Advanced Manufacturing Processes (AMPs)

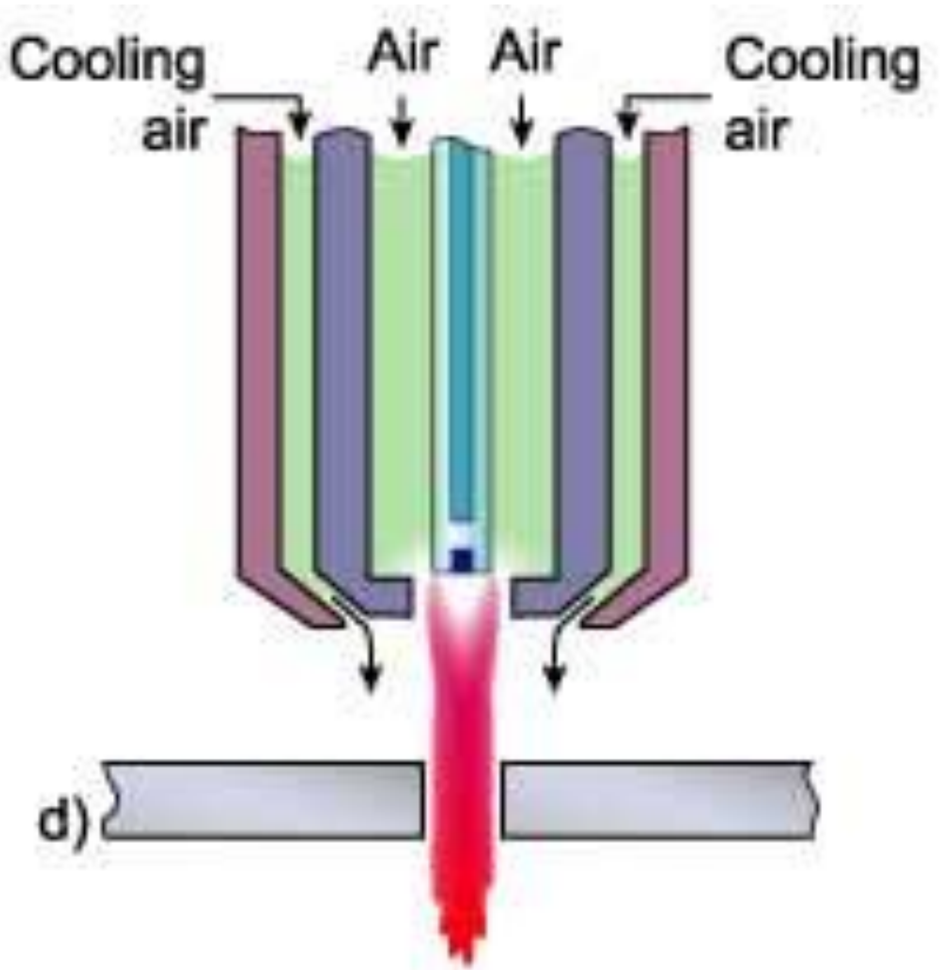
Plasma Beam Machining

by
Dr. Sunil Pathak
Faculty of Engineering Technology
sunilpathak@ump.edu.my

Chapter Description

- Aims
  - To provide and insight on advanced manufacturing processes
  - To provide details on why we need AMP and its characteristics
- Expected Outcomes
  - Learner will be able to know about AMPs
  - Learner will be able to identify role of AMPs in todays sceneries
- Other related Information
  - Student must have some basic idea of conventional manufacturing and machining
  - Student must have some fundamentals on materials
- References
  - ……..
  - ……..
  - ……..

PLASMA BEAM MACHINING (PBM)



PLASMA BEAM MACHINING (PBM)

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

- At room temperature, gases generally are made up of molecules, usually consisting of 2 or more atoms.
- If gas temperature is heated to around 2000 °C, the molecules will dissociate into separate atoms.
- If the temperature is further raised to around 3000 °C, electrons from some atoms will be displaced. Atoms are ionised (electrically charged). In this condition, the gas is termed a plasma.

PRINCIPLES of PBM

- PBM process uses ionised plasma to transfer heat.
- The plasma is obtained by forcing a gas through an electric arc generated between cathode (hot tungsten) and anode (either water-cooled nozzle device usually made of copper or workpiece material).

Effect of constricting electric arc in plasma device:

- ✓ temperature of the ionised gas is increased
- ✓ the heat is focused into a fine flow of gas
- ✓ beam is almost parallel
- ✓ velocity is increased.

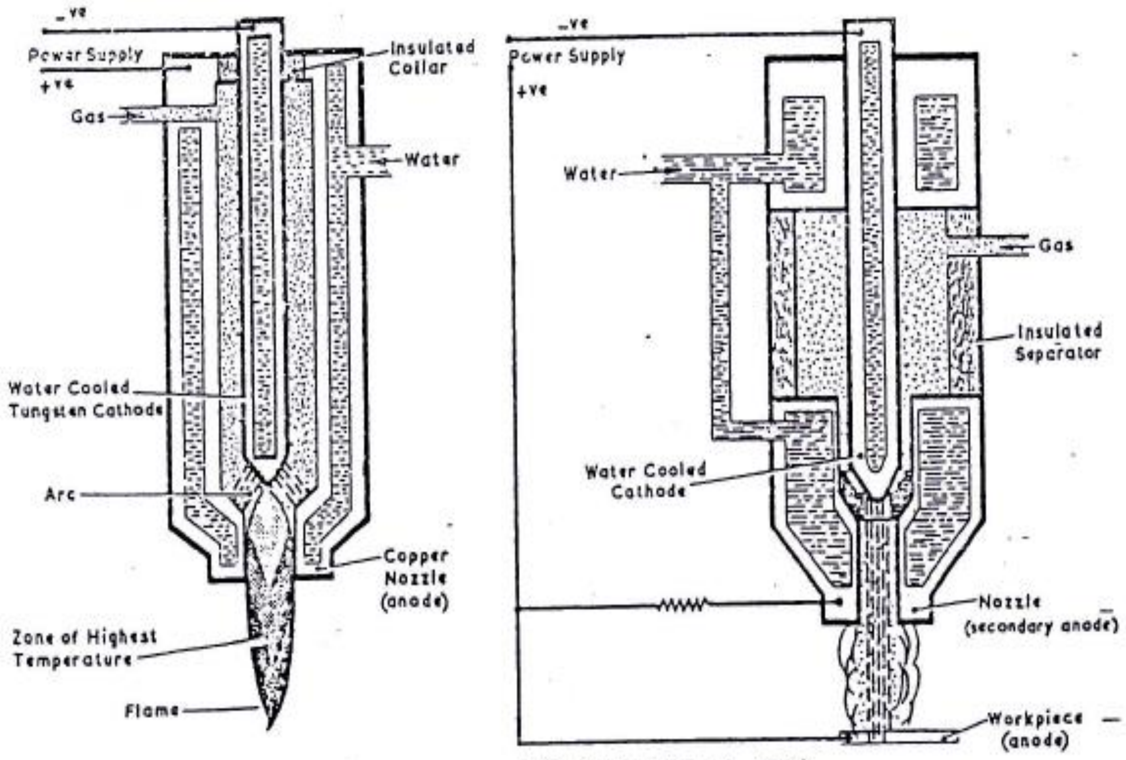
Mechanism of material removal:

- ➢ Heating and melting by high temperature plasma
- ➢ Removal of melted material by high velocity plasma jet.

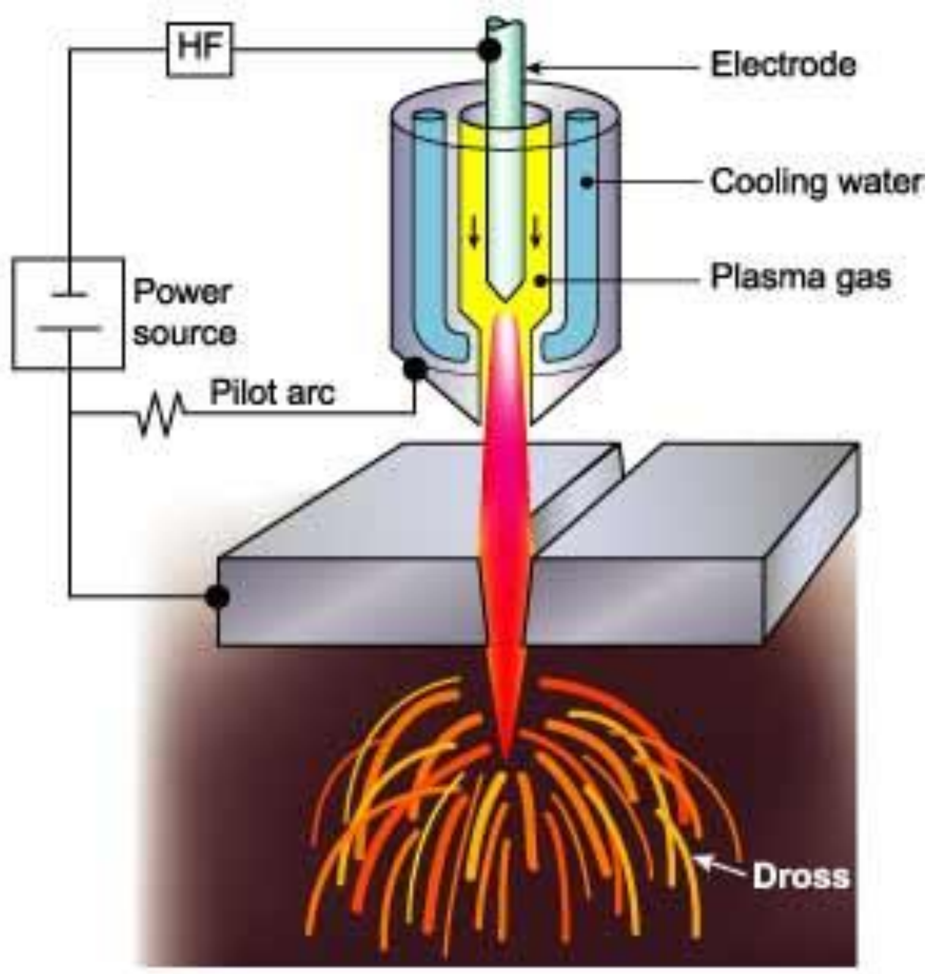
PLASMA BEAM MACHINING (PBM)

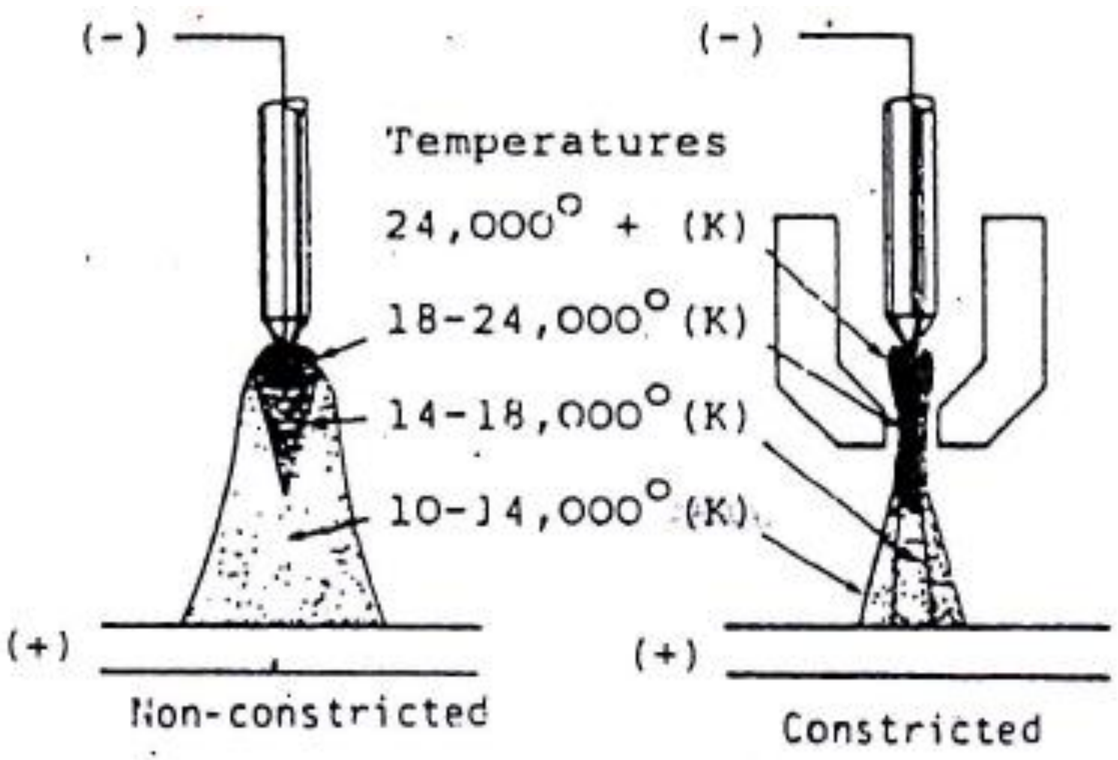
Plasma beam devices are of 2 types:

- Arc is generated between electrode to workpiece (**Transferred Arc**), also known as plasma arc (figure 1 b) – **PAM**
- Arc generated within the device (torch) and only the ionised gas is emitted (**Non-tranferred Arc**), also known as plasma jet (figure 1 a) – **PJM**.



(a) Non-transferred Arc Torch (b) Transferred-arc Torch





Temperature difference

PLASMA BEAM MACHINING (PBM)

PBM EQUIPMENT (Figure)

- Electric power supply (usually direct current generator)
- Gas supply and cooling water supply
- Plasma generator
- Work handling device and servo mechanism for control
- Machine tool which can withstand high temperature
- Protection against heat and high radiation.

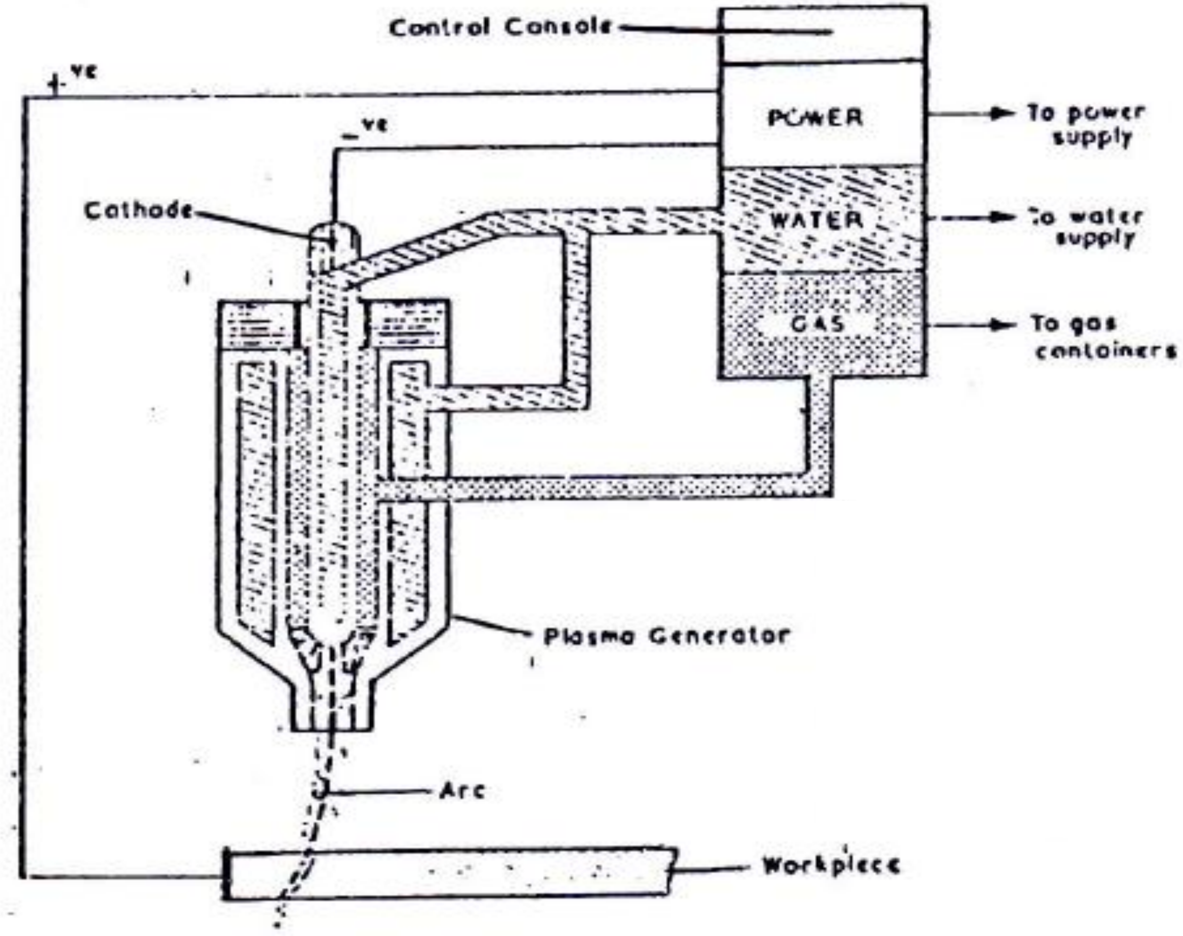
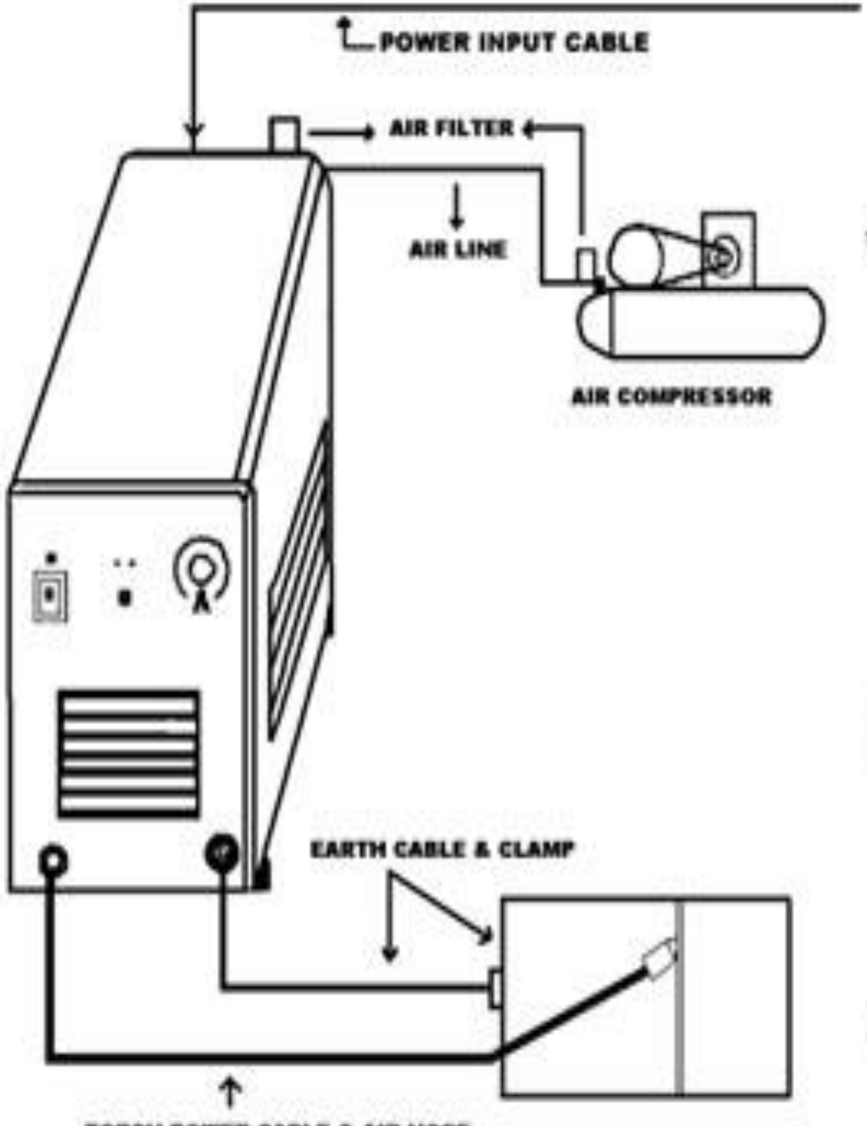
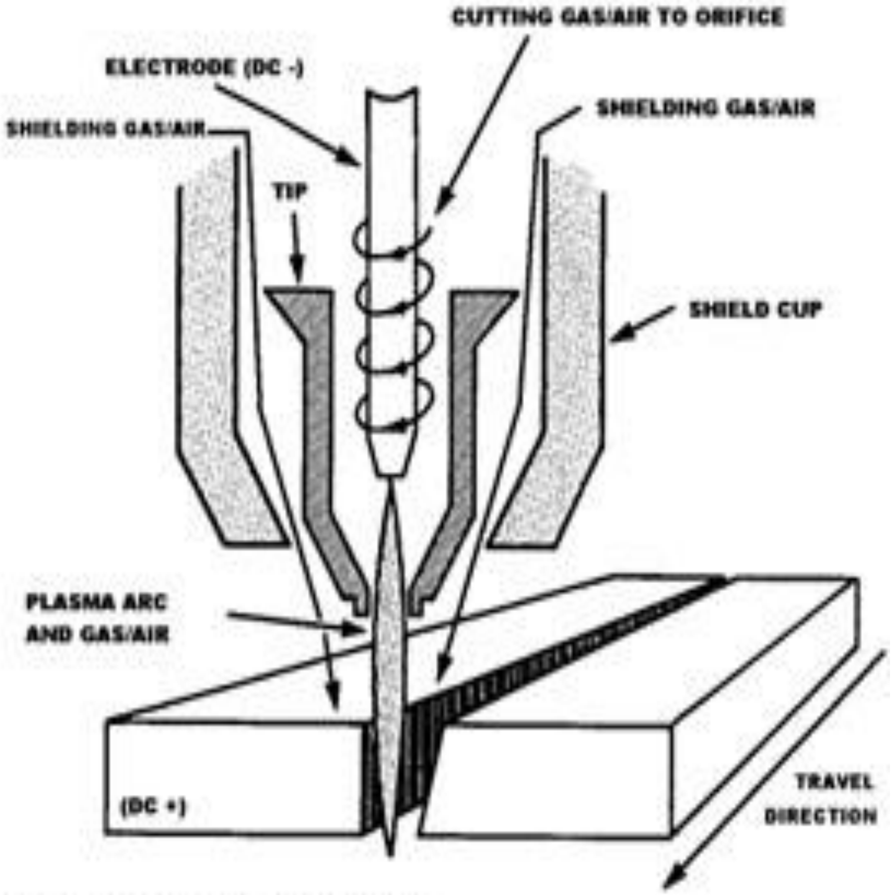


Figure: Layout of typical plasma arc cutting equipment



PLASMA ARC CUTTING SYSTEM



PLASMA ARC CUTTING PROCESS

PLASMA BEAM MACHINING (PBM)

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

OPERATING PARAMETERS

Power capacity: 20 – 200 kW
Voltage: 50 – 200 V
Electric current: 200 – 2000 A

Plasma gas:

- ✓ Argon and hydrogen (65-35 mixture)
- ✓ Nitrogen and hydrogen (80-20 mixture)
- ✓ Nitrogen and oxygen (80-20 mixture).
- ✓ Range of flow rate: 2 – 12 m^3/hr.

Velocity of plasma jet: 500 m/s.

PLASMA BEAM MACHINING (PBM)

OPERATING PARAMETERS (cotd)

Electrode material:

- Tungsten
- Copper hafnium or zirconium (in air plasma machining).

Diameter of nozzle **orifice**:

1.5 – 8 mm (larger size for grooving).

Plasma intensity; maximum heat transfer rate:

6.87 kJ/cm^3/sec (non-transferred arc)
24.53 kJ/cm^3/sec (transferred arc).

Maximum temperature:

16,650 °C (non-transferred arc)
33,300 °C (transferred arc).

Workpiece material:

PAM (transferred arc): workpiece must be conductors
PJM (non-transferred arc): non-conducting materials can be machined.

GENERAL MACHINING PERFORMANCE CHARACTERISTICS

PBM performance depends on power, gas flow and work material characteristics.

Depth of **heat-affected zone** depends on work material, thickness and cutting speed.

Instant cooling of heat-affected zone will cause **micro cracks**.

The cut is generally absent of **slag** but **taper** is produced (not perpendicular to surface of plate).

No problems of **tool wear** or tool breakage because torch is not in contact with workpiece; **gap distance** is normally 5 to 15 mm.

Table 1 General effects of PAM process conditions on formation of grooves (After Lucey and Wylie, 1967)

Machining condition (increasing values)	*Groove condition*	
	Width	*Depth*
Arc power	Increase	Increase
Traverse speed	Decrease	Decrease
Torch angle	Decrease	Increase
Torch height	Increase	Decrease
Nozzle orifice	Increase	Increase

MATERIAL REMOVAL RATE

Specific power to machine mild steel using PAM:

$= 1/245 \text{ kWh/cm}^3$

$= 244 \text{ W/cm}^3\text{/min}$

If input power is 10 kW,

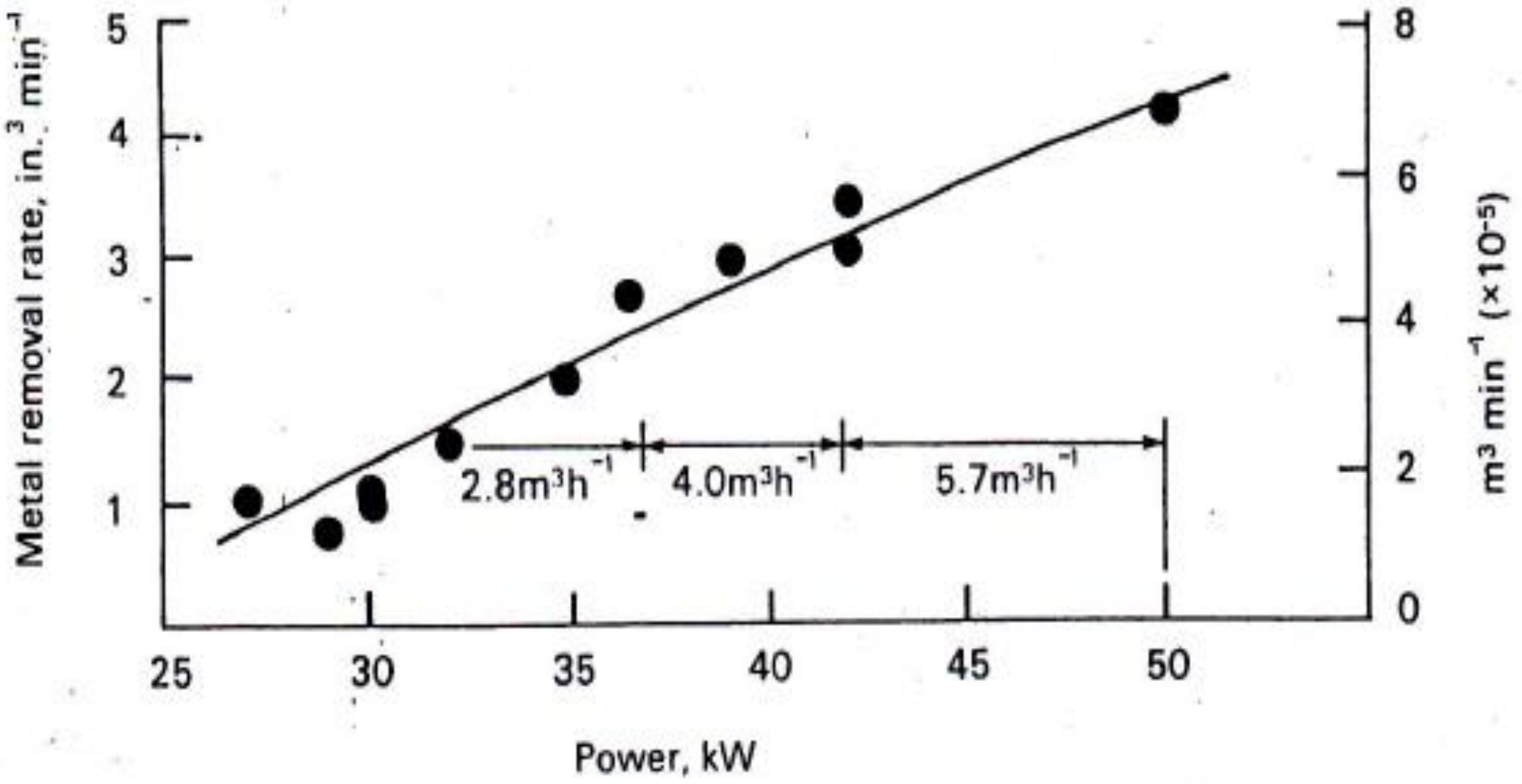
mrr $= 10{,}000/244$

$= 41 \text{ cm}^3\text{/min}$

In optimum plasma operation, of all the electric power fed to the torch:

- up to 45% can be used to machine material
- about 10% is used by the cooling water in the plasma equipment
- remainder is lost in the hot gas and work material.

In practice, higher mrr is usually reported.



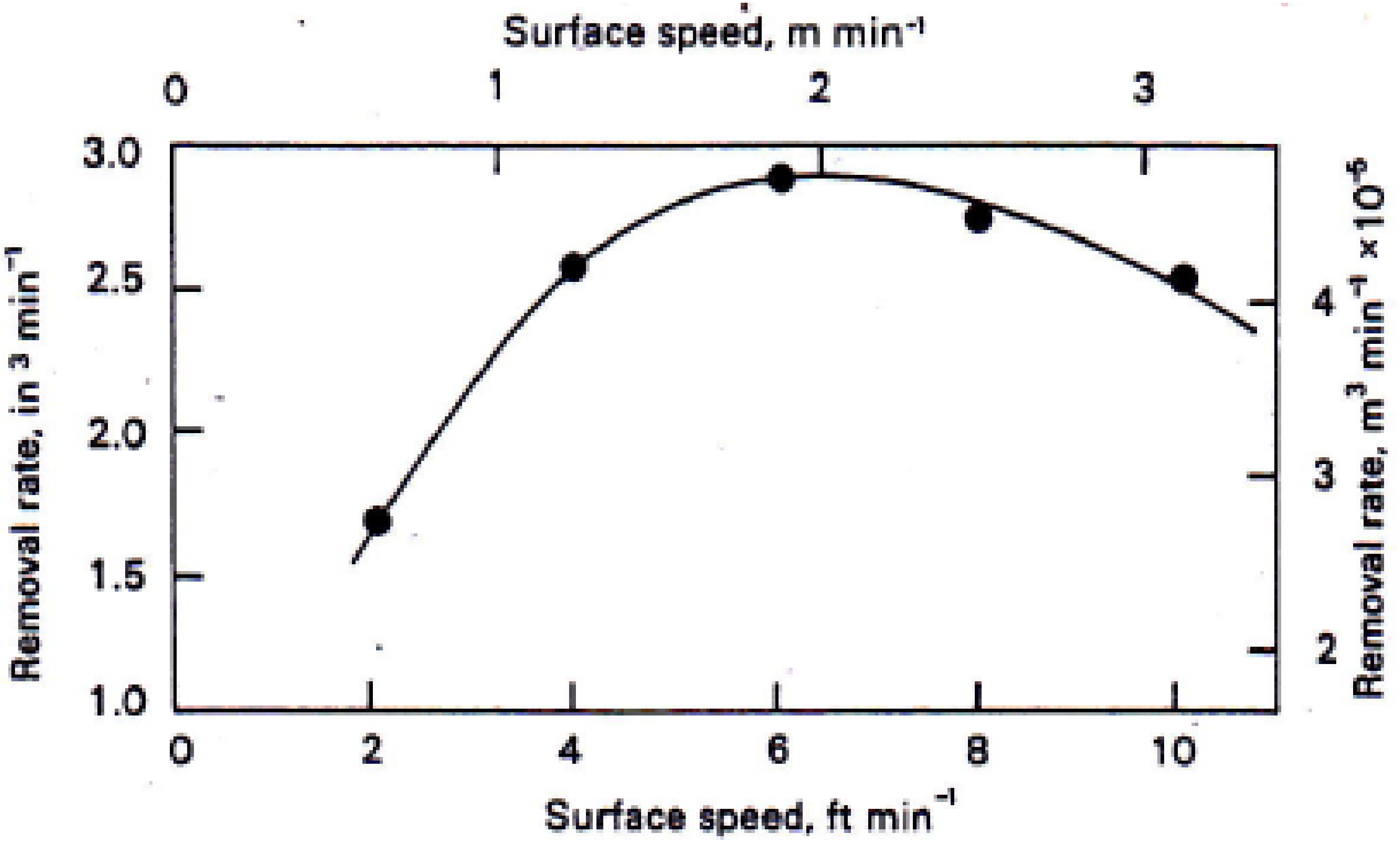
Effect of power on removal rate (surface speed: 2.1 m/min)

MATERIAL REMOVAL RATE (cotd)

Maximum mrr as high as 114.7 cm^3/min has been reported using input power of 50 kW. Assuming 45% power is utilised for cutting, the above relationship gives a mrr of 92 cm^3/min only.

In PBM, the **angle of incident plasma** on workpiece, work material **surface condition** and **gas flow rate** are also important.

Material removal rate also depends on **surface speed**. If surface speed increases, mrr initially increases to a maximum value but reduces then on (Figure).



Effect of surface speed on removal rate
(power: 32 kW; workpiece: alloy steel)

MATERIAL REMOVAL RATE (cotd)

Cutting speed will reduce if thickness of work material is increased.
Using power input of 50 kW, maximum depth of cut is 6 – 9 mm.

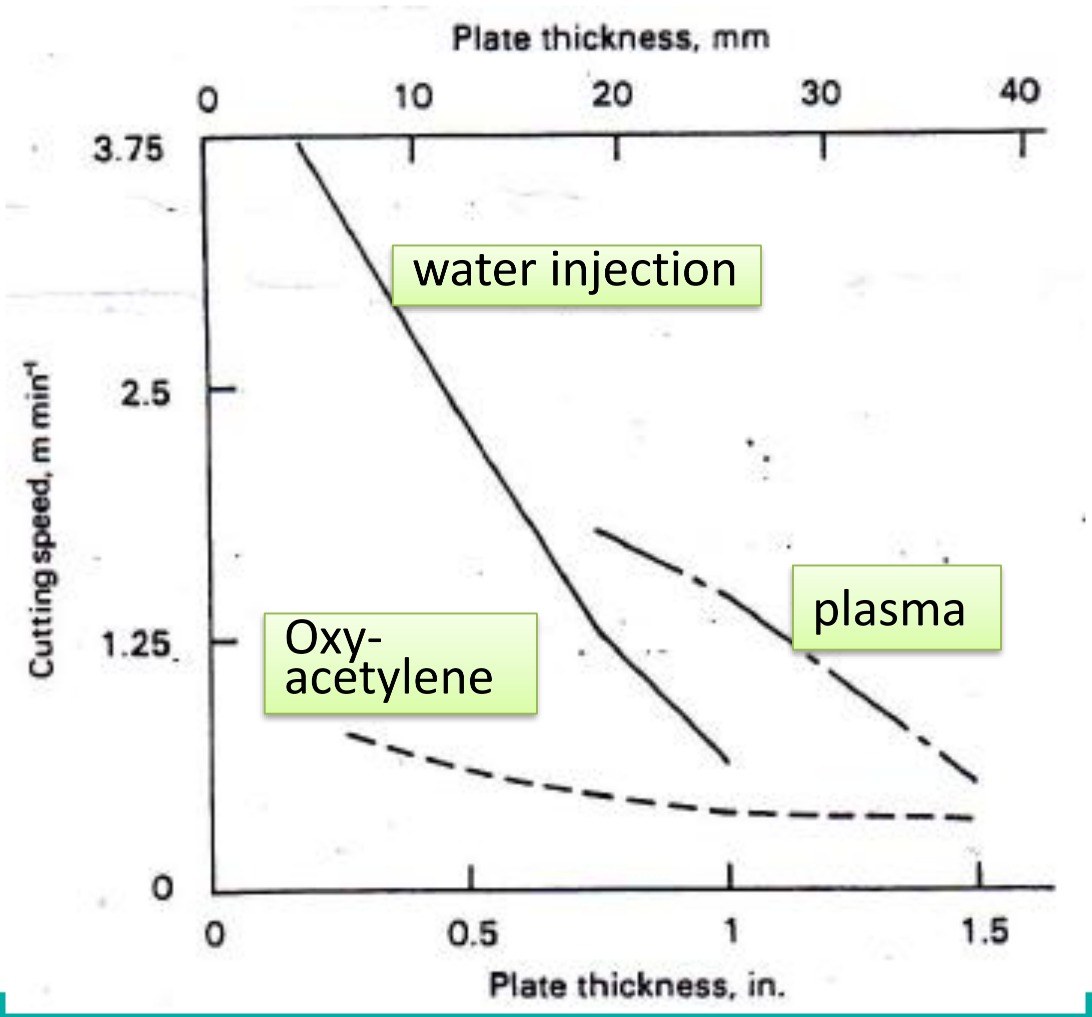


Figure: Decrease of cutting speed with increase in workpiece thickness (mild steel)

OTHER QUALITY CHARACTERISTICS

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

Tolerance better than 1 mm is difficult to obtain.

Taper: about 0.01 mm/mm.

Surface finish left by process is rough: 6 – 12 μm.

Depth of **heat-affected zone**:

- up to 3 mm when turning small diameter work
- up to 5 mm when cutting material up to 25 mm thick.

PBM APPLICATIONS

- Cutting metal profile such as stainless steel, titanium, aluminium alloy and copper alloy (difficult to cut using oxy-gas techniques).
- Cutting refractory materials.
- Rough turning of bar materials from nickel alloy or other difficult to machine materials.
- Forming grooves.
- Cutting light materials such as textile.
- Drilling holes.
- Apart from machining, plasma arc is also used in welding. Non-transferred arc is also used in spraying paint on ceramics and to coat metal with ceramics.

ADVANTAGES

- Main advantage of PBM is: suitable for any material irrespective of hardness or heat resistant characteristics.
- PAM allows high material removal rate (up to 10,000 cm^3/hr) and mrr for high strength materials are comparable with conventional turning.
- Ferrous and non-ferrous materials up to 150 mm thick can be cut.

DISADVANTAGES

- Main disadvantage of PAM/PJM is high electric power requirement (eg 220 kW to cut mild steel plate 12 mm thick at speed of 2.5 m/min).
- Circular holes can be drilled but size limited by nozzle size.
- Depth of hole, tolerance and repeatability are limited.

Dual Flow Plasma
(or Dual Gas Plasma)

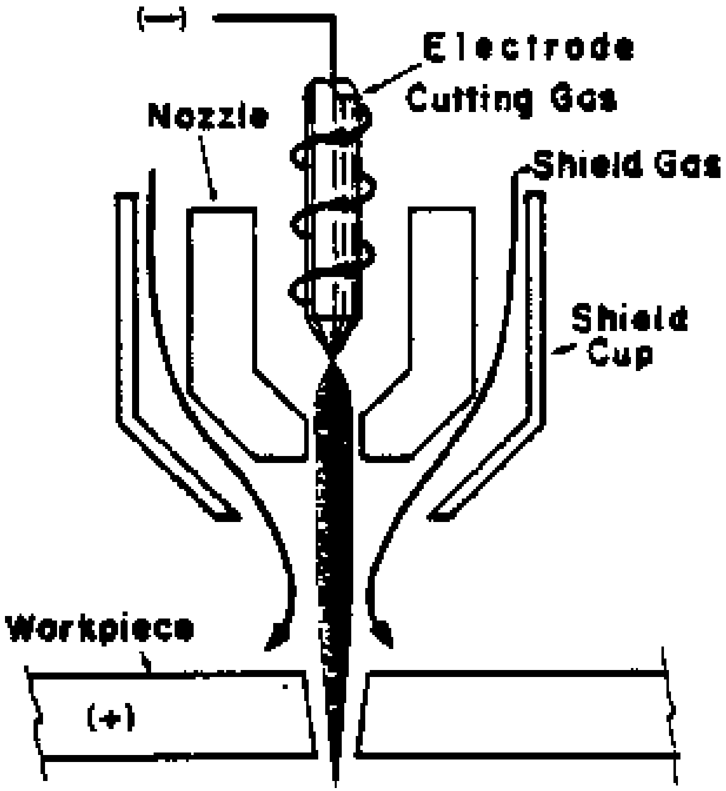
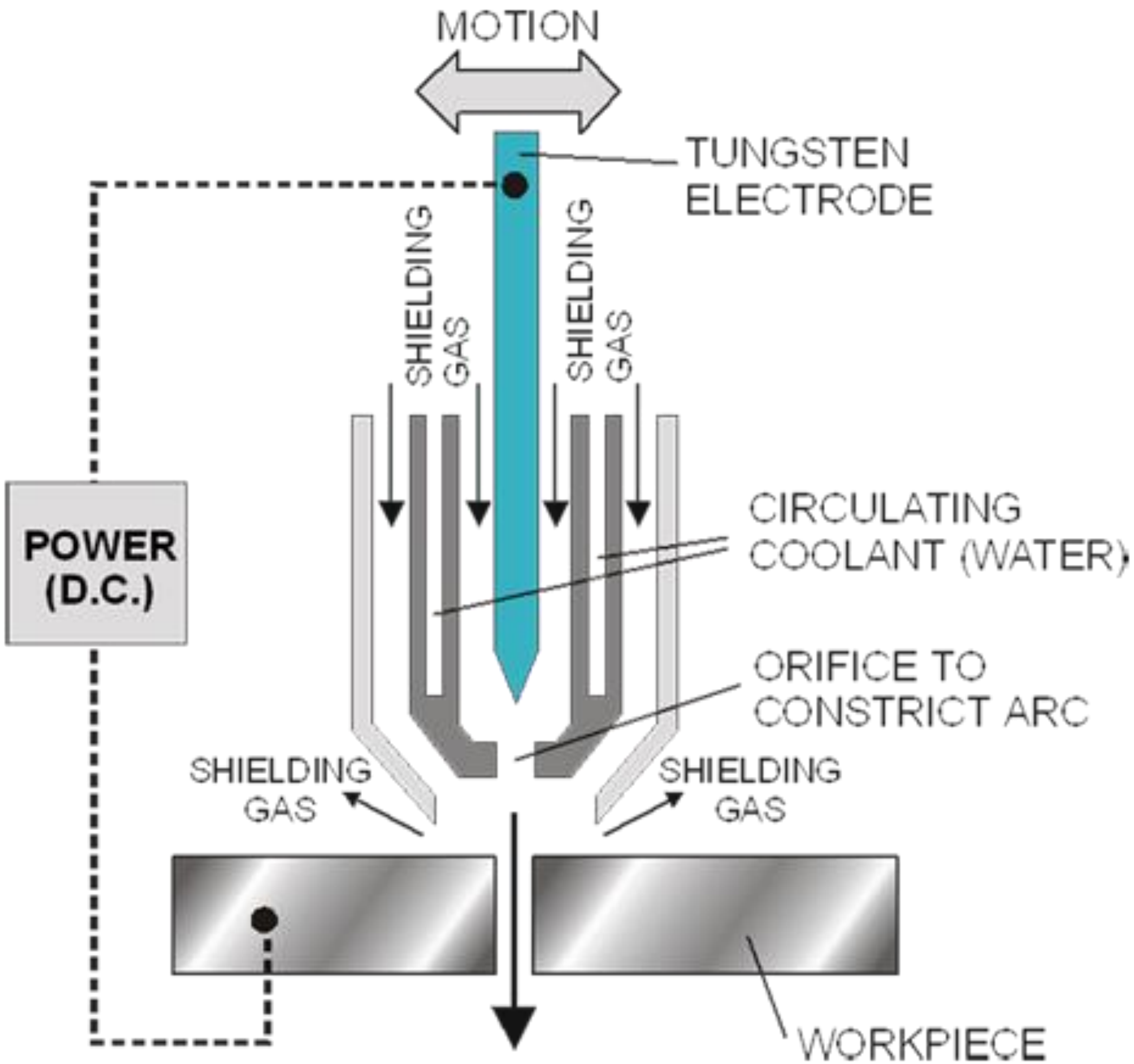


Figure: Dual flow plasma cutting

- Also uses tungsten electrode.
- Uses additional outer shield gas around nozzle to reduce shearing effect of atmosphere on cutting gas.
- Cutting gas is usually nitrogen or argon.
- Shield gas is chosen based on work metal being cut. Examples: hydrogen for stainless steel, aluminium and other non-ferrous metals; CO_2 for ferrous and non-ferrous metals; air or oxygen for mild steel.


MOTION
TUNGSTEN ELECTRODE
SHIELDING GAS
SHIELDING GAS
POWER (D.C.)
CIRCULATING COOLANT (WATER)
ORIFICE TO CONSTRICT ARC
SHIELDING GAS
SHIELDING GAS
WORKPIECE

Water Injected Plasma

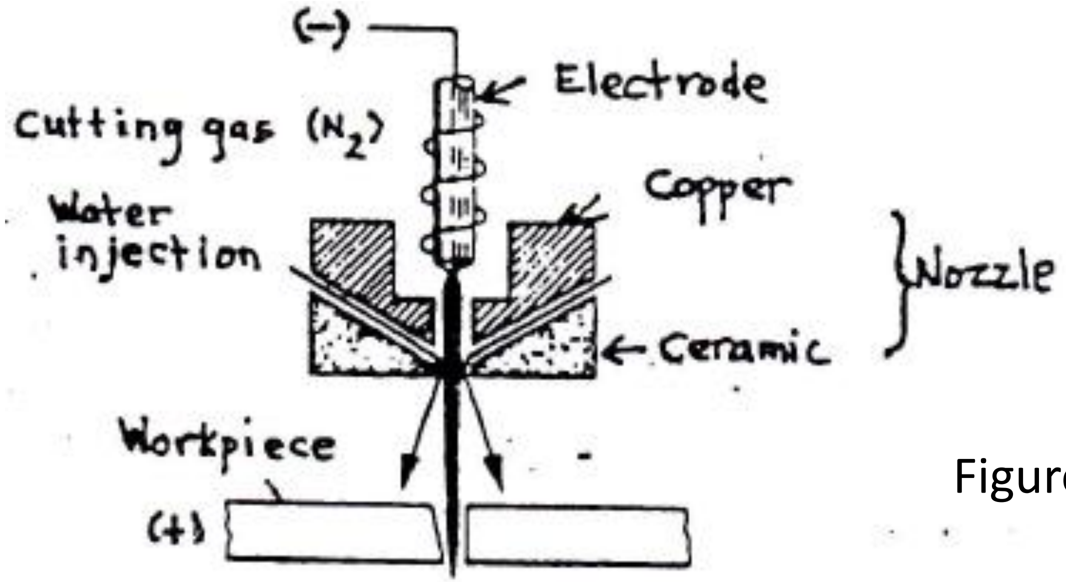
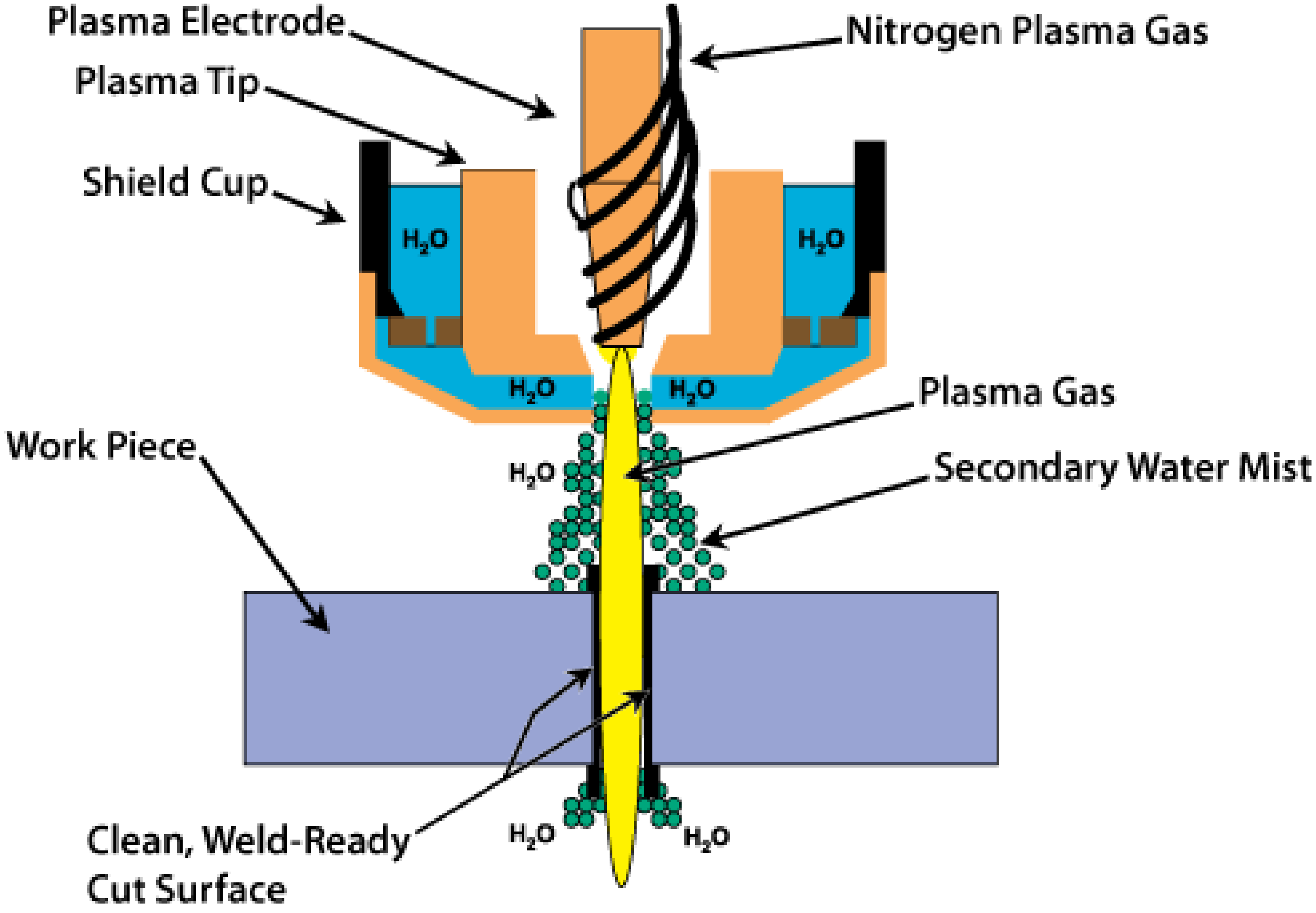


Figure: Water injection plasma cutting

- Nitrogen is used as cutting gas.
- Shield gas is replaced with water. To maximise constriction of arc, radial water-injecting jacket is used.
- Cooling effect of water reduces width of cutting zone and improves quality of cut.

Effect of N_2 / H_2O Plasma on Non-Ferrous

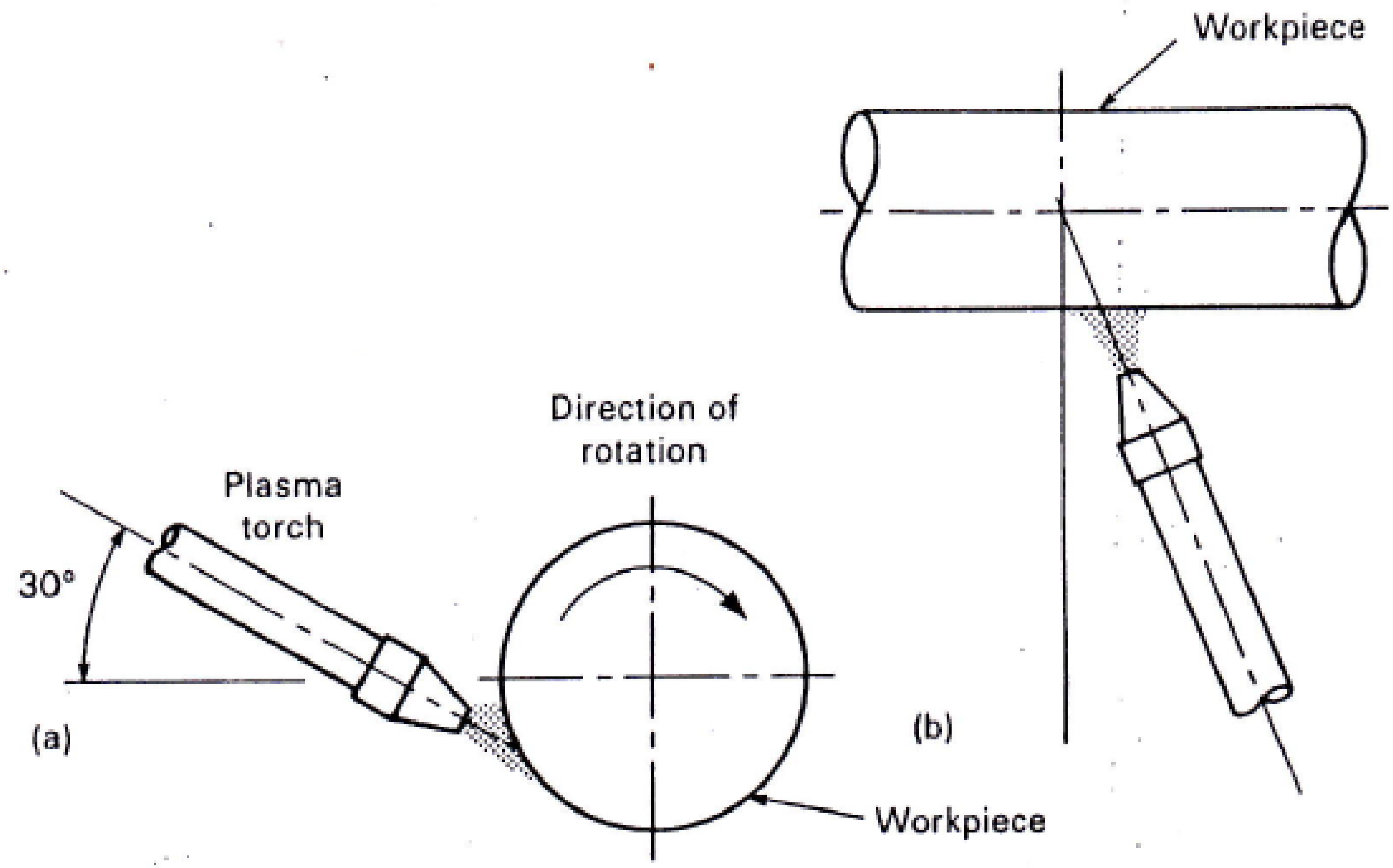


1. Typical cutting data in PAM

Material	Arc power kW	Argon – 15% H_2 flow rate $m^3 h^{-1}$	Torch angle	Cutting time s
89 mm round bar stainless steel	150	5.7	75° trail	15 s
92 mm round bar En3A	150	5.7	75° trail	37 s
114 mm square 2.25% Cr 1% Mo	150	5.7	90°	1 min

2. Comparison of removal rates for conventional methods and PAM

Material	Conventional turning $mm^3 s^{-1}$	Plasma arc	
		Roughing cut	Smooth cut
Rene 41	128	1365	546
Precipitation-hardening stainless steel	490	1230	546
Inconel	560	1090	410



Turning by plasma arc machining

Dr Sunil Pathak, PhD - IIT Indore (MP) India
Senior Lecturer
Faculty of Engineering Technology
University Malaysia Pahang, Kuantan Malaysia
https://www.researchgate.net/profile/Sunil_Pathak4
https://scholar.google.co.in/citations?user=9i_j3sMAAAAJ&hl=en