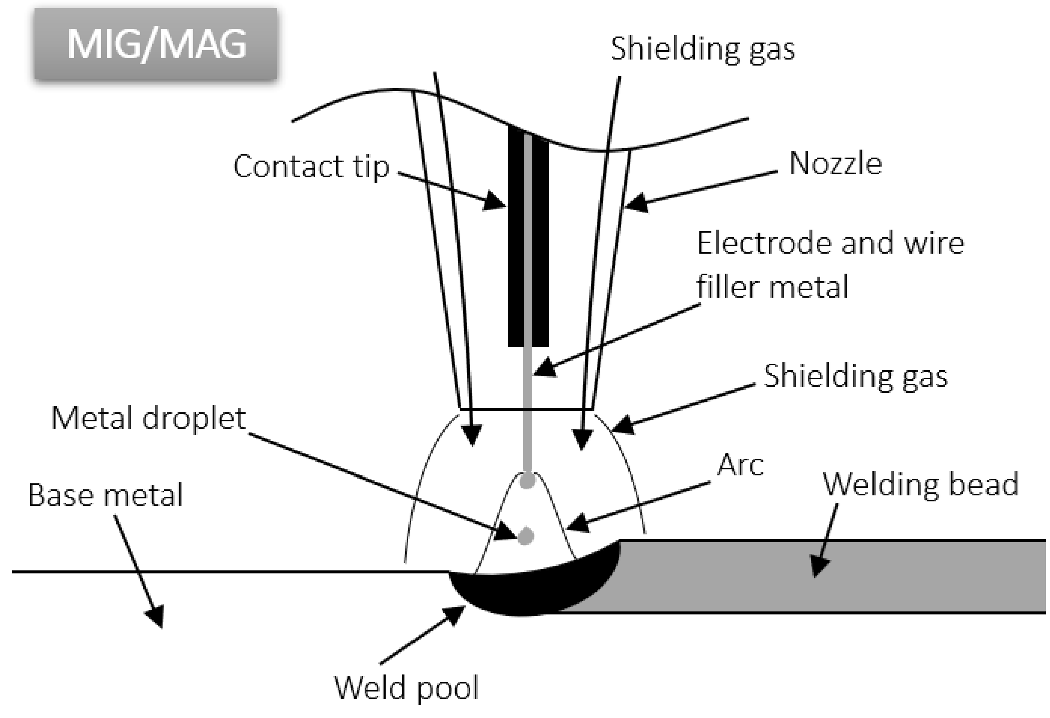
In MIG/MAG processes, the wire is the electrode (concentric), in TIG they are two separate components



Interaction of the heat source and the feedstock

The wire filler metal is the electrode, therefore it is always fed concentrically to the arc.

Welding direction is not relevant.

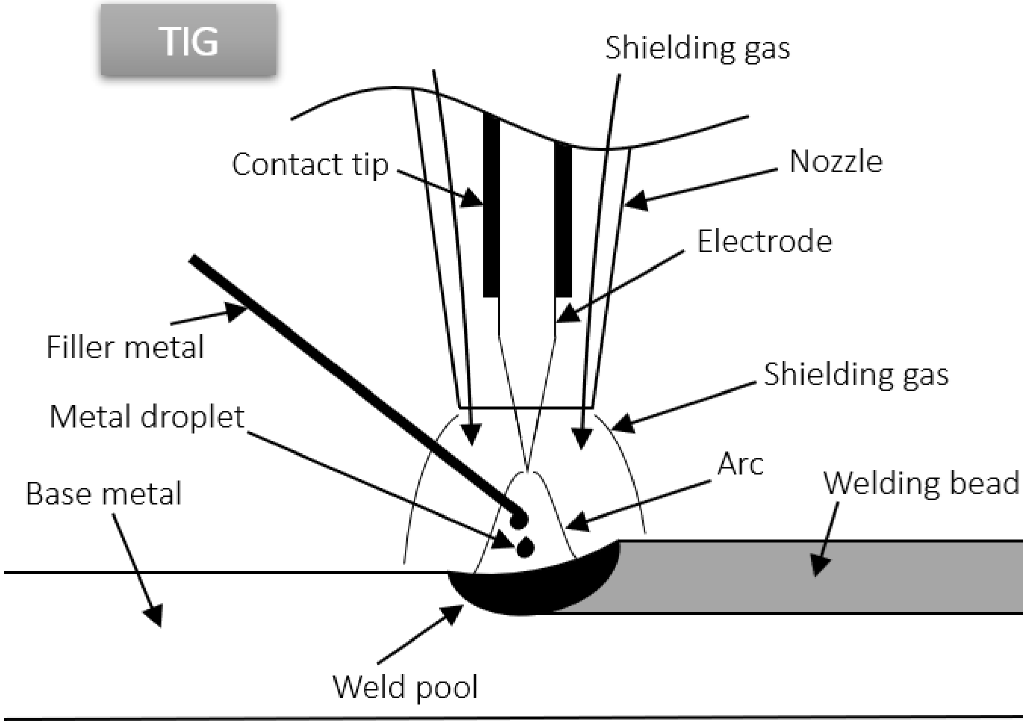


Interaction of the heat source and the feedstock

The wire filler metal is fed from outside → not concentric

The position in which the wire is fed affect the dimensions of the weld pool.

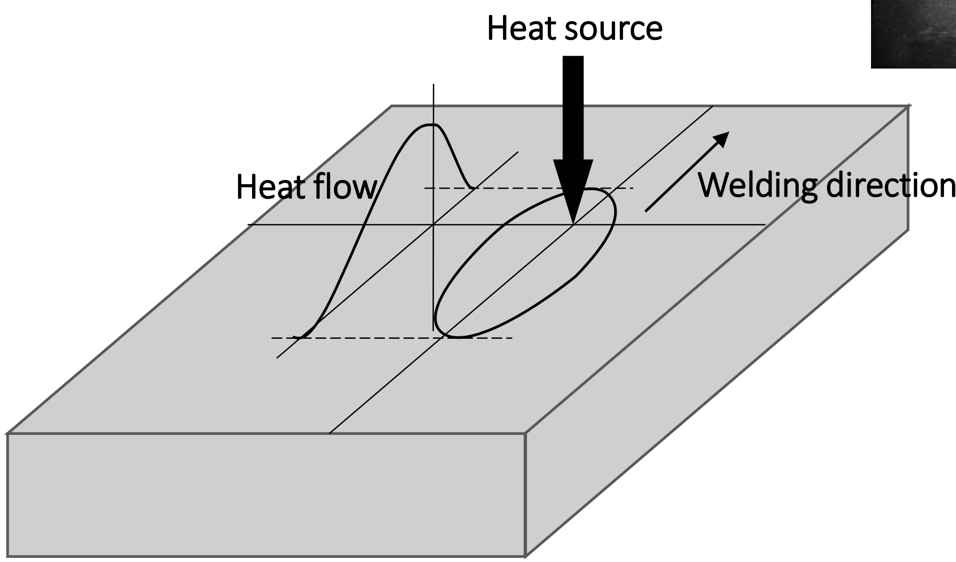
Filler metal usually fed from the front.

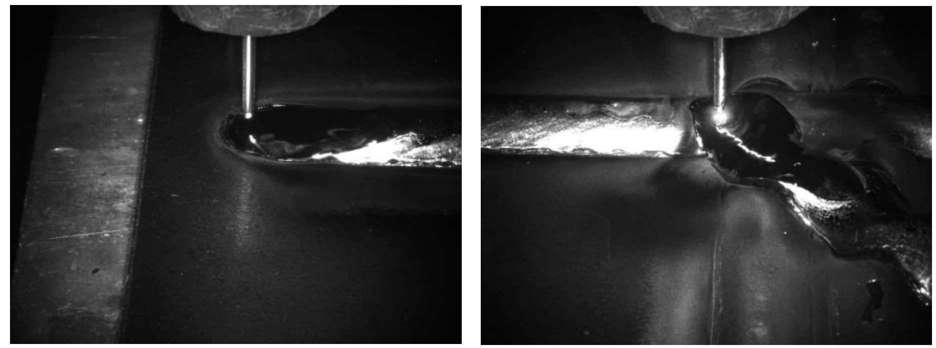


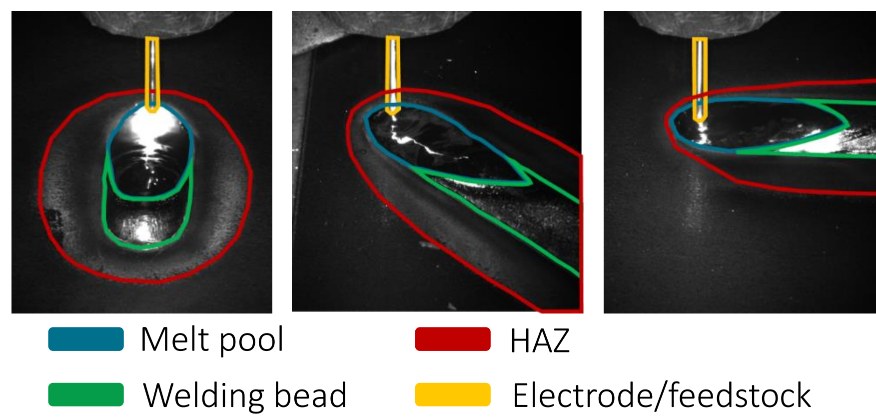
Formation of the weld pool

Formation of the weld pool

The weld pool is not cylindrical, it has an elliptical shape.

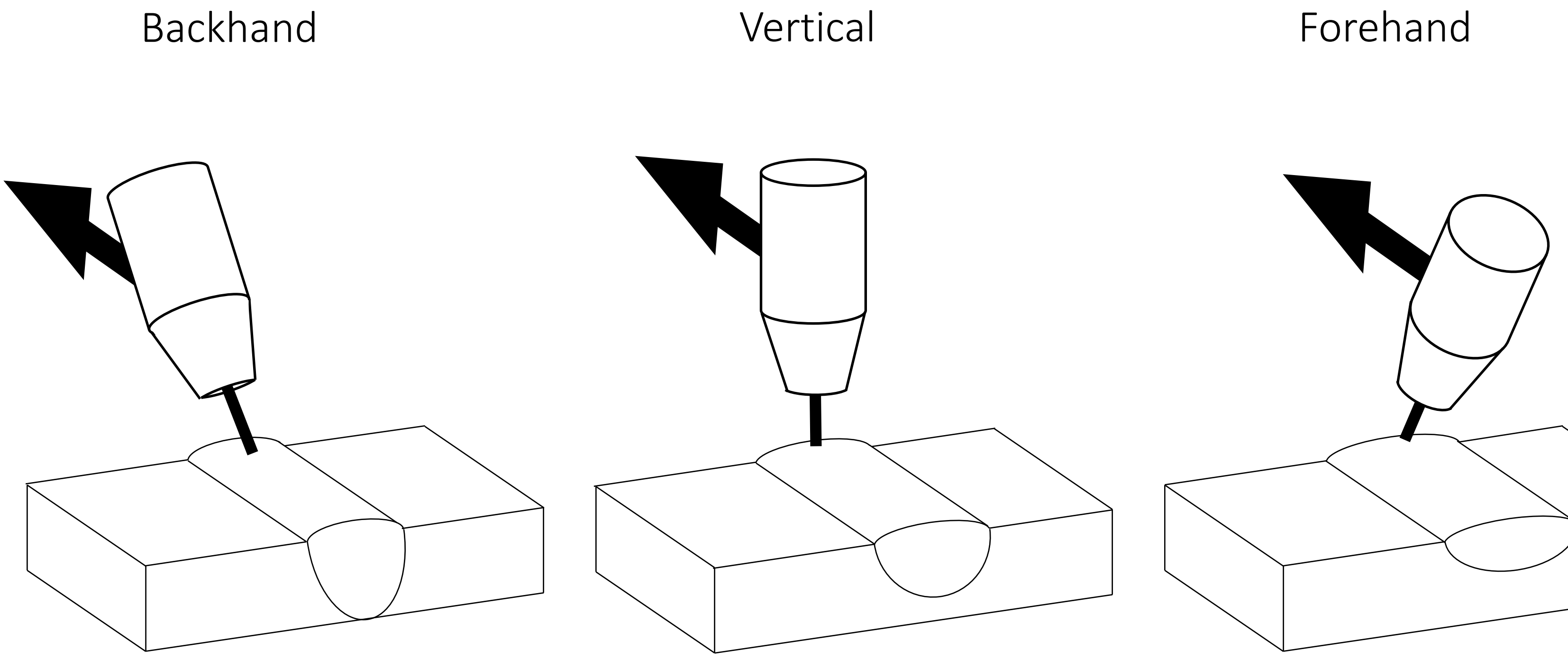






Formation of the weld pool

Torch tilt also affects the shape of the weld pool.



Question time

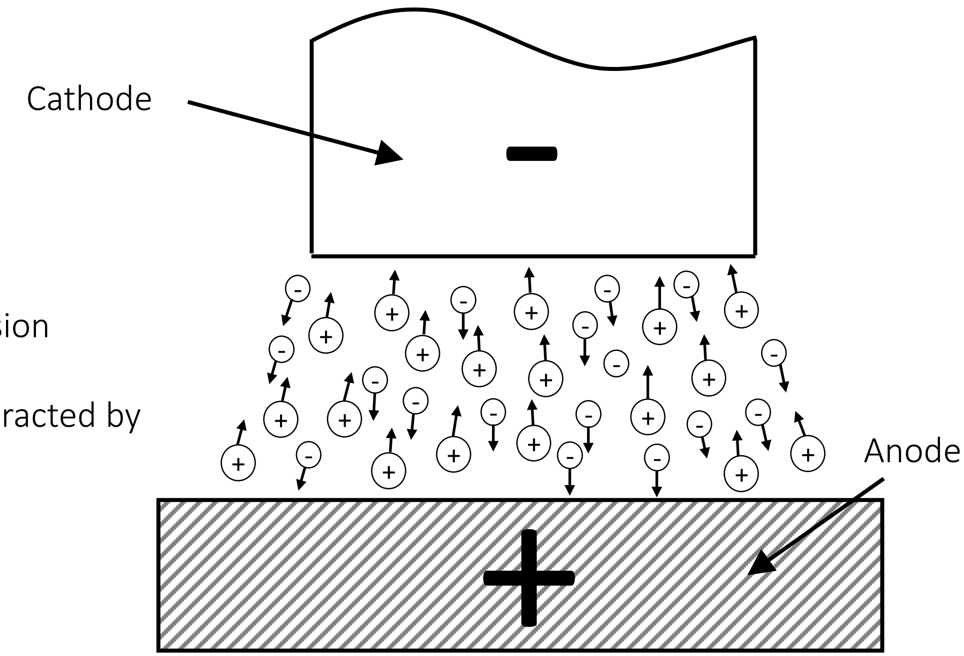
Quiz

5 minutes

https://app.sli.do/event/heo2ern7Zor4y6EzNybofF

Summary

Summary



Arc main components

- Electrode
- Plasma gas

Arc main elements

- Cathode: electron emission
- Plasma gas
- Anode: electrons are attracted by the positive charge

Types of current

- Alternating current: polarity changes periodically
- Direct current → DCSP / DCRP

Time for questions

Lunch break

Session 1.4 – Fundamentals of DED Arc (Part2)

Outline

- Introduction to arc welding processes
- Basics of electricity
- Nature of the electric arc
- Types of current & polarity
- The arc as a heat source
- Interaction of the heat source and the feed-stock
- Formation of the weld pool
- Lunch break
- Shielding gases
- Methods for arc ignition
- Metal transfer modes
- Process principles for common arc welding processes;
    - TIG
    - MIG/MAG
    - PAW

Shielding gases

Shielding gases

Main objective: provide a bridge for the arc, protect the weld pool and help control the cooling rate

Shielding gases are divided in two groups: **active** and **inert**.

Inert gases are very stable gases that do not interact with other elements.

- Argon (Ar)
- Helium (He)

Most used in EU is Argon
Most used in USA is Helium

Active gases react chemically to the temperature of the arc.

- Carbon dioxide (CO_2)
- Hydrogen (H_2)
- Oxygen (O_2)
- Nitrogen (N_2)

Mixtures between Ar or He with any of these elements is considered active.

Not all the shielding gases can be used at a 100% purity: Hydrogen, oxygen and nitrogen are added elements that change the behaviour of the shielding gas.

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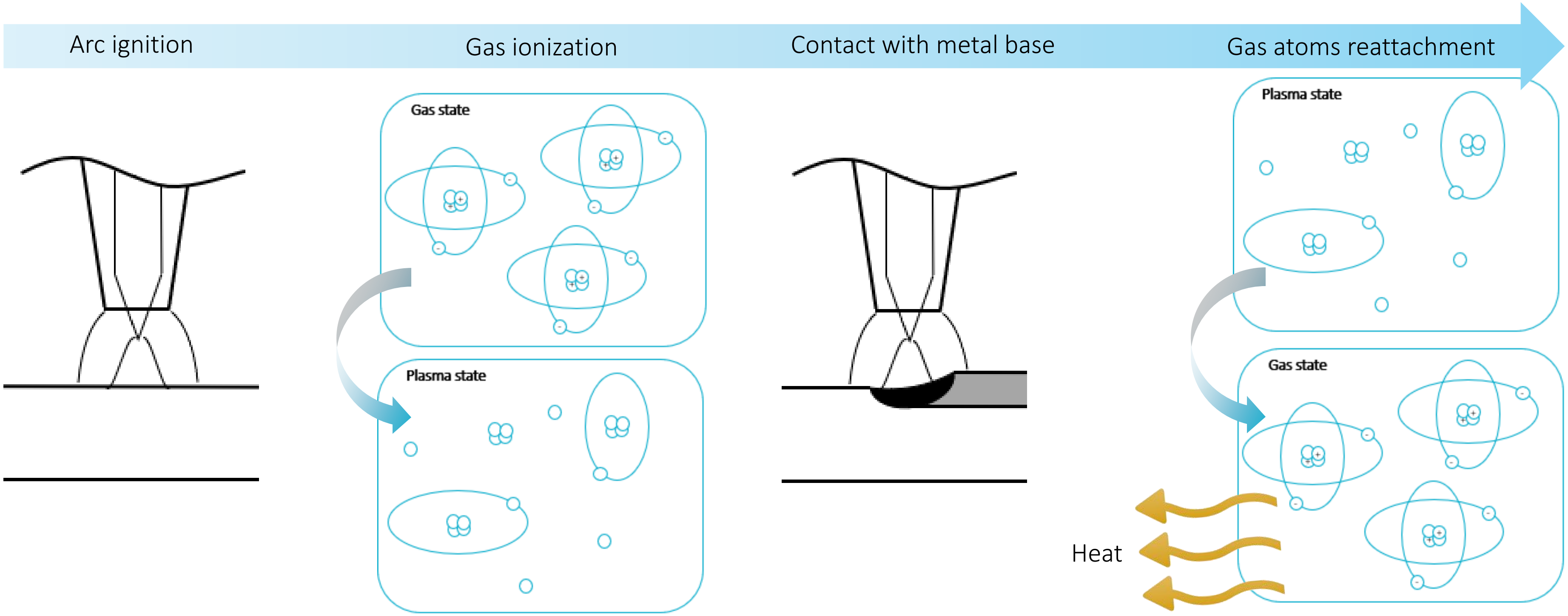
Shielding gases

Gas properties to have in mind:

Ionization energy : The amount of energy required for the atom to loose an electron.



Shielding gases

Gas properties to have in mind:

Ionization energy : The amount of energy required for the atom to loose an electron.

In arc processes, the required energy supply for the gas to ionise and become plasma. The higher the ionization energy of a gas, the more difficult to stablish the arc and less stable but the more heat will be emitted.

Gas	Ionization energy (kJ/mol)
Argon	1520
Helium	2372
Carbon dioxide (CO_2)	1330
Hydrogen (H_2)	1312
Oxygen (O_2)	1313
Nitrogen (N_2)	1402

Shielding gases

Gas properties to have in mind:

Density: amount of mass in a determined volume.

The higher the density of a gas, the less flow rate it will be needed to obtain the same protection, the more easily it covers the area.

Gas	Density (kg/m^3)
Argon	1,784
Helium	0,167
Carbon dioxide (CO_2)	1,976
Hydrogen (H_2)	0,0899
Oxygen (O_2)	1,429
Nitrogen (N_2)	1,251

Shielding gases

Gas properties to have in mind:

Thermal conductivity: easiness to transmit heat.

The higher the thermal conductivity, the more homogeneous the arc will be.

Gas	Thermal conductivity (W/mK)
Argon	0,01772
Helium	0,138
Carbon dioxide (CO_2)	0,0166
Hydrogen (H_2)	0,172
Oxygen (O_2)	0,0238
Nitrogen (N_2)	0,0234

Shielding gases

Main characteristics of the gases:

Argon

- **Efficient shielding due to high density:** argon is 1,4 heavier than air and ten times heavier than helium.
- **Ease arc ignition:** lower ionization energy than helium, which eases the arc ignition
- **Arc stability:** the low ionization energy also originate stable arc and low projections.
- **Economical:** argon is cheaper than helium, although its more expensive than CO_2. In USA there is more helium, which makes it cheaper than argon.
- **Ideal for low thicknesses:** because of the low ionization energy it need less voltage, enabling reduced heat inputs.
- **Welding bead shape and penetration:** argon has less thermal conductivity than helium, therefore heat concentrates in the centre of the arc producing thin welding beads with high penetration.

Shielding gases

Main characteristics of the gases:

Helium

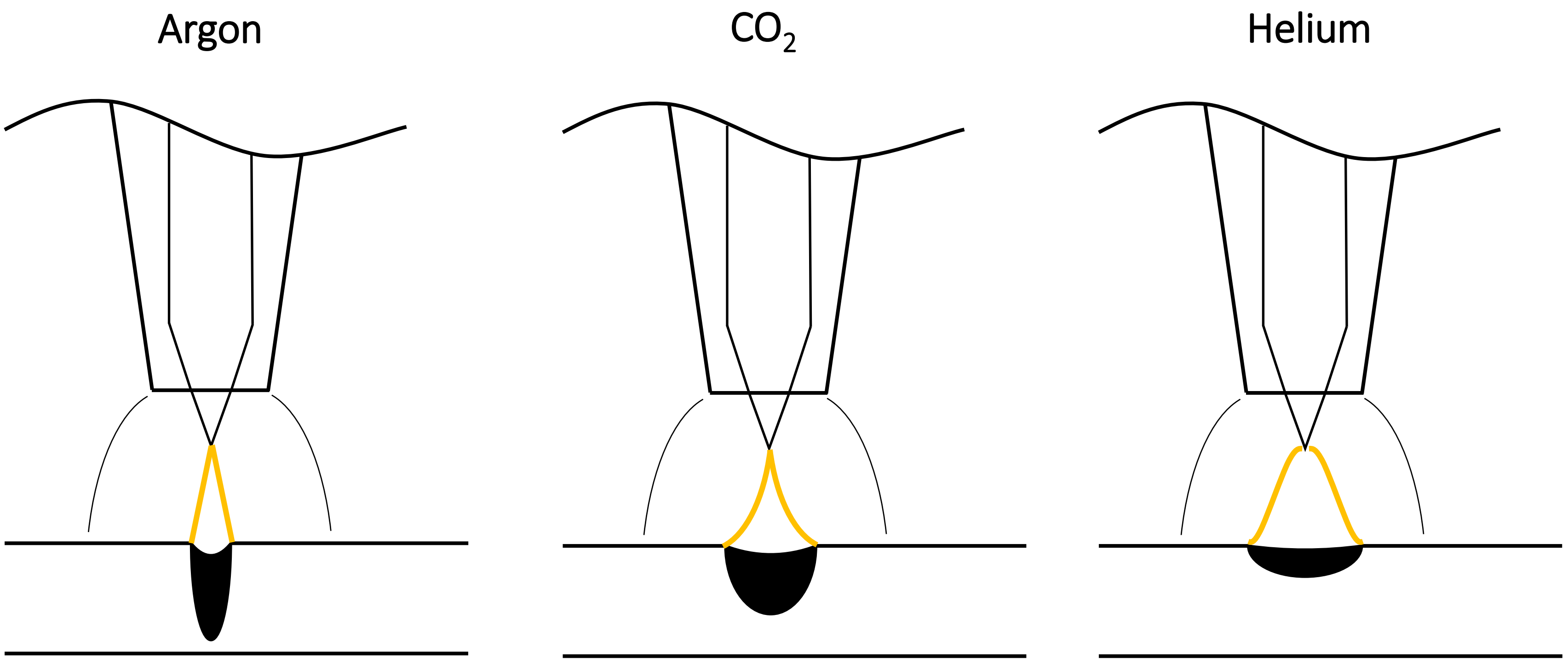
- **High ionization energy:** high heat input, possibility to increase travel speed.
- **High thermal conductivity:** wide welding beads with low penetration. Enables the welding of materials with high thermal conductivity such as copper without preheating needed.
- **Low density:** higher shielding gas flow rates needed, which makes it even more expensive to use.

CO_2 (the only active gas that can be used as shielding gas)

- **Cheap.**
- **High penetration** but the surface of the welding bead is left slightly oxidated.
- **High travel speed** but lots of projections.

Shielding gases

Main characteristics of the gases:



Shielding gases

Addition of other gases

Oxygen

- Stabilize the arc
- Increase the amount of droplet formation
- Improves the appearance of the welding
- Improves the fluency of the welding bead

However it can never be used in large amounts (>8%) because it oxidises the material

Hydrogen

- Increase the heat input
- Enables to increase the travel speed
- Increases the width and penetration of the welding

Only added to argon (up to 5%)

Nitrogen

- Cheap
- Increase the heat input
- Increase the width and penetration of the weld

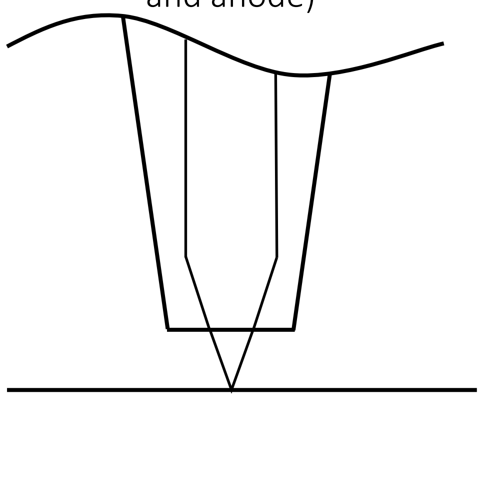
Not common, used almost exclusively to weld copper alloys

Methods of arc ignition

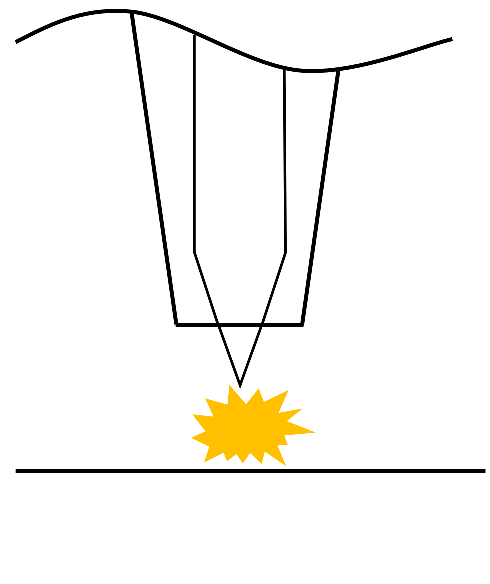
Methods of arc ignition

Two main methods:

Ignition by contact:
short-circuiting between both conductors (cathode and anode)



Ignition without contact:
using auxiliary means



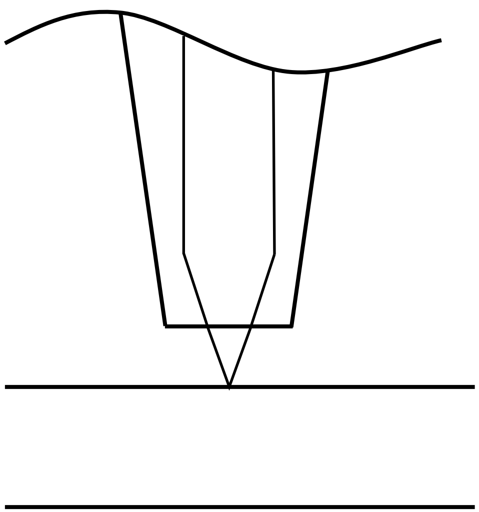
Methods of arc ignition

Ignition by contact

Consists in generating the arc by short-circuiting the electrode and metal base, heating them and favouring the electron emission by the cathode.

Afterwards, separating both elements, electron emission occurs and the gas ionization, igniting the arc.

Note: the contact entails local fusions between the electrode and metal base, leaving "ignition imprints" that have to be removed, and this contact can also contaminate the electrode.



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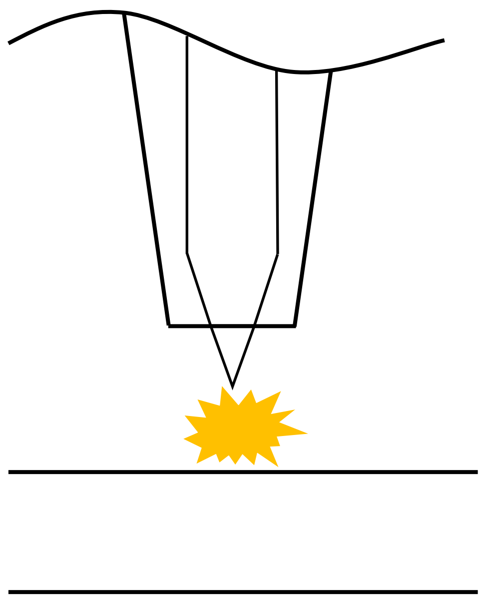
Methods of arc ignition

Ignition without contact

Consists in using high voltage impulses to produce a spark that pre-ionise the gap between conductors. The arc ignites in a 2-3 mm gap.

Useful to avoid electrode contamination.

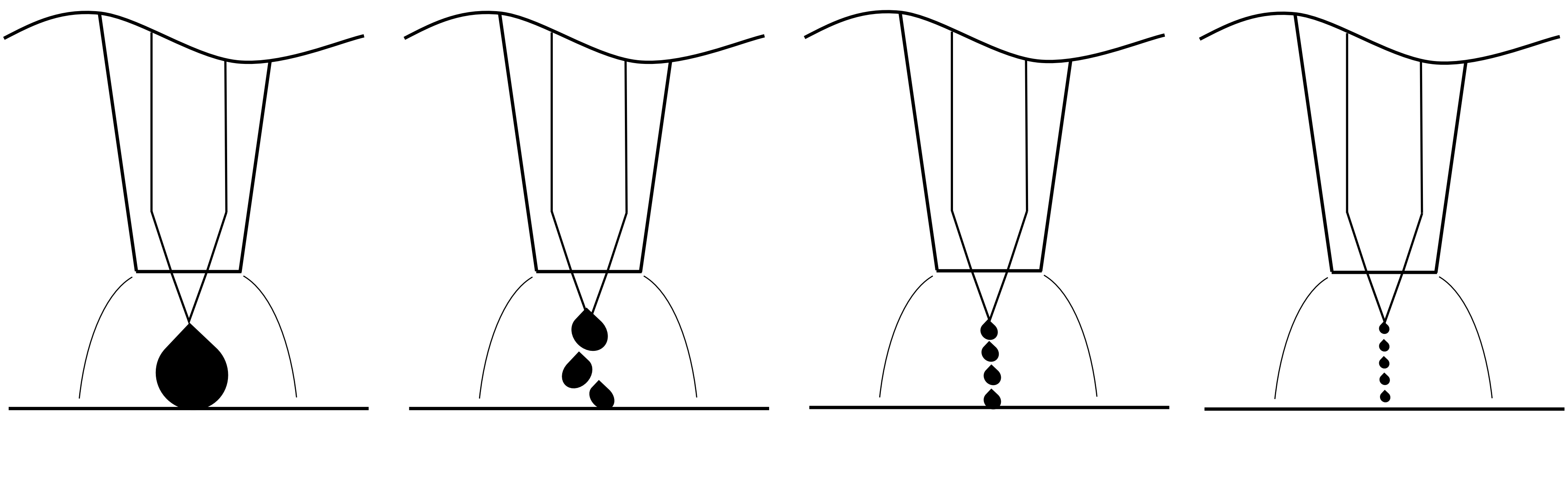


Metal transfer modes

Metal transfer modes

Four main transfer modes:

Short-circuit Globular Pulsed Spray



The determination of which transfer mode is used is influenced by the variables: intensity, electrodes chemical composition, electrode Ø, type of shielding gas, CTWD and voltage.

Metal transfer modes

Least used

	Short-circuit	Globular	Pulsed	Spray
Description	Transfer occurs due to the contact between the electrode and welding bead	Transfer in droplet shape bigger or same size to electrode Ø (gravity)	Transfer in small droplet shape, axial current and electromagnetic force	Transfer in spray shape in regular interval (pulsed current)
Conditions	16-22 V, 50-150 A	20-35 V, 70-255 A With He, CO_2 all the range	24-40 V, 150-500 A	< 20V, < 200 A
Characteristics	• Low voltage and intensity • Small wire Ø • Low heat input: reduced deformation and residual stress • Small welding bead • Welding of small thicknesses • Poor fit-up (tolerance) • Welding in every position • Reduced deposition rate • Ar, He, CO_2 and mixtures	• Intermediate voltage and intensity, considered a transition regime, not wanted • Enables high travel speed • High number of spatter, low welding quality • Low electrode efficiency (87-93%) • Welding in every position for thin wire Ø • Defects: lack of fusion • Cheap process • Ar, He, CO_2 and mixtures	• High voltage and intensity • High heat input: elevated distortions • Big welding bead dimension • To weld horizontally (not every position) • Less spatter • High deposition rates • High electrode efficiency (>98%) • High welding quality • High presence of fumes • Ar and Ar/CO_2 mixtures	• Low heat input: less distortion • Welding of small thicknesses • Lack of spatter • Less defects such as lack of fusion • Less fumes • Welding in every position • High welding travel speed • Ar/CO_2 mixtures
Materials	Steel, Stainless steel and Aluminium	Steel, Stainless steel	Steel, Stainless steel and Aluminium	Steel, Stainless steel and Aluminium

Process principles for common arc welding

Co-funded by the Erasmus+ Programme of the European Union

Question time

Name the most common arc welding processes.

5 minutes

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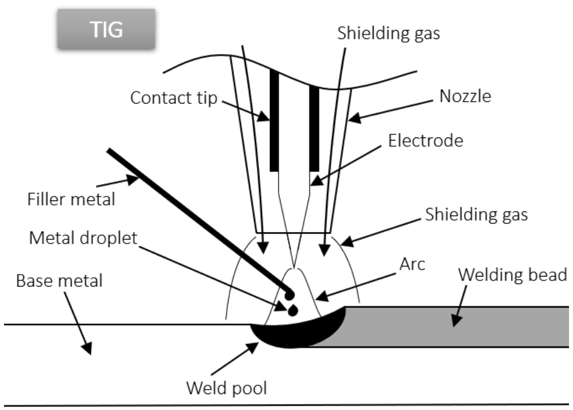
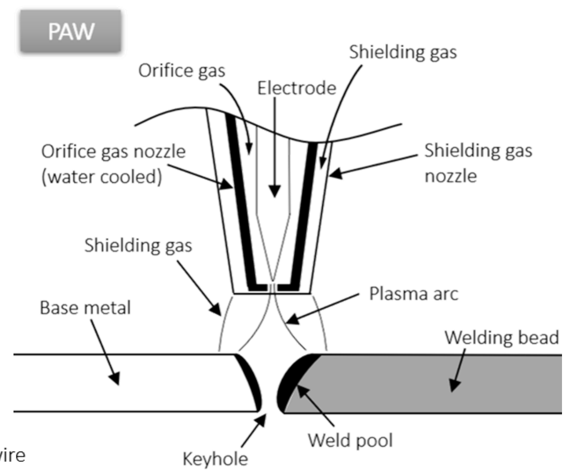
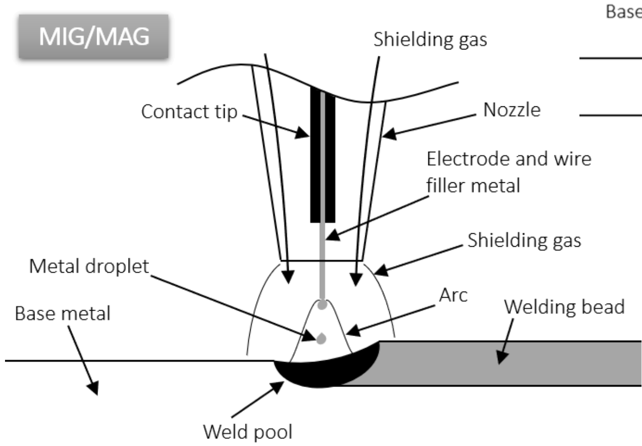
Co-funded by the Erasmus+ Programme of the European Union

Process principles for common arc welding







Process	Characteristics	Main Limitation
GMAW Gas Metal Arc Welding	• Consumable wire electrode • Typical deposition rate 3-4 kg/h	• Poor arc stability, spatter
GTAW Gas Tungsten Arc Welding	• Non consumable electrode • Separate wire feed process • Typical deposition rate 1-2 kg/h	• Low deposition rate • Wire and torch rotation needed (non-coaxial process)
PAW Plasma Arc Welding	• Non consumable electrode • Separate wire feed process • Typical deposition rate 2-4 kg/h	• Wire and torch rotation needed (non-coaxial process)

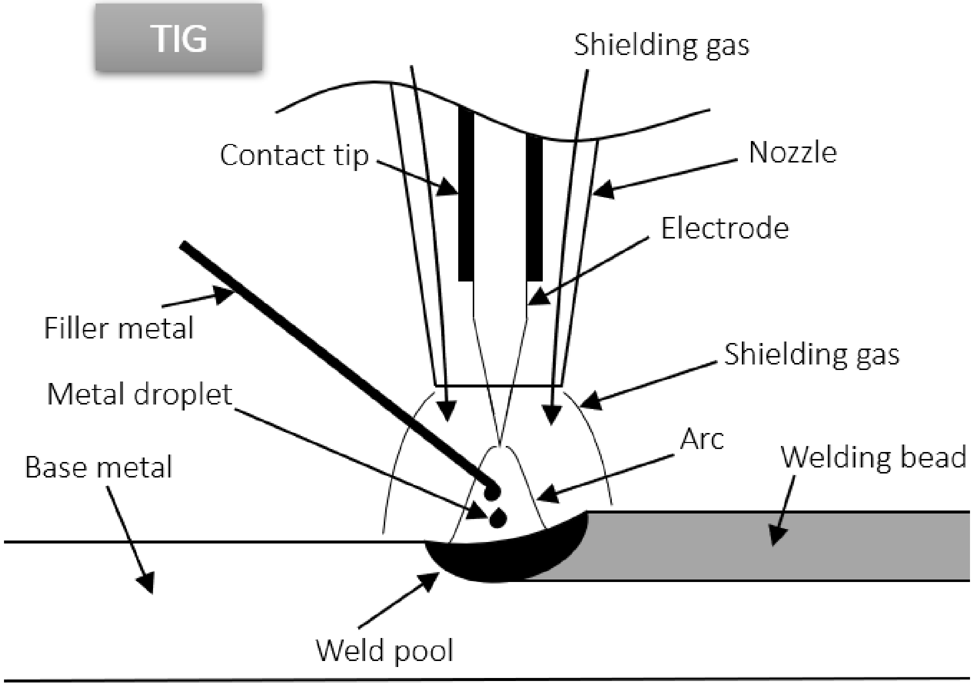
TIG

Tungsten Iner Gas

- Tungsten non consumable electrode
- Inert gas (Argon/Helium)
- Filler metal (optional)

Other names:

- GTAW, Gas Tungsten Arc Welding (ANSI/AWS A3.0)
- Gas-Shielded Tungsten-Arc Welding (United Kingdom)



TIG

Advantages

- Suitable to weld most metals
- Stable and concentrated arc
- Manual/Robotic
- No spatter
- No slag
- Regular and smooth welding
- Filler metal is optional
- Applicable in every position
- High quality
- Excellent penetration control
- Independent control of heat input and wire feed speed

Limitations

- Low deposition rate compared to other processes
- Manual welding relies in welder capability
- Difficulty to protect the welding in the presence of breeze
- Non coaxial process
- Expensive

TIG

Applications

It can be used for almost every material, including aluminium and magnesium and easily oxidating materials such as titanium, zirconium and their alloys.

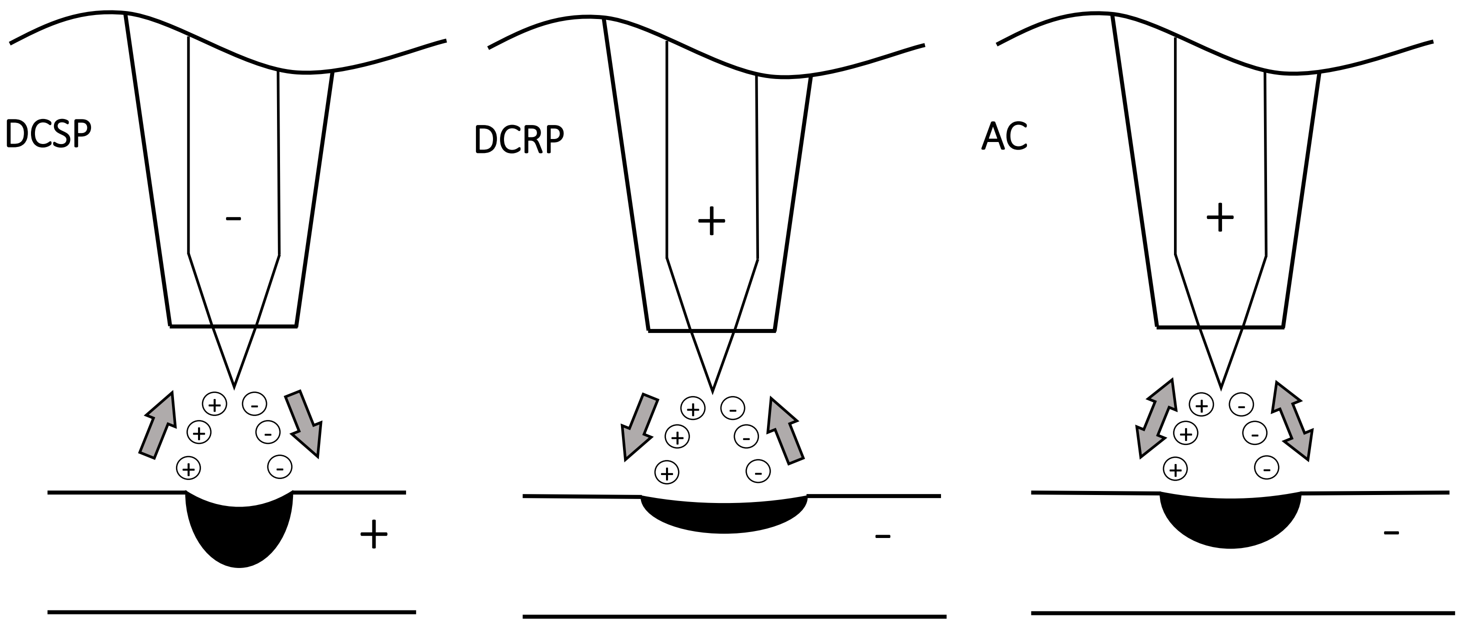
Ideal process to weld parts for the high requirement industries due to the high quality of the welding lacking defects and with smooth surface finish. Among those industries: oil and gas, chemical, petrochemical, food processing, energy, nuclear and aerospace.

Because of its low deposition rate, it is an expensive process to weld thicknesses above 6-8 mm. In those cases, TIG is used in the root welding, and another process is used for the filling.

It can also be used to spot weld.

TIG

Type of current



Stripping effect	No	Yes	Yes. Every other semi-cycle
Heat balance	70% part 30% electrode	30% part 70 % electrode	50% part 50% electrode
Penetration	Thin and deep	Wide and shallow	Medium
Electrode efficiency	Excellent	Poor	Good

TIG

Nozzle or Torch

- **Shape**

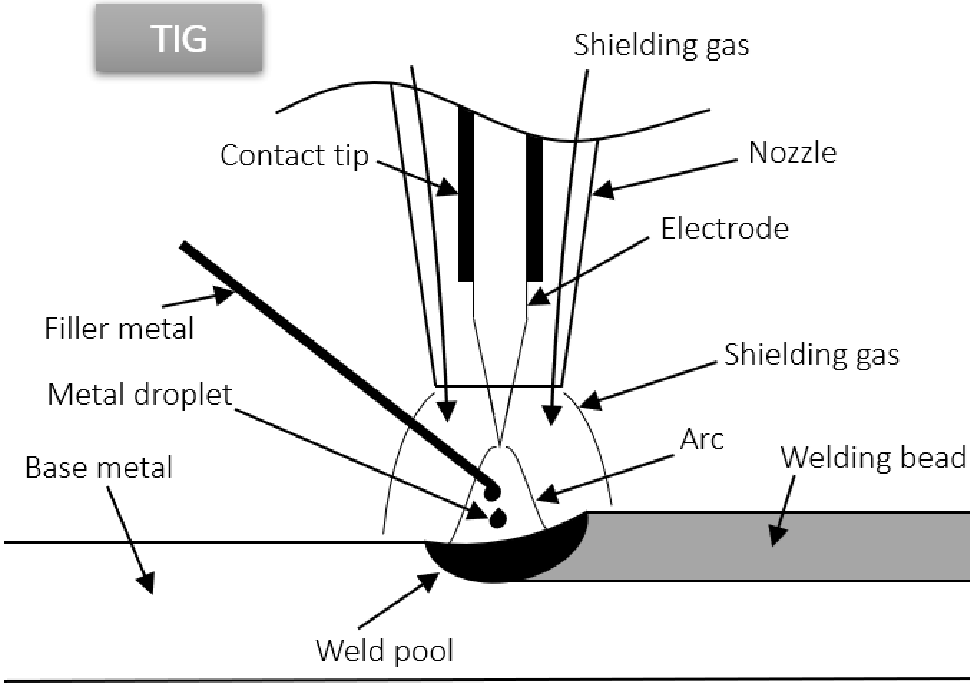
The shape of the nozzle can be straight or conic, depending on the application

- **Material**

The material of the nozzle can be metallic or ceramic

- **Cooling**

The cooling of the nozzle can be carried out by water, coolant or the shielding gas itself



TIG

Type of non consumable electrodes (UNE-EN ISO 6848 and AWS A5-12)

	Symbol	Composition			Identification colour	Equivalent AWS nomenclature
		Added oxide		Minimum wolfram content		
		Nature of the added oxide	%			
Pure	WP	-	-	99,8	Green	EWP
Thorium	WTh10	ThO_2	0,80 – 1,20	Rest	Yellow	EWTh-1
	WTh20	ThO_2	1,70 – 2,20	Rest	Red	EWTh-2
	WTh30	ThO_2	2,80 – 3,20	Rest	Violet	
	WTh40	ThO_2	3,80 – 4,20	Rest	Orange	
Zirconium	WZr3	ZrO_2	0,15 – 0,50	Rest	Brown	EWZr-1
	WZr8	ZrO_2	0,70 – 0,90	Rest	White	
Lanthanum	WLa10	LaO_2	0,90 – 1,20	Rest	Black	EWLa-1
	WLa15	LaO_2	1,30 – 1,70	Rest	Gold	
	WLa20	LaO_2	1,80 – 2,20	Rest	Blue	
Cerium	WCe20	CeO_2	1,80 – 2,20	Rest	Grey	EWCe-2 (orange)

TIG

Types of non consumable electrodes

- **Pure tungsten:** Used with AC to weld Aluminium. Good arc stability and durability.

- **Tungsten with thorium:** Used with DC to weld carbon steel, stainless steel, copper, titanium, etc. Higher emissivity (electron flow), better ignition, higher contamination resistance, and stable arc. Careful! Thorium is radioactive.

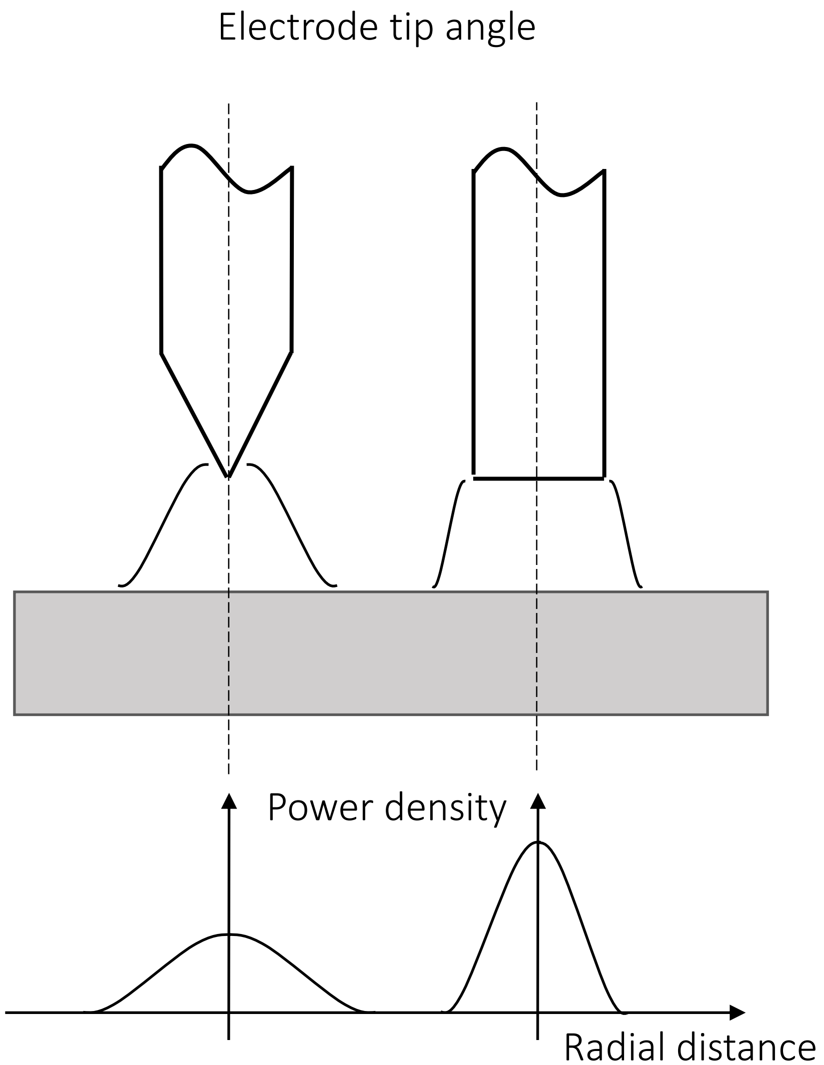
- **Tungsten with zirconium:** Medium characteristics compared to the previous ones. Used in DC and AC. Usually in AC to weld Aluminium and Magnesium.

- **Tungsten with lanthanum and cerium:** Higher intensities can be applied with a stable arc as a result. Used with the same applications as the thorium, but these are not radioactive.

TIG

Types of non consumable electrodes

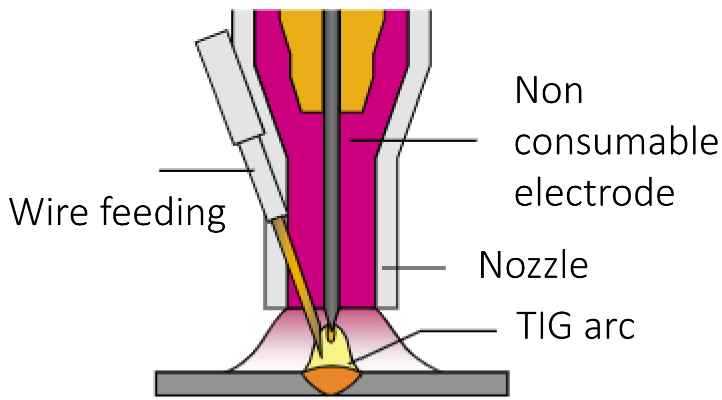
Intensity used related to the electrode diameter			
Ø (mm)	AC	DCSP	DCRP
1	5 – 50	25 – 70	15
1,6	50 – 100	60 – 150	10 – 20
2,4	100 – 160	150 – 200	15 – 30
3,2	130 – 180	200 – 350	25 – 40
4	170 – 240	350 – 520	40 – 60

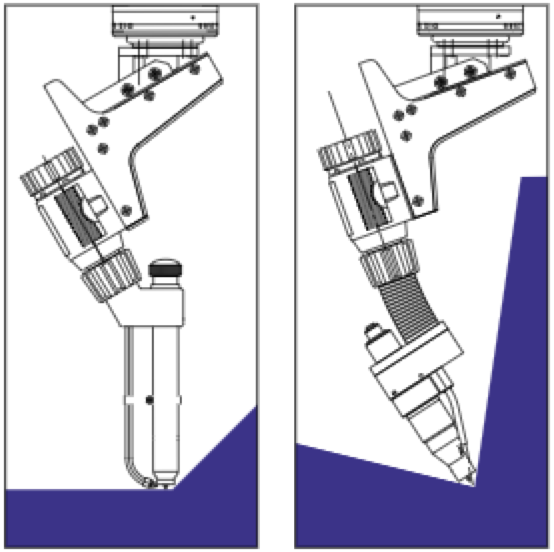


TIG

Process variants:

TOPTIG process changes the torch → wire fed through the torch, process is coaxial





Air Liquide TOPTIG torch
https://docplayer.es/36704038-Toptig-un-nuevo-procedimiento-de-soldadura-robotizada-para-la-industria.html

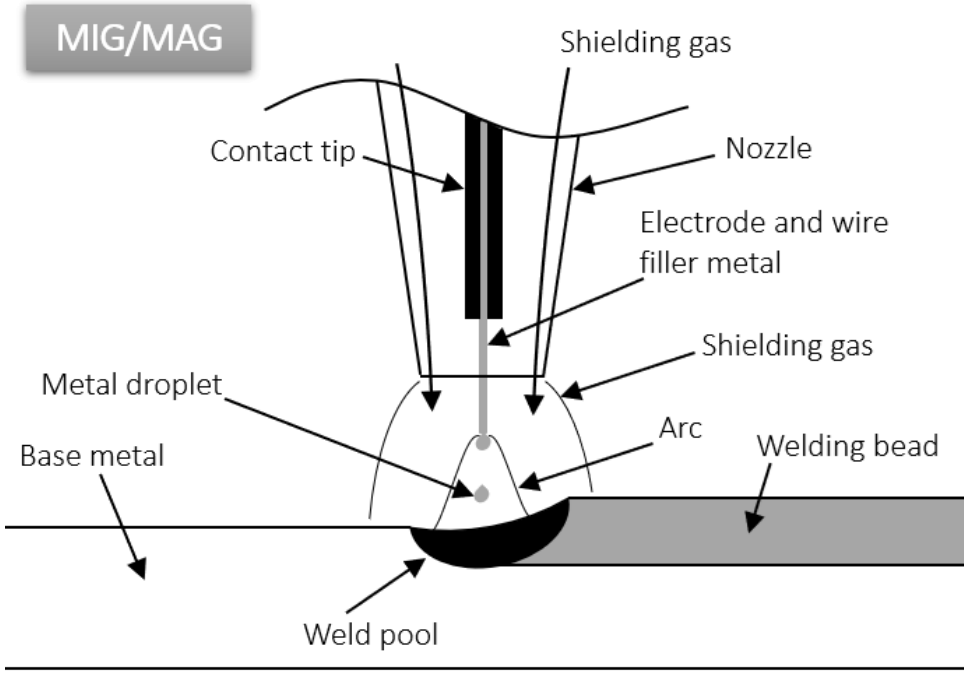
MIG/MAG

Metal Inert Gas/Metal Active Gas

- Electrode is the filler metal (consumable)
- Depending on the gas used
- Filler metal mandatory

Other names:

- GMAW, Gas Metal Arc Welding (ANSI/AWS A3.0)
- MIG, Metal Inert Gas (ANSI/AWS A3.0)
- MAG, Metal Active Gas (ANSI/AWS A3.0)



MIG/MAG

Advantages

- Can be used to weld any material
- Continuous electrode, increase in productivity and high deposition rate
- Higher travel speed achieved compared to TIG
- Weld in every position
- Enable long welding beads without junction between welding beads with high risk of imperfections
- No slag

Limitations

- Poor arc stability, has spatter
- The equipment is more complex, bigger and less transportable
- Process sensitive to superficial contamination that can generate porosity, cracking, lack of fusion, etc
- Process sensitive to breeze, difficult to weld outside

MIG/MAG

Wire feeding

Wire feeding can be carried out by three systems: push, pull and push-pull

- **Push system:** the wire is fed through rollers located in the energy source that push it through the equipment until it reaches the torch.
- **Pull system:** the wire is pulled by rollers placed in the torch.
- **Push-pull system:** if the energy source is far from the torch, ether of the previous systems can be complicated to use, therefore a combination is employed using rollers in both the energy source and torch.

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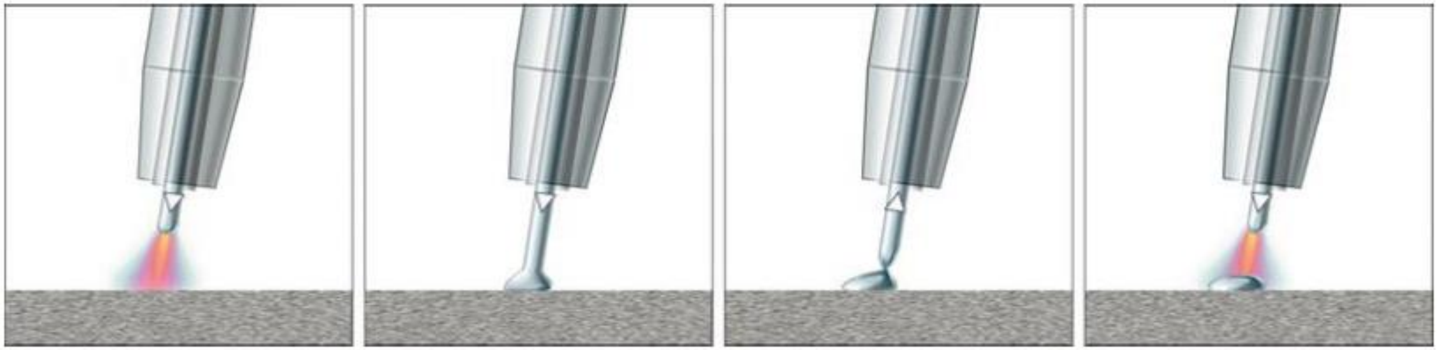
MIG/MAG

Process variants:

CMT (Cold Metal Transfer)



Arc ignites while the wire approaches the weld bead	Arc stops once the wire touches the weld bead	Wire moves backwards helping the metal drop	Arc ignites again starting the forward movement of the wire

Up to 70 times per second

Effect of arc mode in cold metal transfer process on porosity of additively manufactured Al-6.3%Cu alloy (https://doi.org/10.1007/s00170-014-6346-x)

MIG/MAG

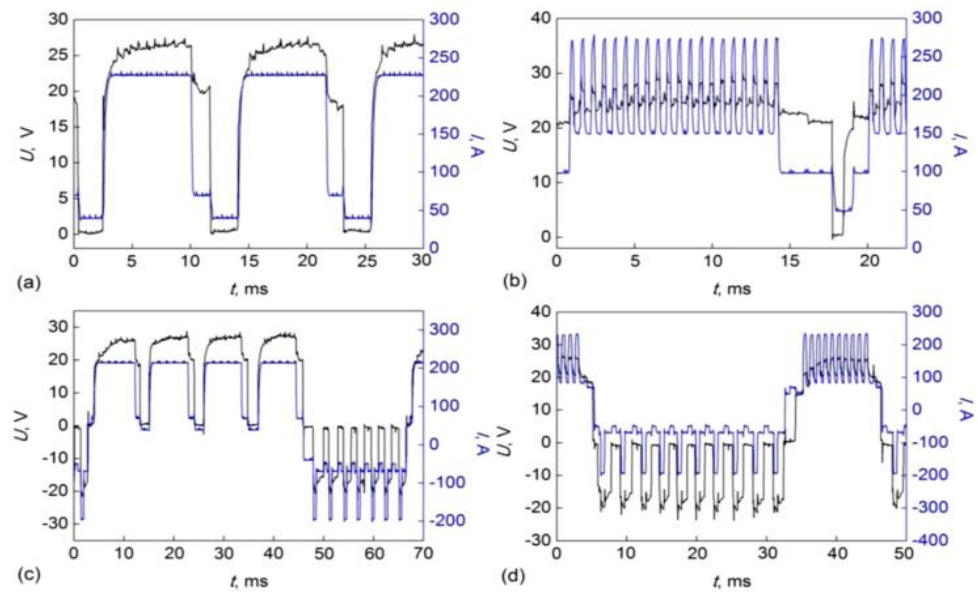
Process variants:

CMT (Cold Metal Transfer)

CMT-P (Cold Metal Transfer – Pulsed)
Combines CMT technology with pulsed voltage arc
- Higher heat input
- Higher deposition rate

CMT-ADV (Cold Metal Transfer – Advanced)
CMT cycles with positive and negative polarity, the polarity change occurs during the short-circuiting

CMT-PADV (Cold Metal Transfer – Pulsed Advanced)
CMT cycles in negative polarity and CMT-P cycles in positive polarity

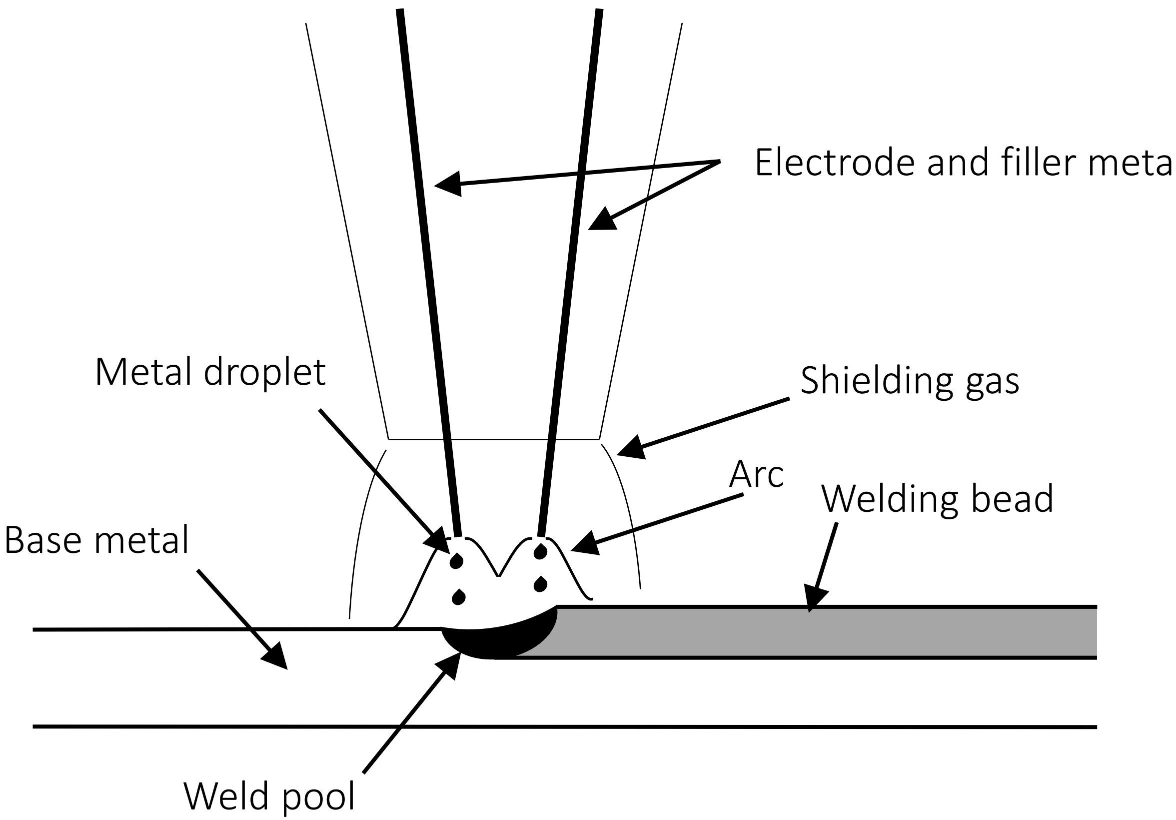


MIG/MAG

Process variants:

CMT-Twin

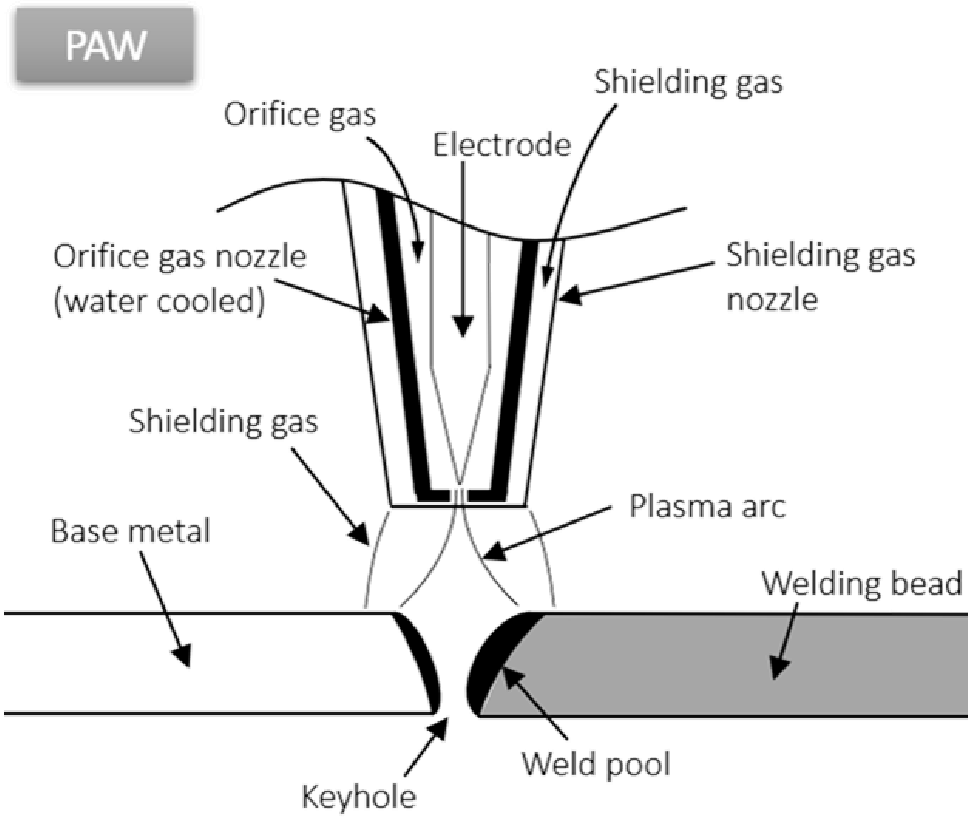
- Higher deposition rates and welding width
- Higher heat input
- Possibility to customize the chemical composition of the deposited material



PAW

Plasma Arc Welding

- Tungsten non consumable electrode
- Electrode is located inside the nozzle and there is a plasma gas inside the nozzle separated from the shielding gas
- Arc is thinner than TIG, very stable, higher energy density (less distortion)
- TIG arc 11.000 ºC vs. PAW arc 28.000 ºC
- Filler metal (optional) wire or powder



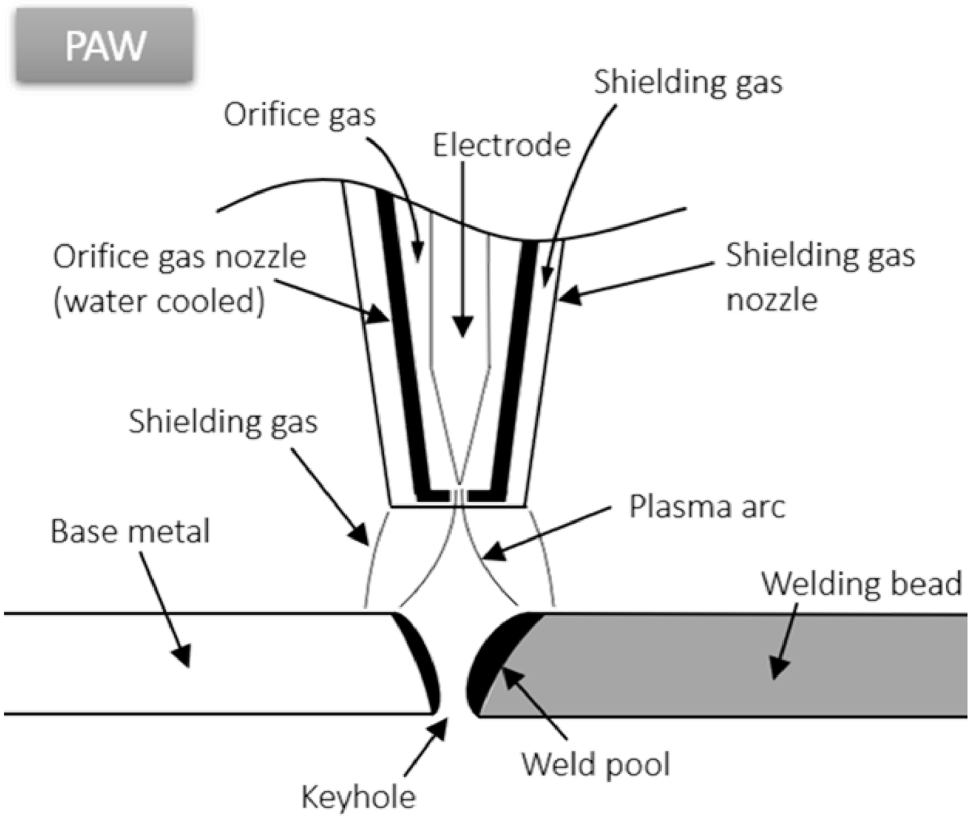
PAW

Plasma Arc Welding

Arc ignition:

A pilot arc is used, this is ignited due to a high frequency circuit that establishes the arc between the electrode and the inner nozzle (water cooled). The pilot arc is hidden inside the principal nozzle.

When the energy source supplies the welding current or the torch comes close to the base metal, the arc is transferred from the inside of the nozzle to the base metal.



PAW

Advantages

- Free of spatter
- High quality of the welding bead
- High durability of the electrode
- Does not need arc ignition methods (pilot arc)
- Higher deposition rates and travel speed
- Low distortion and HAZ, possibility to weld small thicknesses (0,025 mm)

Limitations

- Sensitive to CTWD variations
- Filler metal not coaxial
- Process complexity
- The nozzle surrounding the electrode needs to be changed constantly
- Very expensive

PAW

Three operating modes:

- **Microplasma welding:**

Welding is by conduction, almost triangular welding beads. Intensities up to 15 A (DCSP).

- **Intermediate plasma:**

Similar to TIG welding, intensities up to 100 A. Welding is by conduction as in the previous mode (DCSP).

- **Keyhole:**

Very different to TIG welding. Intensities > 100 A. High intensities and plasma gas flow rate enable the formation of a cavity (keyhole) limited by the surrounding weld pool. With this process high penetrations are obtained. Applied in robotised processes.

Summary

Summary

Shielding gases:

Inert
- Argon
- Helium

Active
- Hydrogen
- Oxygen
- Carbon dioxide
- Nitrogen

Ionization energy

Density

Thermal conductivity

Arc ignition methods

- By contact
- Without contact

Metal transfer modes

- Short-circuiting
- Globular
- Pulsed
- Spray

Tungsten inert gas (TIG)

- Tungsten non consumable electrode
- Inert gas (Argon/Helium)
- Filler metal (optional)

Metal inert/active gas (MIG/MAG)

- Electrode is the filler metal (consumable)
- Depending on the gas used
- Filler metal mandatory

Plasma arc welding (PAW)

- Tungsten non consumable electrode
- Electrode is located inside the nozzle
- Arc is thinner than TIG, very stable, higher energy density (less distortion)
- TIG arc 11.000 ºC vs. PAW arc 28.000 ºC
- Filler metal (optional) wire or powder

Feedback

What would you like to see more of in next presentations?

5 minutes

https://app.sli.do/event/74nmF4YBcGvjs2TnR7jH1i

Time for questions

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Thank you

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