# PLASMA ARC MACHINING (PAM)

## Basic Introduction

It is a process used to machine electrically conductive materials by means of an accelerated jet of hot plasma.

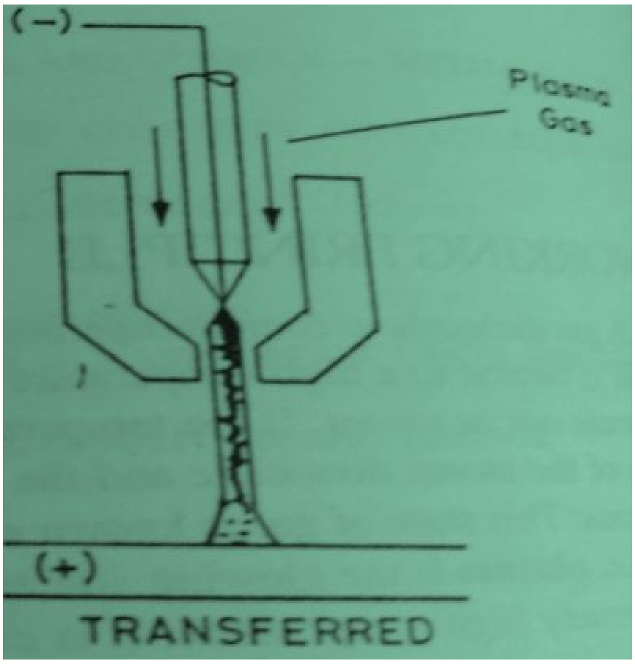
- Typical materials cut: steel, aluminum, brass & copper & other conductive metals.
- Often used in fabrication & welding shops, automotive repair & restoration, industrial construction, salvage & scrapping operations.
- It sees a widespread usage from large scale industrial CNC applications down to small hobbyist shops.
    - Due to the high speed, precision cuts, combined with low cost of operation.

What is Plasma?

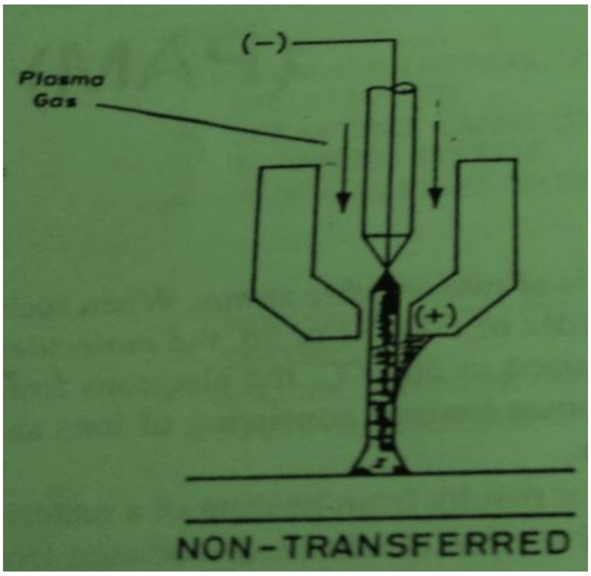
- It is the 4$^{th}$ state of matter apart from Solid, Liquid & gas.
- It consists of matter at extreme high temperature (upto 30000'C) where the atoms are stripped off their electrons.
- Contains +ve nuclei & -ve electrons.
- It is highly conductive due to presence of free electrons (or high charge densities).
- It is very bright due to photon emission.
- It has high oxidation resistance.

## Types

- Transferred arc
    - Efficiency 85 - 95%
    - Arc between electrode & workpiece.
    - Workpiece must be electrically conductive.
    - Gas pressure: 1.4 Mpa
    - Flowing gas constricts plasma jet & acts as a coolant.




- Non-transferred arc
    - Efficiency 65 - 75%
    - Arc between electrode & nozzle.




### Working principle

- High velocity jet of superheated plasma is directed on the workpiece.
- High temperature produced by anode heating (direct electron bombardment).
- Convective heating also takes place.
- Metal melts & carried away by gas.

### Equipment

- 
- 

### Process Description

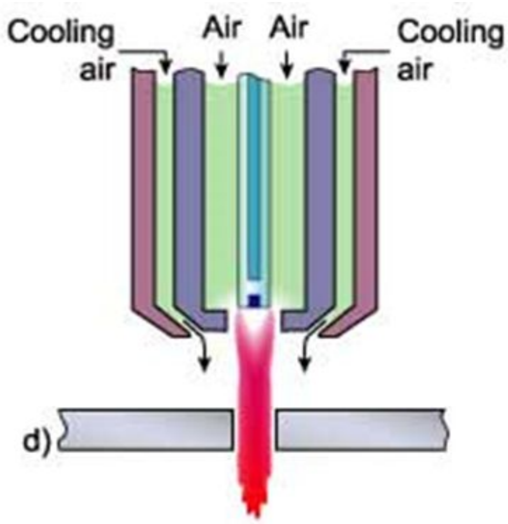
Steps in formation of Plasma

- Temperature is raised to 2000°C increasing collisions.
- Stripping of electrons leads to Ionization.
- Further heating takes place by
  - Collisions between free electrons & atoms.
  - Increase of Thermal Kinetic energy.
  - Heating by relaxation.
  - Production of light by De-excitation of atom.
- The final resultant temperature may go up to 30000°C. which is enough to melt & even vaporize most of the metals.
- An electrical channel of ionized gas i.e. plasma from the plasma cutter itself, through the workpiece to be cut, thus forming a completed electric circuit back to the plasma cutter via a grounding clamp.
- A suitable compressed gas is blown through a focused nozzle at high speed.
- An electrical arc is formed within the gas,
  - between an electrode near or integrated into the gas nozzle & the workpiece.
- The electrical arc ionizes some of the gas
  - An electrically conductive channel of plasma is created.
- It delivers sufficient heat to melt through the work piece.
- At the same time, much of the high velocity plasma & compressed gas blow the hot molten metal away, thereby separating i.e. cutting through the work piece.

## Process Variations

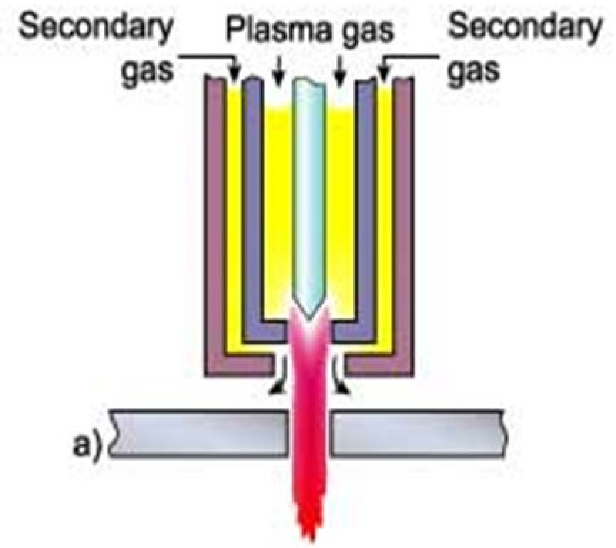
### Air Plasma Arc Cutting

- Developed in 1960 - for cutting mild steel
- Air can be used as plasma forming gas (inexpensive).
  - Expensive gases avoided inert or un-reactive gases like argon or nitrogen.
- Requires a special electrode of
  - hafnium (Most expensive) or
  - zirconium mounted in a copper holder.
- Oxygen in air provides additional energy from exothermic reaction with molten steel.
  - Thus boosting cutting speeds by 25%.
- Can cut stainless steel & Aluminium.
- Oxidized surface obtained limits usage.



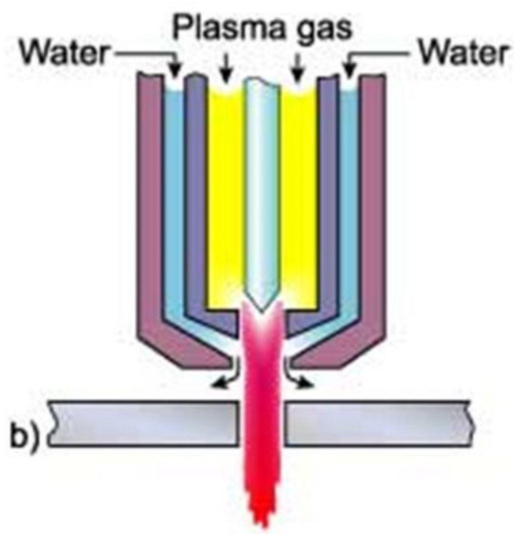

### Dual Flow Plasma Arc Cutting

- Gives increased arc constriction & more effective 'blowing away' of the dross.
- The advantages compared with conventional plasma:
- Reduced risk of 'double arcing'
- Higher cutting speeds
- Reduction in top edge rounding
- The plasma forming gas is normally argon, argon-$H_2$ or $N_2$.
- Secondary gas preferred for different materials is:
  - Steel: Air, $O_2$, $N_2$
  - Stainless steel: $N_2$, argon-$H_2$, $CO_2$
  - Aluminium: argon-$H_2$, $N_2$ / $CO_2$




**Water injection**

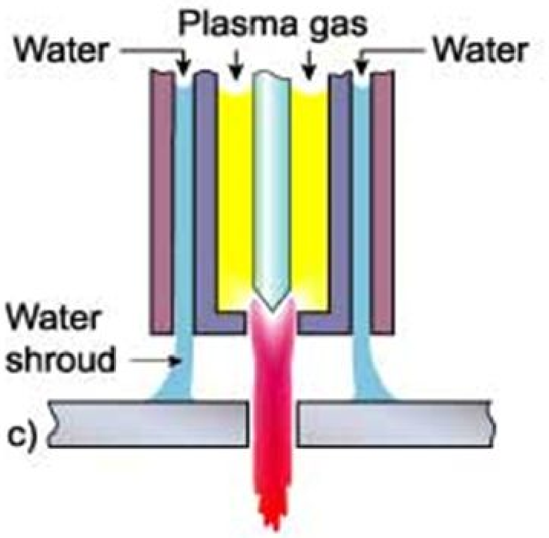
- Nitrogen is normally used as the plasma gas.
- Water is injected radially into the plasma arc to induce a greater degree of constriction.
- The temperature is increased considerably (as high as 30,000°C).
- Advantages:
    - Improvement in cut quality &
    - squareness of cut
    - Increased cutting speeds
    - Less risk of 'double arcing'
    - Reduction in nozzle erosion




**Under water Plasma Cutting**

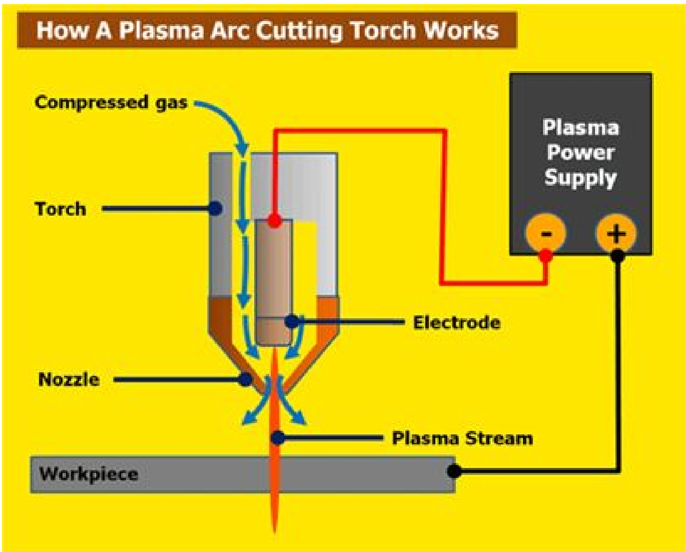
- Can be operated either with a water shroud or
- With the workpiece submerged some 50 to 75mm below the surface of the water.
- Water acts as a barrier giving following advantages:
    - Fume reduction
    - Reduction in noise levels
    - Improved nozzle life
- Noise levels for conventional plasma at
- high current levels: 115dB

- With a water shroud noise level: 96dB
- Under water cutting: 52 to 85dB.
- Water shroud does not increase the degree of constriction, hence squareness of the cut edge & the cutting speed are not noticeably improved.




### Conventional Plasma Arc Cutting

- Arc is constricted by a nozzle only.
- No shielding gas is added.
- Cutting gas is injected tangentially to the electrode.
- The swirling action of the gas causes the cooler portions of the gas to move radially outward forming a protective boundary layer on the inside of the nozzle bore.
- This helps prevents damage to the nozzle & extends its life.




## Process Parameters

- Stand off distance:
  - It refers to the distance between the nozzle & the workpiece.
  - It is inversely proportional to depth of penetration.
  - Long distance gives narrow widths at the bottom.
  - Short distance damages the workpiece.
  - Preferred range: 5 to 10mm
  - Varied depending on thickness to be cut & material of the workpiece.

- Speed of cutting
    - It refers to the relative speed between the nozzle & the workpiece.
    - High cutting speed gives narrower bottom width.
    - Slower cutting speed widens the bottom of the kerf.
    - At optimum speed, nearly perpendicular & parallel kerf surfaces can be obtained.
- Jet velocity: 500 m/s
- Specific energy: 100 W/(cm$^3$.min)
- Power Range: 2-200 Kw
- Voltage: 30-250 V (DC)
- Current: Upto 600 A
- Plasma gases
    - It flows through the spark & gets ionized.
    - Hydrogen has high heat capacity
        - Achieves best conditions for transfer of plasma arc heat.
        - Has smooth cutting action.
    - Nitrogen is cheap but not smooth.
        - Cutting speed is considerably less.
    - Nitrogen + Hydrogen most generally used.
    - Sometimes argon is added.
    - Selection depending on materials:
        - Stainless steel (t<50mm)    Nitrogen – Hydrogen mixture
        - Aluminium & Magnesium    Nitrogen,
        - Nitrogen – Hydrogen mixture
        - Plain carbon steel    Mixture containing Oxygen

### Performance Characteristics

- MRR    150 cm$^3$/min
- Machining speed    0.1 - 7.5 m/min
- Maximum Plate thickness    200 mm
- Accuracy & Surface Finish
    - Edges have small bevels due to swirling of gas.
    - 0.8mm accuracy on 6-30mm thick plates.
    - 3mm accuracy on 100-150mm thick plates.
    - Depths of fused metal - upto 0.2mm.
    - Low Distortions due to high machining speeds.
    - Cutting speeds of 2 m/min & feedrate of 5mm/rev with surface finish of 0.5mm Rt.
    - Machining speed decreases with the thickness of workpiece or cutting widths.
-

### Advantages

- Any workpiece can be machined.
- No maintenance required.
- No harmful chemicals or acids used.
- No extra cleaning required (like de-greasing, blasting or solvent cleanings.)
- 5 times machining speeds compared to oxy-gas cutting.
- Fast production & high accuracy possible by CNC.

### Disadvantages

- Rougher Surface finish

- Metallurgical damage at the surface.
- Large power requirement
  - Ex: 220 kW for 12mm MS plate at 2.5 m/min.
- Overheating damage if not properly controlled.
  - Nozzle is surrounded by water jacket for cooling.
- May produce some toxic gases.
- Workpiece has to be conducting if transferred arc method is used.

## Applications

- Used in cutting most of the metals difficult to cut by conventional methods.
  - Ex: Aluminium, magnesium, stainless steels, carbon & alloy steels.
- Plate beveling, profile cutting, piercing.
- CNC controlled PBM is used in profile cutting.

## Extra points:

History:

- Plasma cutting grew out of plasma welding in the 1960s, and emerged as a very productive way to cut sheet metal and plate in the 1980s.
- Advantages over traditional cutting:
  - no metal chips, giving accurate cuts,
  - producing a cleaner edge than oxy-fuel cutting.
- Early plasma cutters were large, somewhat slow and expensive
  - therefore, tended to be dedicated to repeating cutting patterns in a "mass production" mode.
- CNC (computer numerical control) technology was applied to plasma cutting machines in the late 1980s into the 1990s,
  - Gave plasma cutting machines greater flexibility to cut diverse shapes "on demand" based on a set of instructions that were programmed into the machine's numerical control.[3]
  - These were, generally limited to cutting patterns and parts in flat sheets of steel, using only two axes of motion (referred to as X Y cutting).

Safety

- Proper eye protection and face shields are needed to prevent eye damage called arc eye as well as damage from debris, as per Arc Welding.
  - Gas welding goggles not enough as they do not give UV protection
- It is recommended to use green lens shade #8 or #9 safety glasses for cutting to prevent the retinas from being "flashed" or burned.
- OSHA recommends a shade 8 for Arc Current less than 300, but notes that "These values apply where the actual arc is clearly seen.
- Experience has shown that lighter filters may be used when the arc is hidden by the workpiece."
- Lincoln Electric, a manufacturer of plasma cutting equipment, says, "Typically a darkness shade of #7 to #9 is acceptable."
- Longevity Global, Inc., another manufacturer, offers this more specific table for Eye Protection for Plasma Arc Cutting at lower amperages :

| Current Level in Amps | Minimum Shade Number |
|---|---|
| Below 20 | #4 |
| 20-40 | #5 |

| | |
|---|---|
| 40-60 | #6 |
| 60-80 | #8 |

Leather gloves, apron and jacket are also recommended to prevent burns from sparks and debris.