Non-Traditional Manufacturing Processes (NTMP)

Lecture 7: Plasma Arc Machining

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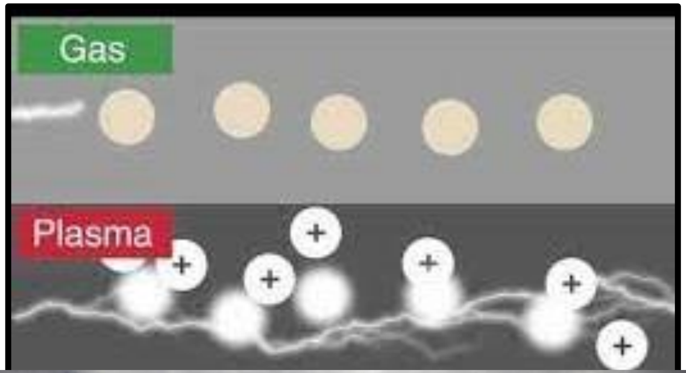
Plasma Arc Machining (PAM)

What is Plasma?

- This is the 4th state of matter – Ionized gas (Electrically conducting and responsive to magnetism)
- Electrically neutral -numbers of negative charge (electron + negative ions) and positive charge equal.

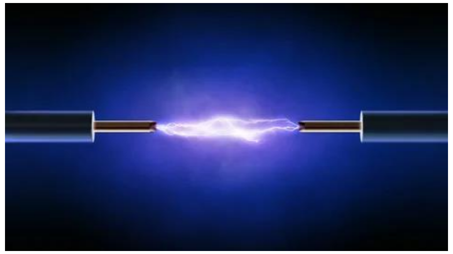


Ex: Ionized air (plasma)

What is an Arc?

- An **electric arc** is a discharge of electric current across a gap in a circuit.
- An arc discharge is characterized by a low voltage and relies on thermionic emission of electrons from the electrodes supporting the arc.

-It can be sustained by plasma.



Electric arc

Plasma Arc Machining

Plasma Arc

High temperature ionized gas produced by flowing gas through the arc established between cathode and work piece and/or Nozzle.

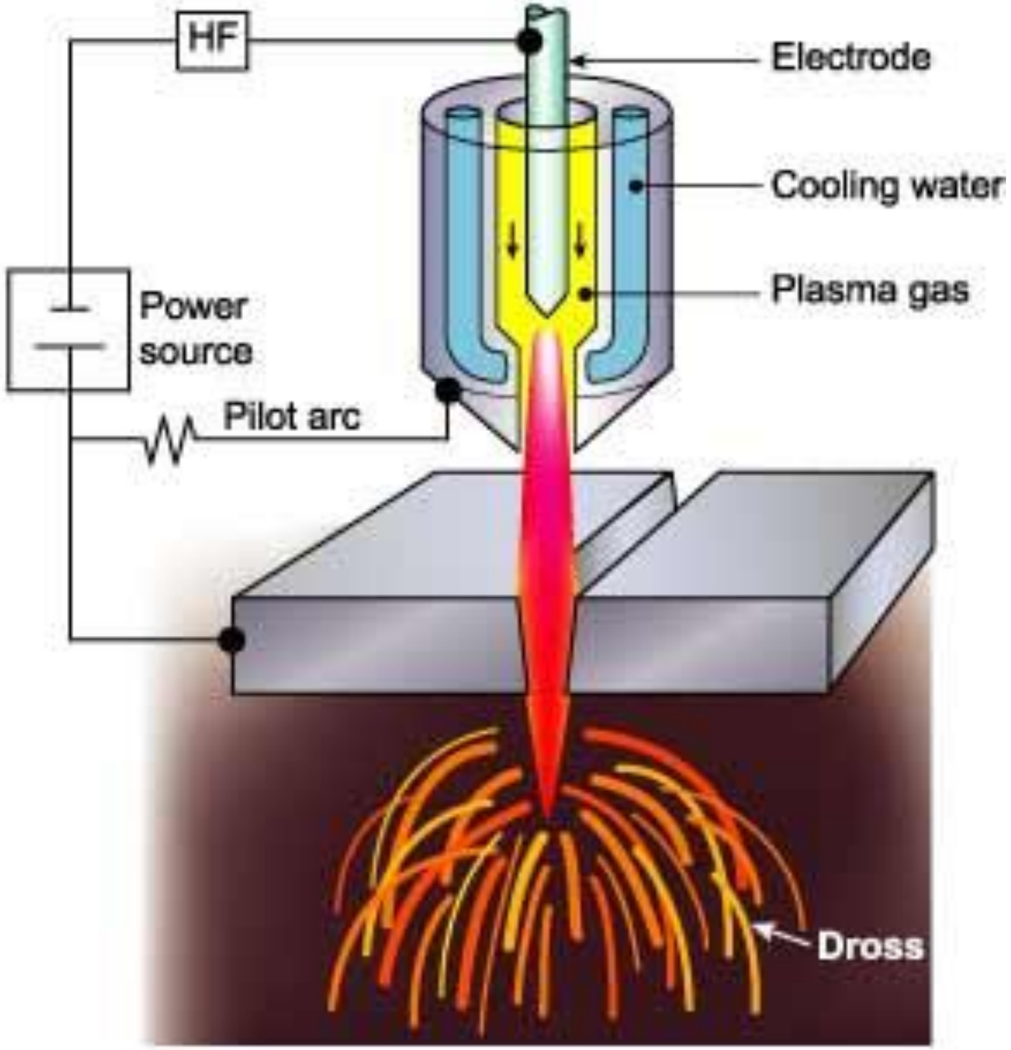


Fig. Schematic of plasma arc machining

Applications of Plasma Arc Machining

- Cutting a wide variety of conducting materials e.g. SS, Aluminum, Cr-Ni alloys, Copper, titanium, etc..
- Mostly planer cutting
- Contour cutting of complex shape integrated with CNC
- Welding of materials such as Titanium, SS etc
- Plasma arc surfacing and spraying

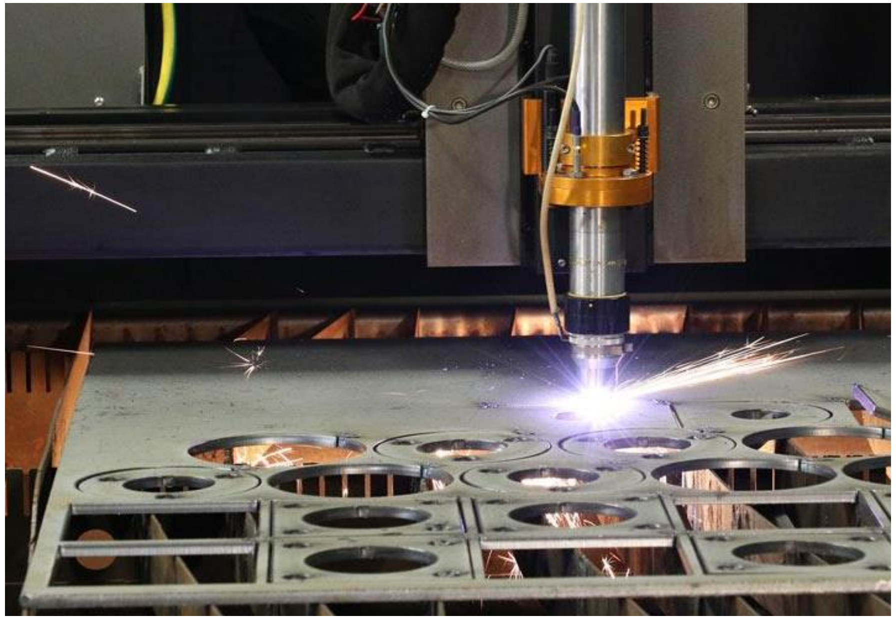


Fig. Cutting an alloy sheet using plasma arc cutting

Plasma Arc Cutting

First Plasma Arc Cutting machine: Developed by Union Carbide, USA in 1957 modifying Tungsten Inert Gas (TIG) welding machine.

Plasma : Passed through a water-cooled narrow nozzle

- Constricted the plasma
- Increased the arc sustaining voltage and Plasma temperature
- Higher Power Density on workpiece

Basic Principle, Equipment, Process parameters, Process Capability, Applications, Advantages & Limitations

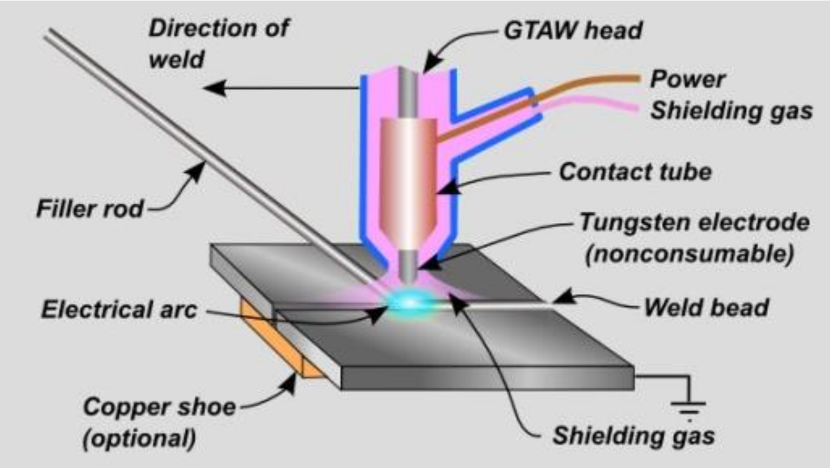
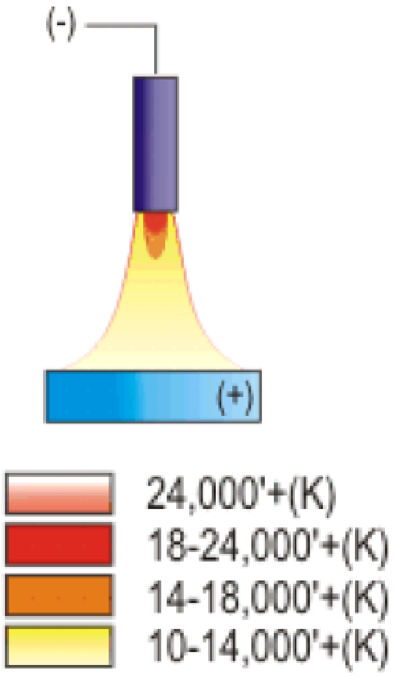
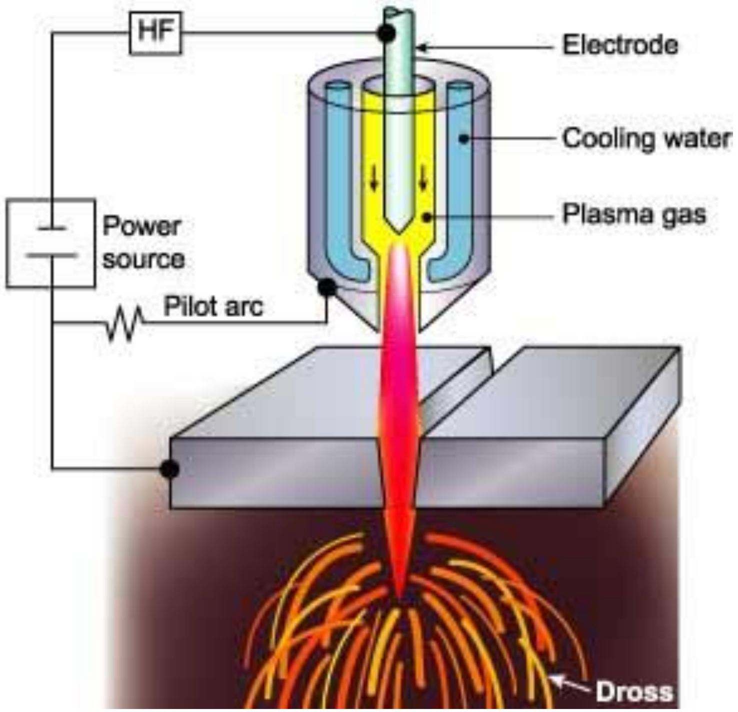


Fig. Schematic of TIG





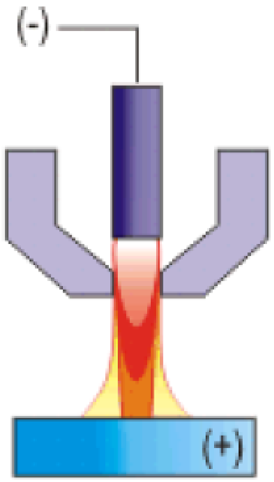


Fig. Schematic of PAC

Plasma Arc Cutting: Basic Principle

Plasma Arc: High temperature ionized gas produced by flowing gas through the arc established between cathode and work piece and/or Nozzle.

PAC: A thermal process in which a high velocity, superheated ionized gas jet impinges on the work-piece, melts and ejects the molten material.

Primarily used **to cut thick sections** of electrically conducting materials e.g. stainless steel and aluminum.

Since 1970, after the development of the Water-Injected Plasma Cutting Machine this process is finding widespread application in cutting thick sections of MS, SS, Al, etc.

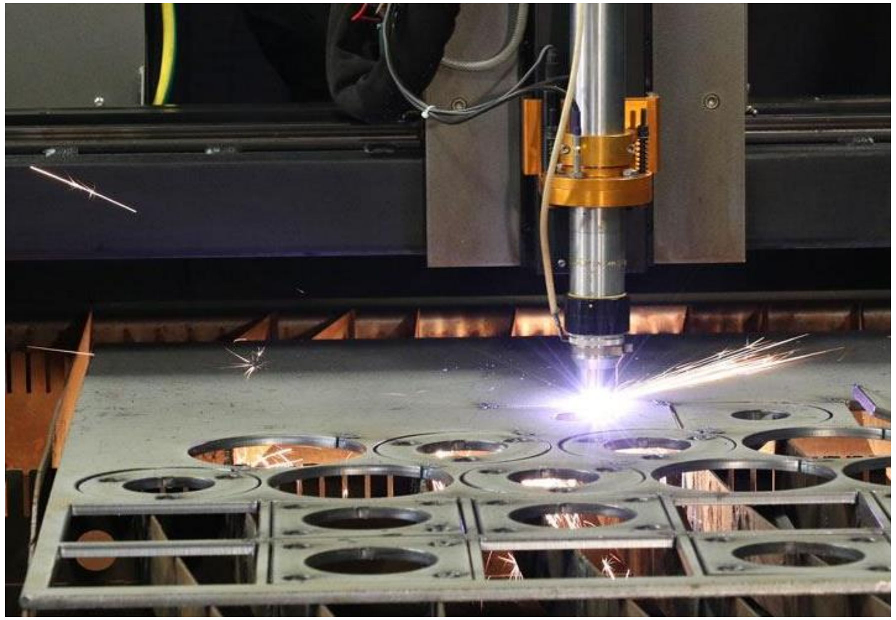


Fig. Cutting an alloy sheet using plasma arc cutting

Plasma Arc Cutting: Basic Principle

- **PAC** uses a high velocity jet of plasma to cut through the metal by melting it.
- High gas flow rate : Facilitate the removal of molten metal through the kerf.
- Modern day PAC Machine can deliver up to 1000A current at approx. 200VDC and generate plasma temperature up to 33000 ºC.

Gases Used:

Primary Gases: Gases that are used to create the plasma arc. Examples: Nitrogen, Argon, Hydrogen, or their mixture.

Secondary Gases or Water: Surrounds the electric arc to aid in confining it and removing the molten material.

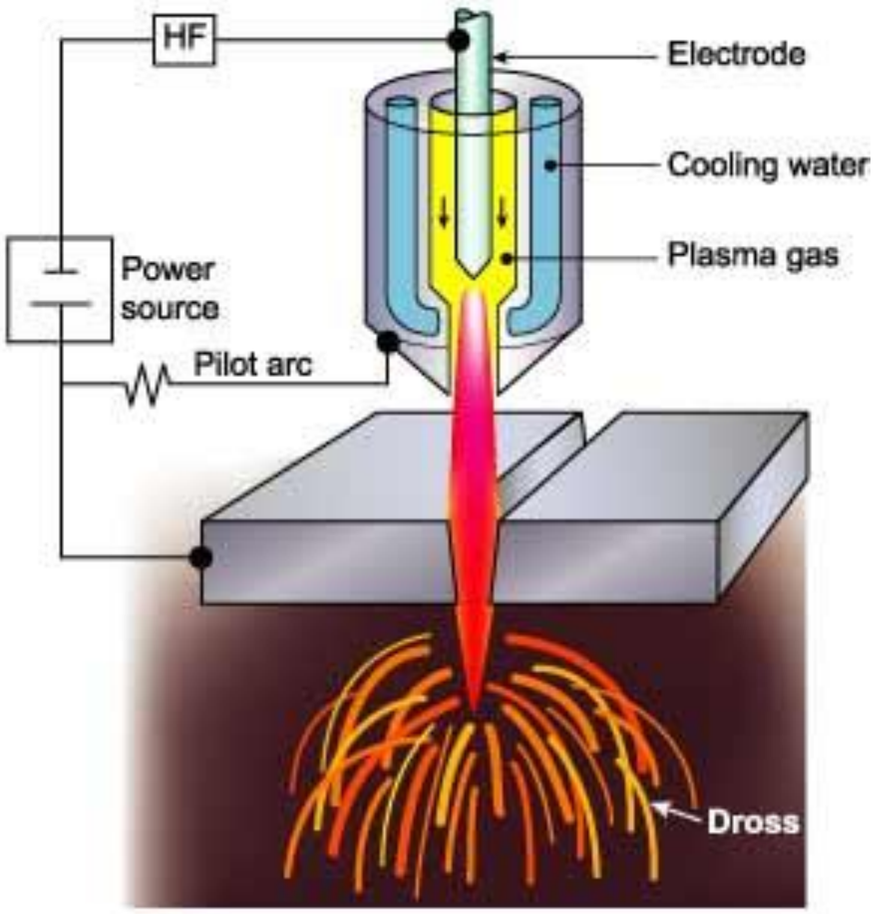


Fig. Schematic of plasma arc machining

Plasma Arc Cutting: Equipment

a) Plasma Torch

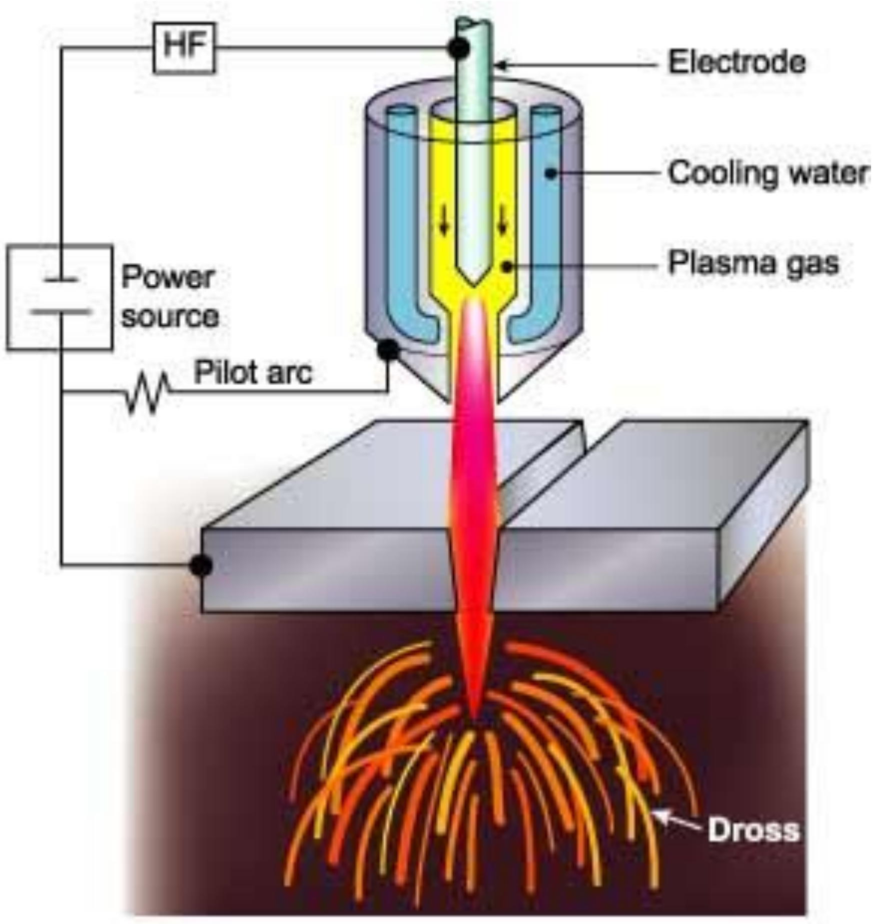
b) Power Supply

c) Arc Starting Circuit

d) Gas Supply

e) Cooling Water System

f) Control System



Type of Arcs

Transferred arc

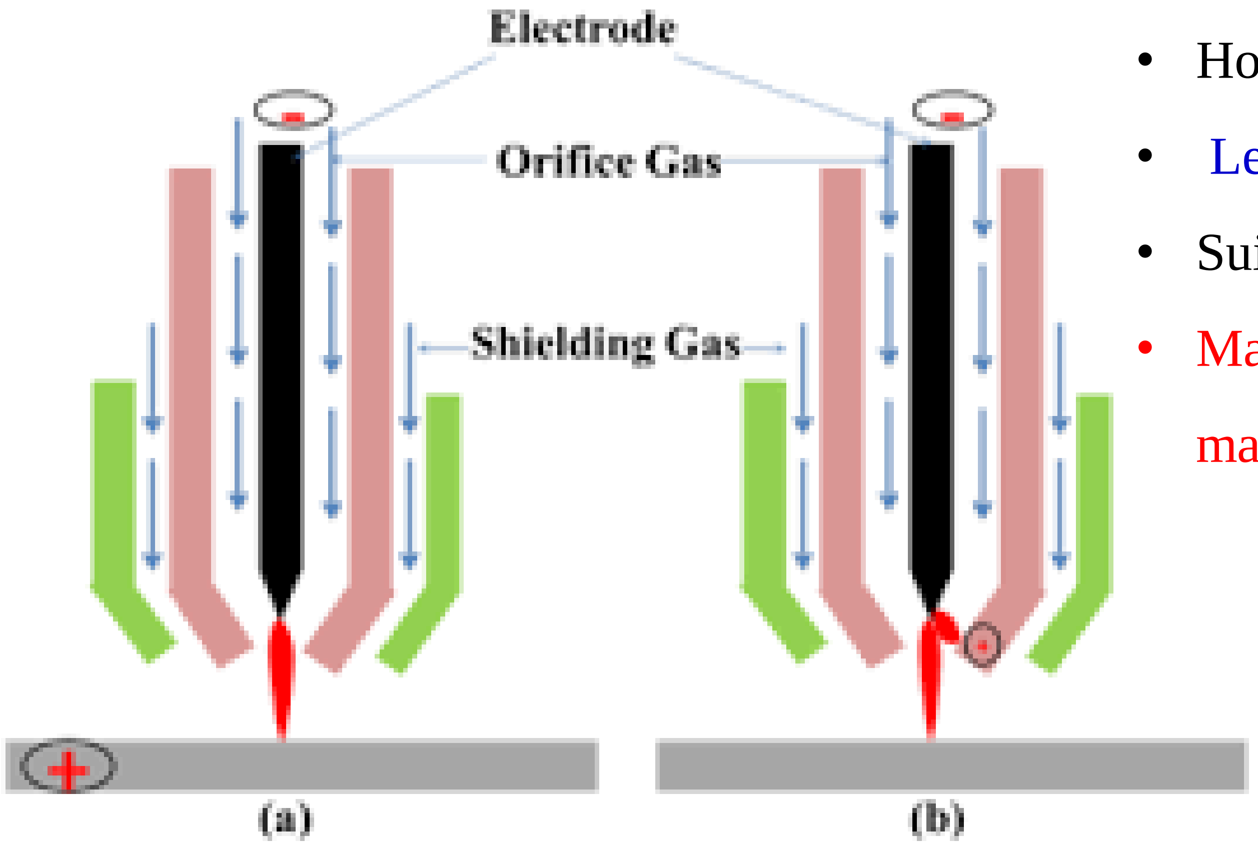
Arc is maintained between the electrode (Cathode) and the work-piece (Anode)

- Most popular,
- Higher Cutting Efficiency (85-90%)
- Application: Cutting, Welding, Surfacing of conducting work piece

Non-transferred arc

Arc is maintained between the electrode (Cathode) and the nozzle (Anode) and heat is carried to the workpiece by plasma gas.

- Hottest portion within nozzle,
- Less efficient 65-75% ;
- Suitable for Arc Spray &
- Machining non-conducting materials-Ceramic



Process Parameters

- Plasma torch
- Arc Current, Voltage, Electrode gap - Power of Plasma
- Primary gas : Air, N_2- Efficient & Effective Carrier of heat
- Secondary gases O_2, Ar, H_2 & mixture.
- Torch heads: Different for cutting, welding & spraying
- Gas Flow Configurations.
- High speed gas flow: Turbulent mode- Short Flame up to 150 mm @ 400A : Suitable for Cutting and spraying.
- Low speed gas flow: Laminar Mode- Long Flame up to 900 mm, suitable for Welding, melting ceramic where no sputtering desired.
- Nozzle dimensions: Short (3-5 mm) length, 3-5 mm diameter for Cutting torch

  Long (25-100 mm) 3-4 mm dia for Welding torch

Process Capabilities

- Maximum cutting thickness- up to 200 mm, Practical range-3-75 mm
- Cutting Speed : Typically, 5-8 times faster than oxy-acetylene cutting method

Cutting speed depends on thickness of the material being cut, type of material, and current being used in the cutting.

A rough estimation of cutting speeds using a 500 A PAC system:

$S = 25.4 / T$, (where, S in m/min & T material thickness in mm)

Cutting speed: Dependent on material characteristics; Al cuts ~25% faster than steel at same operating parameters.

- Kerf width: 1.5-3 mm for thin plates, ~5 mm for 25 mm plate & 19 mm for 150 mm plate
- Tolerance obtained are poor and depends on thickness of material : $\pm$0.8 mm in thickness less than 25 mm, higher for higher thickness , $\pm$ 3 mm for > 150 mm thickness.
- Taper can vary with parameters and generally ~5-7^{o}
- Surface finish : 5-75 µm
- HAZ- 0.75-5 mm depending on thickness

Advantages of Plasma Arc Machining

- **Rapid Cutting Speeds:** Faster (5-10 times) than oxy-fuel for cutting steel up to 50 mm thick and is competitive for greater thicknesses.

Faster than those of laser cutting systems for thicknesses over 3 mm.
Up to 12m per minute integrated with CNC

- **Wide Range of Materials and Thicknesses :** **F**errous and nonferrous metals. Thicknesses up to 200mm thick steel, up to 75mm more common

- **Easy to use & automate:** Minimal operator training. Easy to operate and Much simpler than laser and E-beam cutting systems.

- **Economical :** More economical than oxy-fuel for thicknesses under 1 inch, and comparable up to about 2 inches.

For example, for ½ inch steel, plasma cutting costs are about half those of oxy-fuel.

Limitations of Plasma Arc Machining

- Large heat affected zone.
- Rough Surfaces
- Difficult to produce sharp corners.
- Smoke and noise.
- Burr often results.
- Need for safety equipments.

Applications of Plasma Arc Machining

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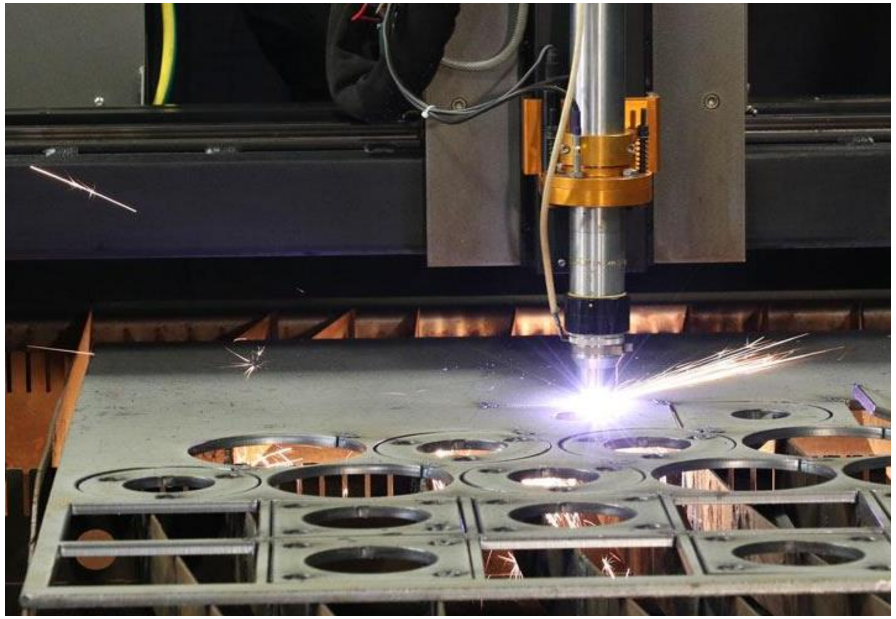

Fig. Cutting an alloy sheet using plasma arc cutting

Summary of Plasma Arc Machining

Mechanism of Material Removal: Melting & Ejection

Medium: Plasma

Tool: Plasma jet

Current : 50-100A and Voltage : 30-250V

Power : Up to 200 kW and Typical Plasma Temperature : 16000^{o}C

Plasma jet velocity: 500 m/s and MRR: 100-150 cm^3/min

Cutting Speed : 0.1-7.5 m/min and Stand off distance: 6-10 mm

Nozzle orifice diameter: 1.5-6.5 mm

Kerf width : 1.5 mm and higher depending up on plate thickness

Taper: 2-7^{o}

Maximum Plate thickness : 200 mm (5-75 mm practical)

Specific Cutting Energy: 10-50 J/mm^3

THANK YOU!