Introduction

Online course on
Analysis and Modelling of Welding

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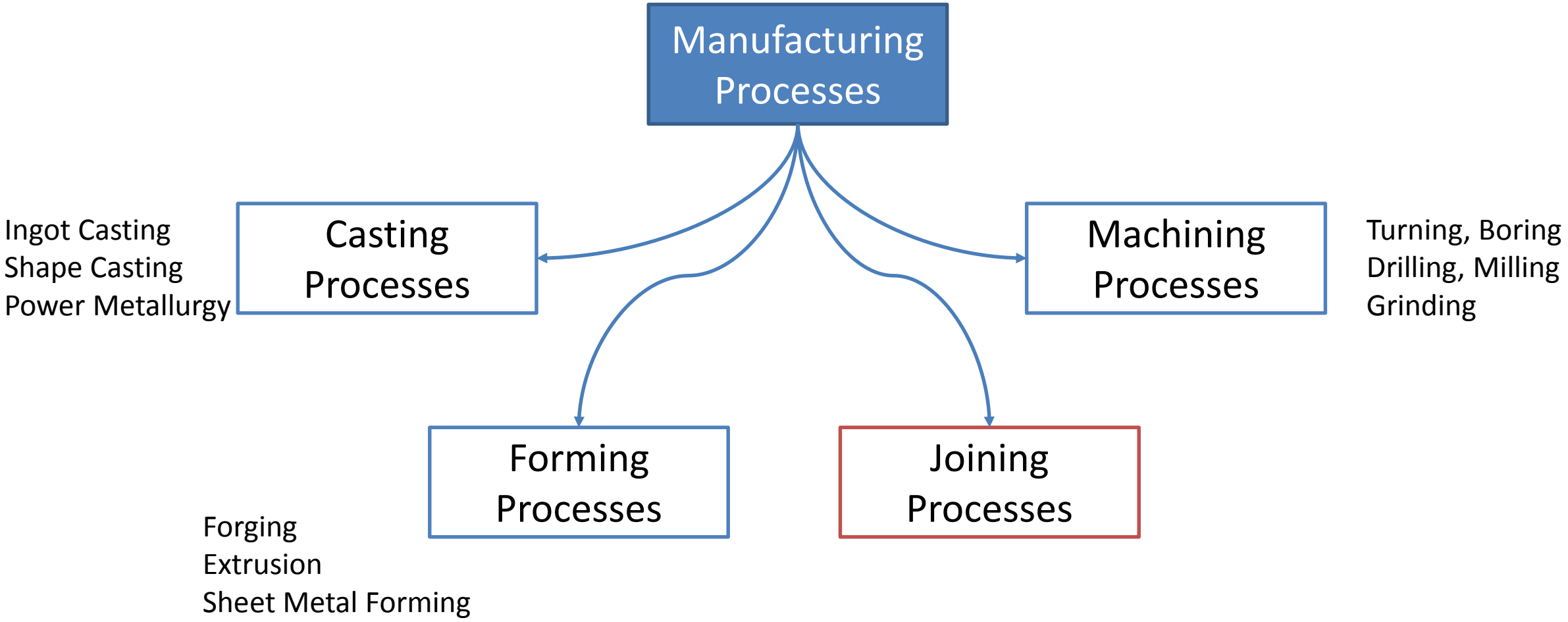
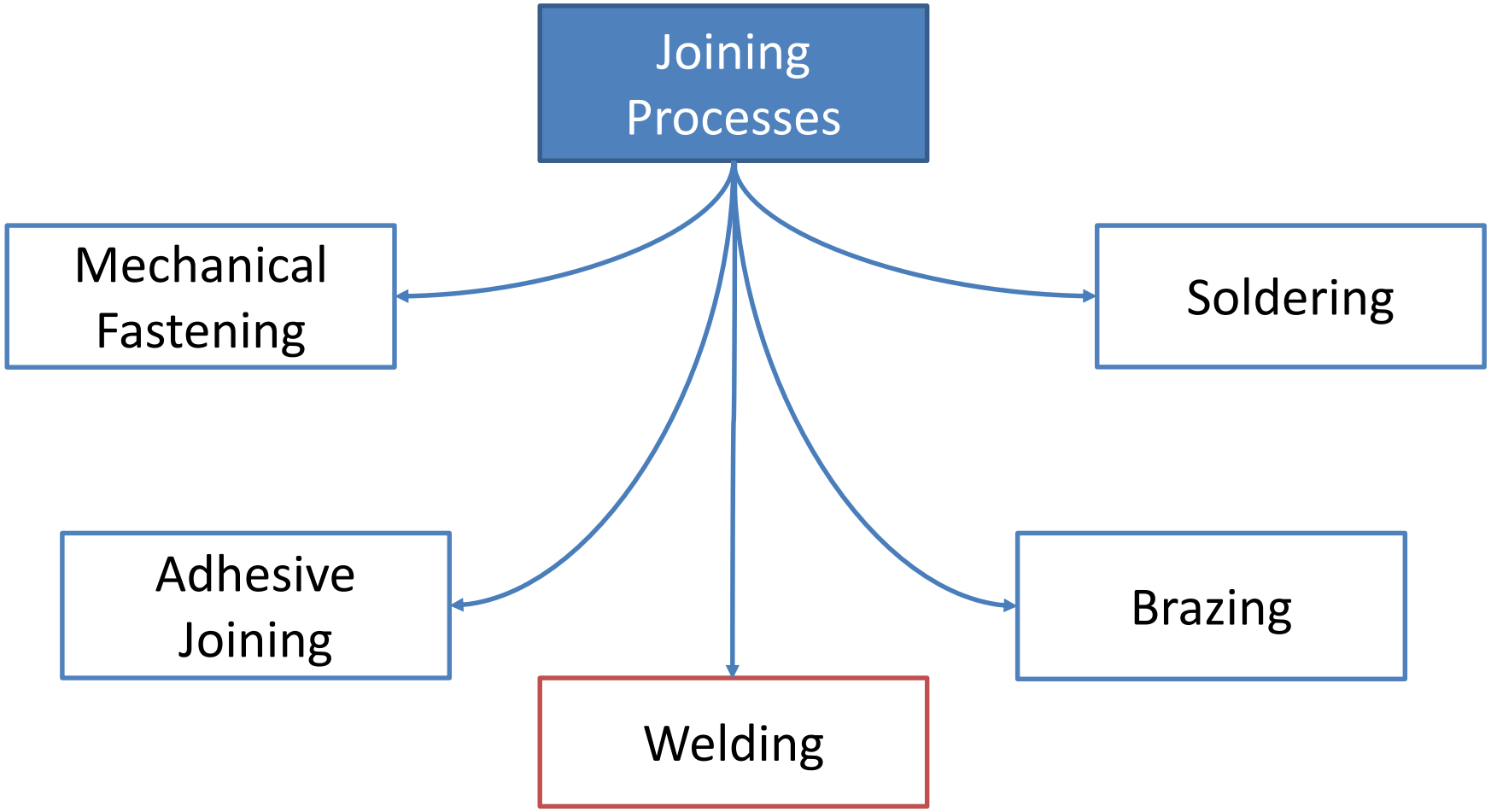
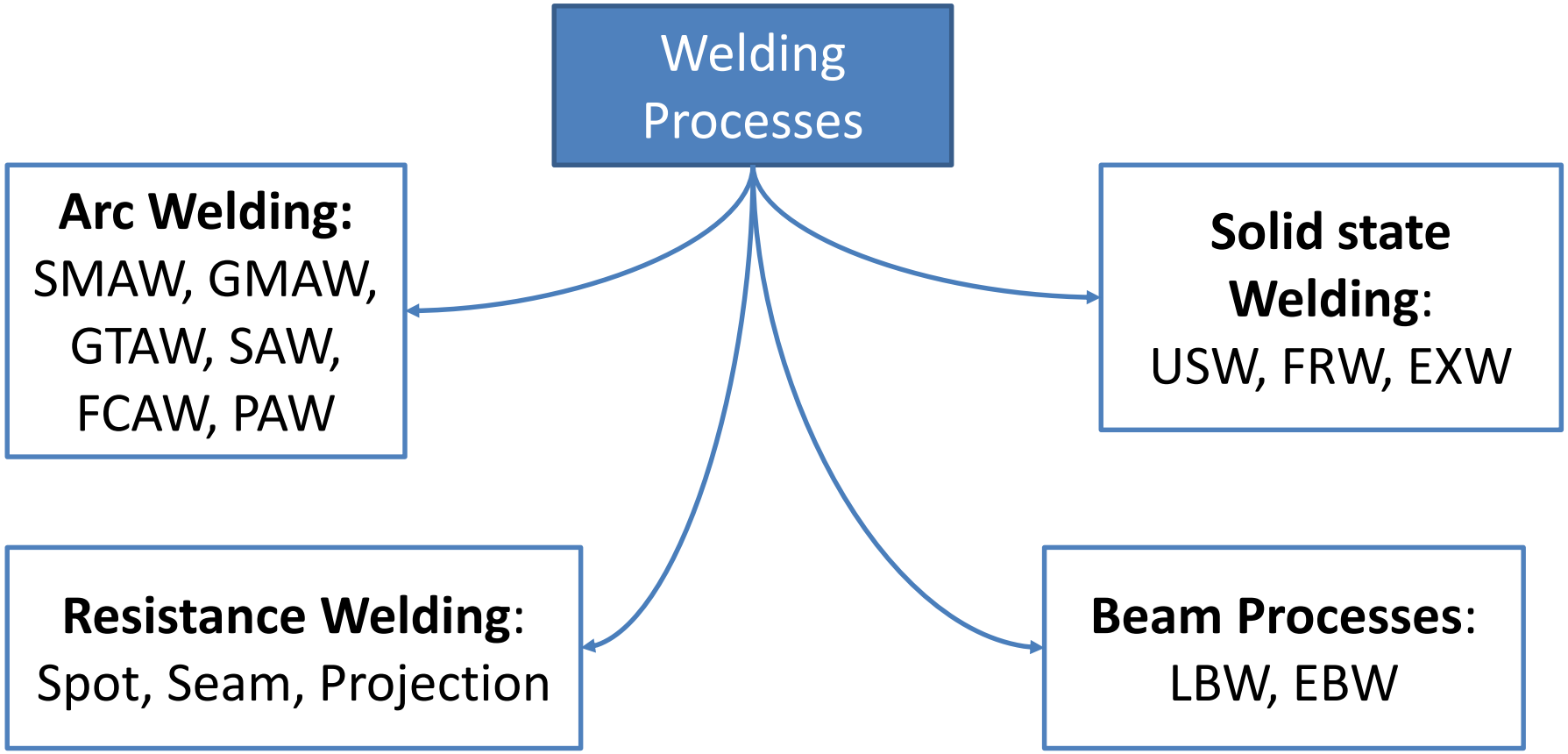
Classification of Manufacturing Processes



Classification of Joining Processes

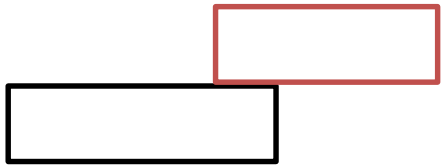


Different Welding Processes

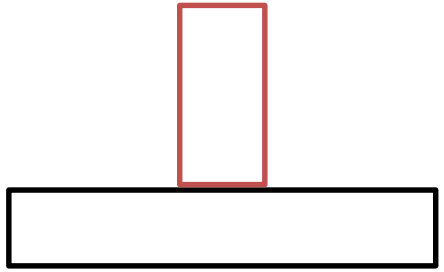


Five basic joint designs

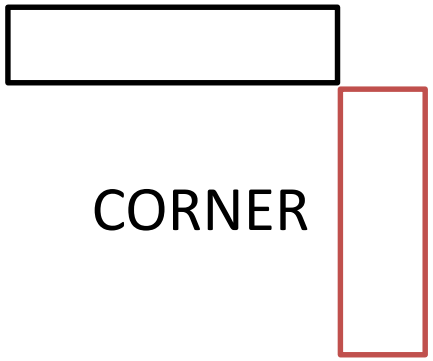
BUTT



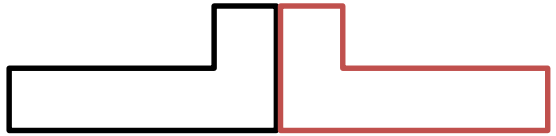
LAP



TEE



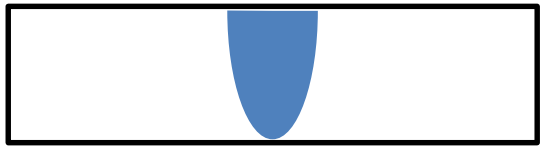
CORNER



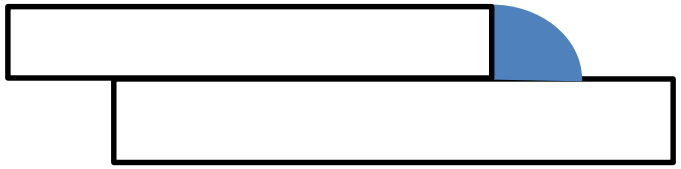
EDGE

Four basic types of fusion welds

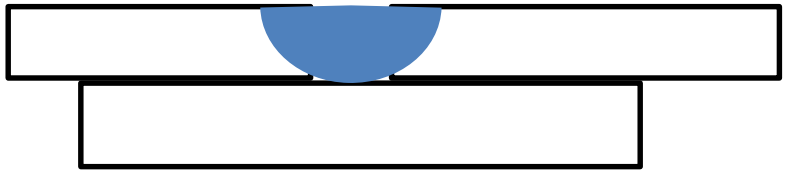
Bead / Surface Weld



Groove Weld



Fillet Weld



Plug Weld

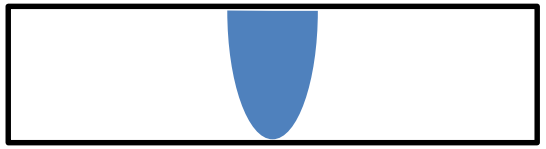
Bead / Surface Welds

Bead / Surface Weld

- For butt welds
- No edge preparation
- Thin sheets of metal
- Building up surfaces
- Weld overlay

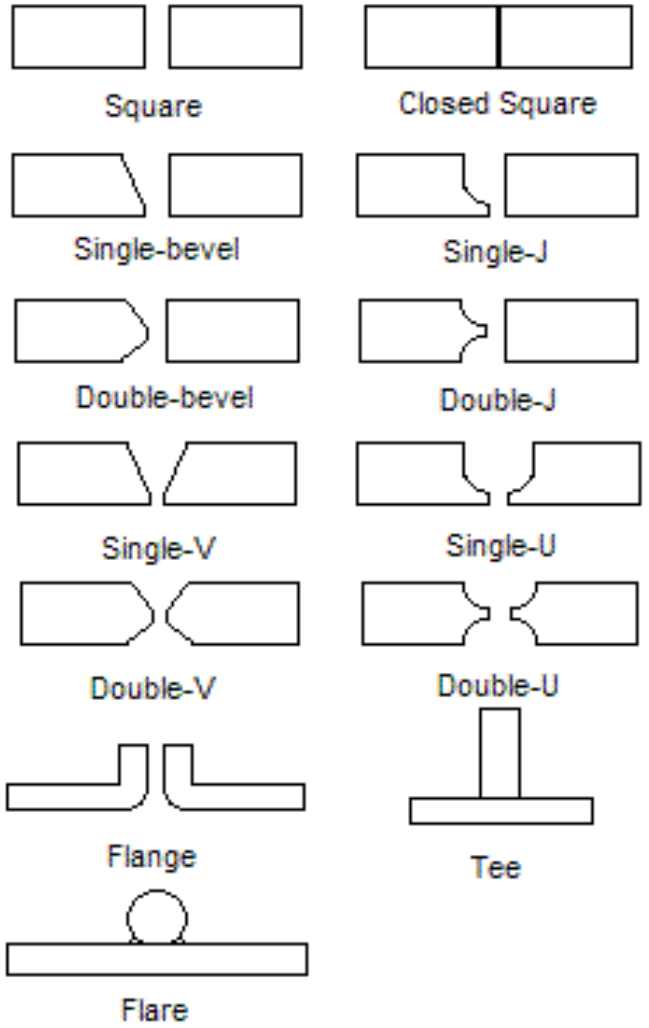
Groove Welds

- For butt welds
- Thicker materials
- Full thickness welding
- Detailed edge preparation
- Multi-pass welding



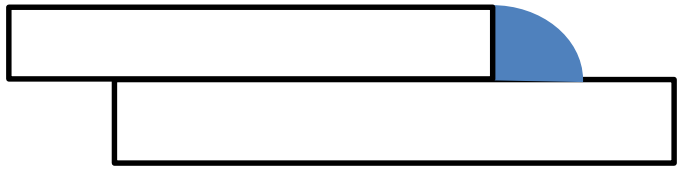
Groove Weld

Groove preparations



Ref: Wikipedia, public domain. Contributed by Benrunge

Fillet Welds

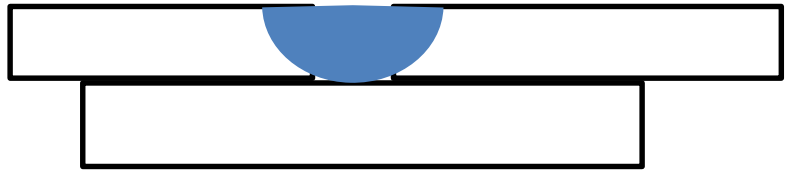


Fillet Weld

- For Tee, Lap and Corner joints
- No edge preparation

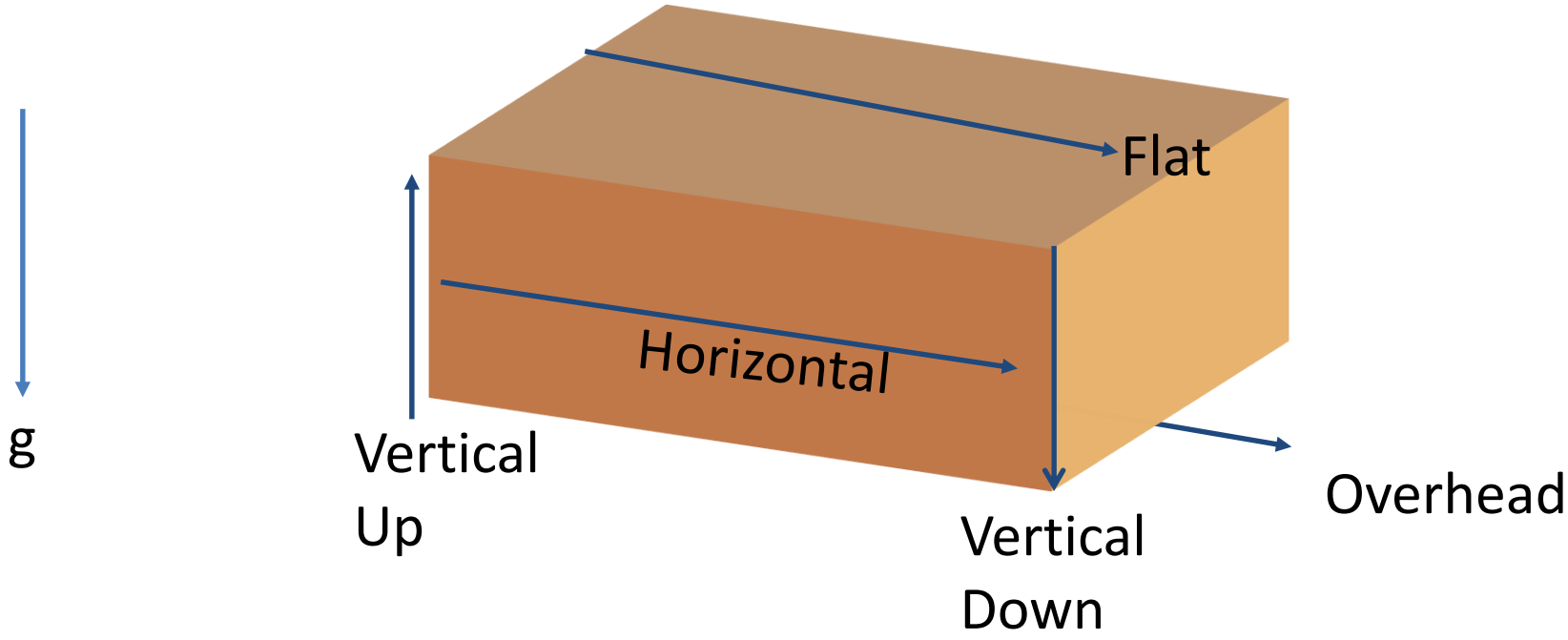
Plug Welds

- Hole drilled on the top sheet
- To replace bolts and rivets
- When excess deposit is not desirable by design



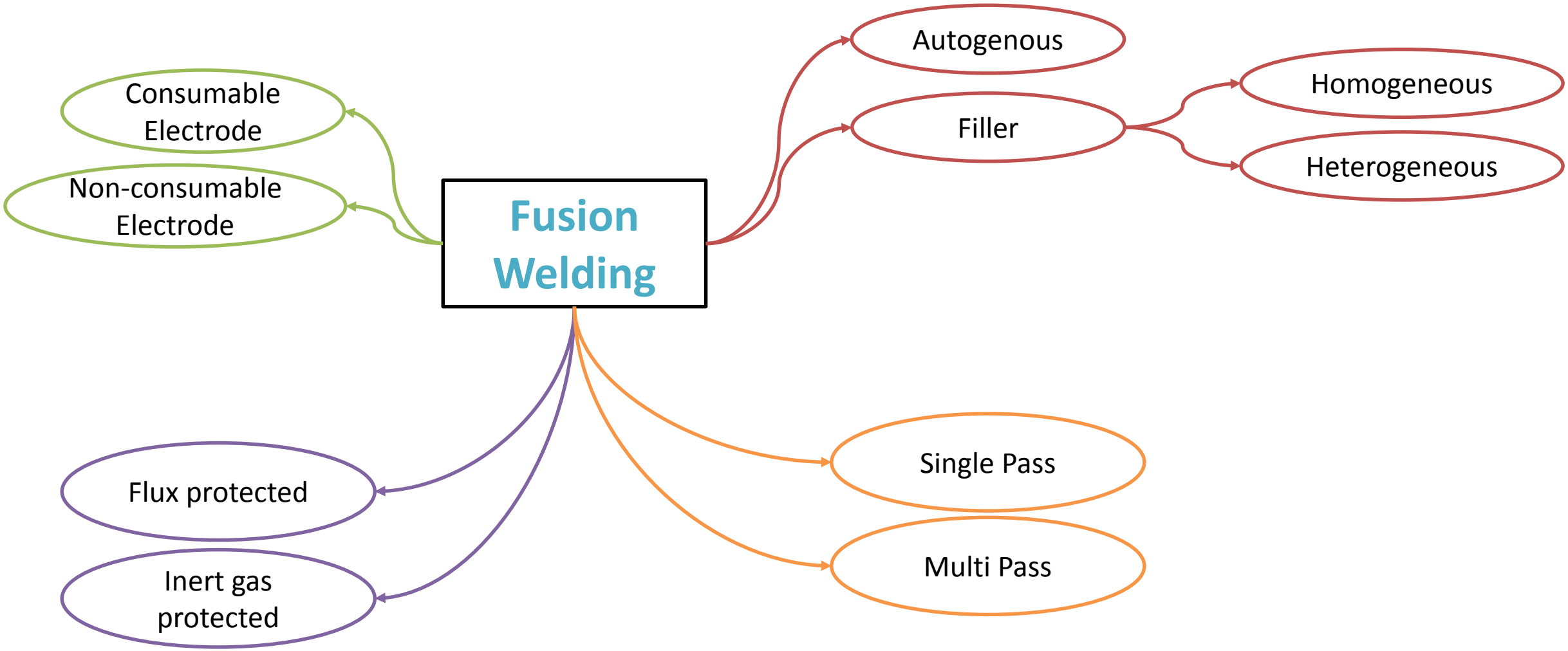
Plug Weld

Five Welding Positions



Arrow shows the direction of motion of the electrode / torch.
The torch is held approximately normal to this direction.

Classification of Welding



Some terminology

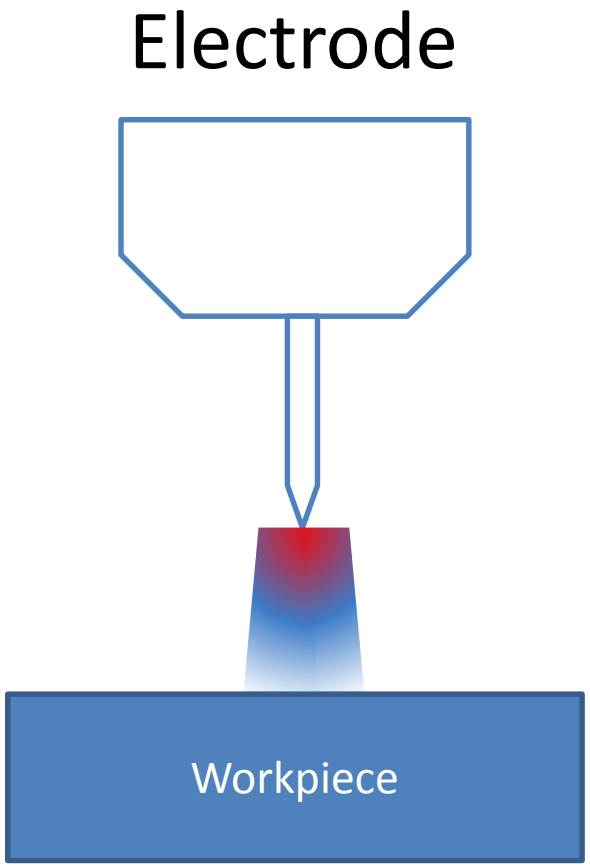
- Traverse rate : velocity of the welding source : m/s
- Heat Input : ratio of power to velocity : J/m
- Rate of heat input or heat intensity : W/m^2
- Heat intensity distribution : Q(x,y)

Overview of few welding processes

- SMAW : Shielded (Manual) Metal Arc Welding
- GMAW: Gas Metal Arc (MIG) Welding
- GTAW: Gas Tungsten Arc (TIG) Welding
- PAW: Plasma Arc Welding
- SAW: Submerged Arc Welding
- EBW: Electron Beam Welding
- LBW: Laser Beam Welding

Electric Arc

- Generated between two conductors of electricity, upon application of voltage and separated by a small distance
- Presence of ionisable gas
- Sustained electric discharge through ionized gas column between the two electrodes



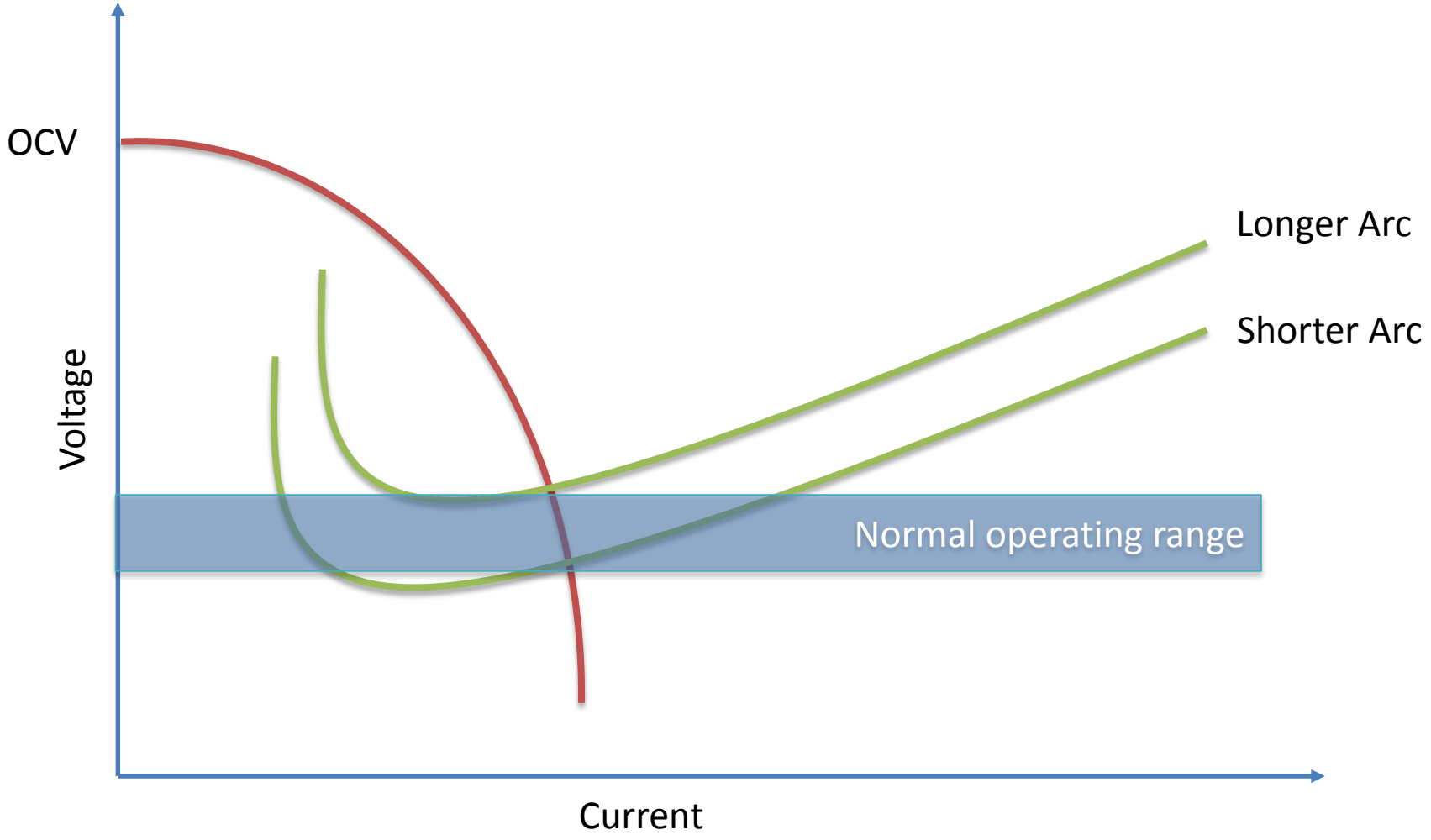
Role of gases in arc welding

- Inert / active
- Shielding effect
- Stability of arc

Gas	Ionization Potential
CO_2	14.4 eV
O_2	13.2 eV
N_2	14.5 eV
H_2	13.5 eV
Ar	15.7 eV
He	24.5 eV

Ref: Welding Metallurgy, 2nd Edition by Sindo Kou, Wiley-Interscience ISBN: 0471434914

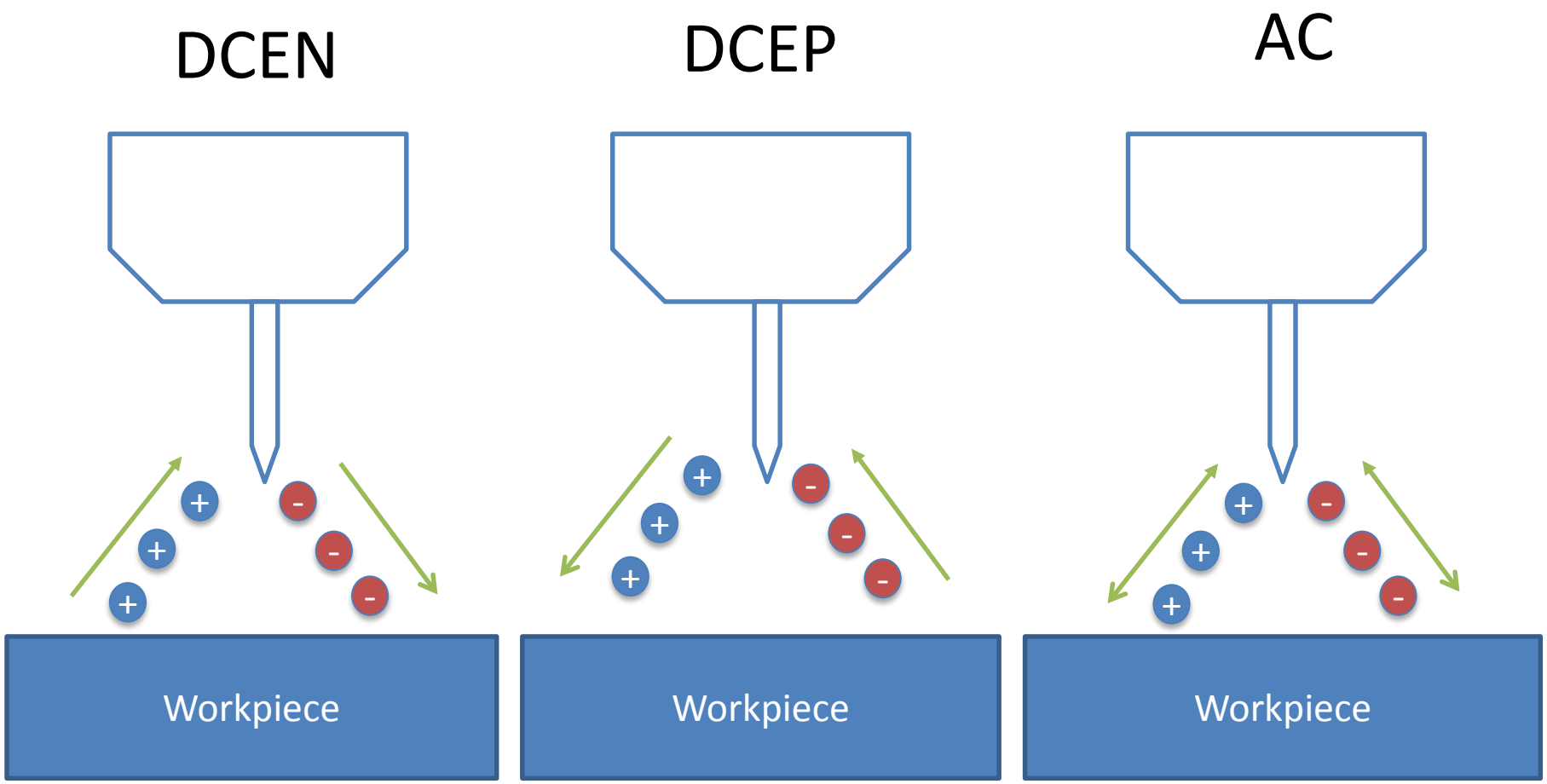
Arc characteristics



Ref: Principles of Welding Technology, 3rd Edition by L. M. Gourd, ISBN: 8176490296

Electrode Polarities

- Direct Current Straight Polarity (DCSP) : Electrode is negative. Deeper penetration.
- Direct Current Reverse Polarity (DCEP) : Electrode is positive. Enhanced deposition rate for consumable electrode.
- Alternating Current (AC) : Polarity is switched at a frequency.

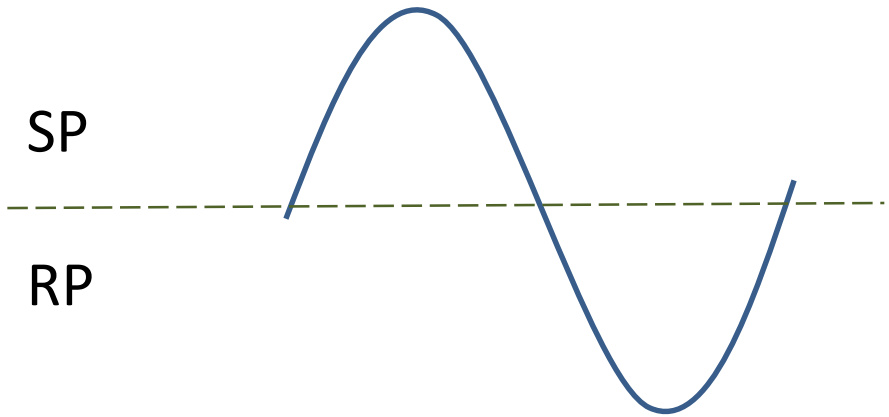


70% Heat to workpiece
30% Heat to Electrode

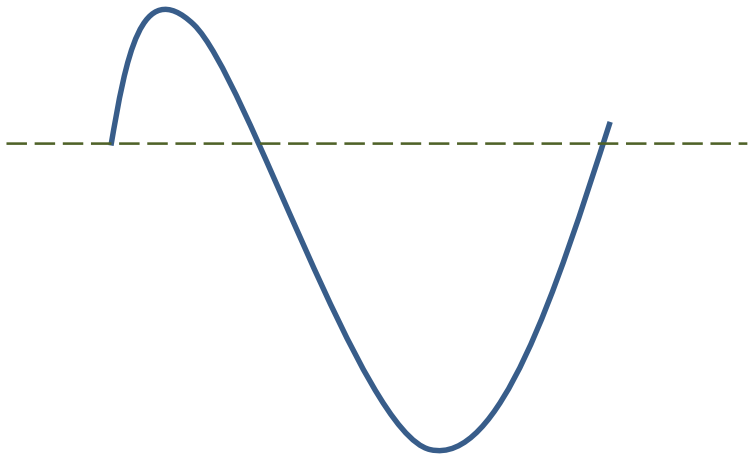
30% Heat to workpiece
70% Heat to Electrode
Surface Cleaning

50% Heat to workpiece
50% Heat to Electrode
Surface cleaning half-the-time

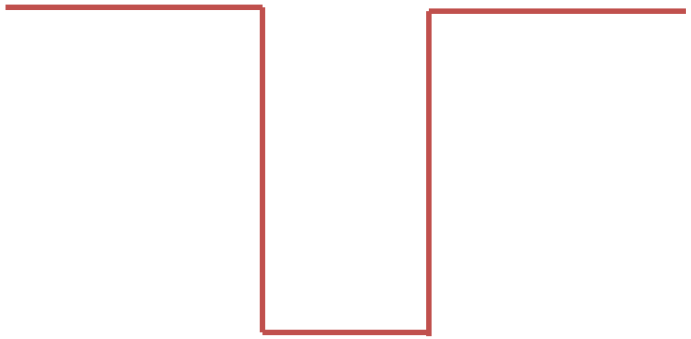
Temporal profiles



Balanced Sine Wave



Unbalanced Sine Wave

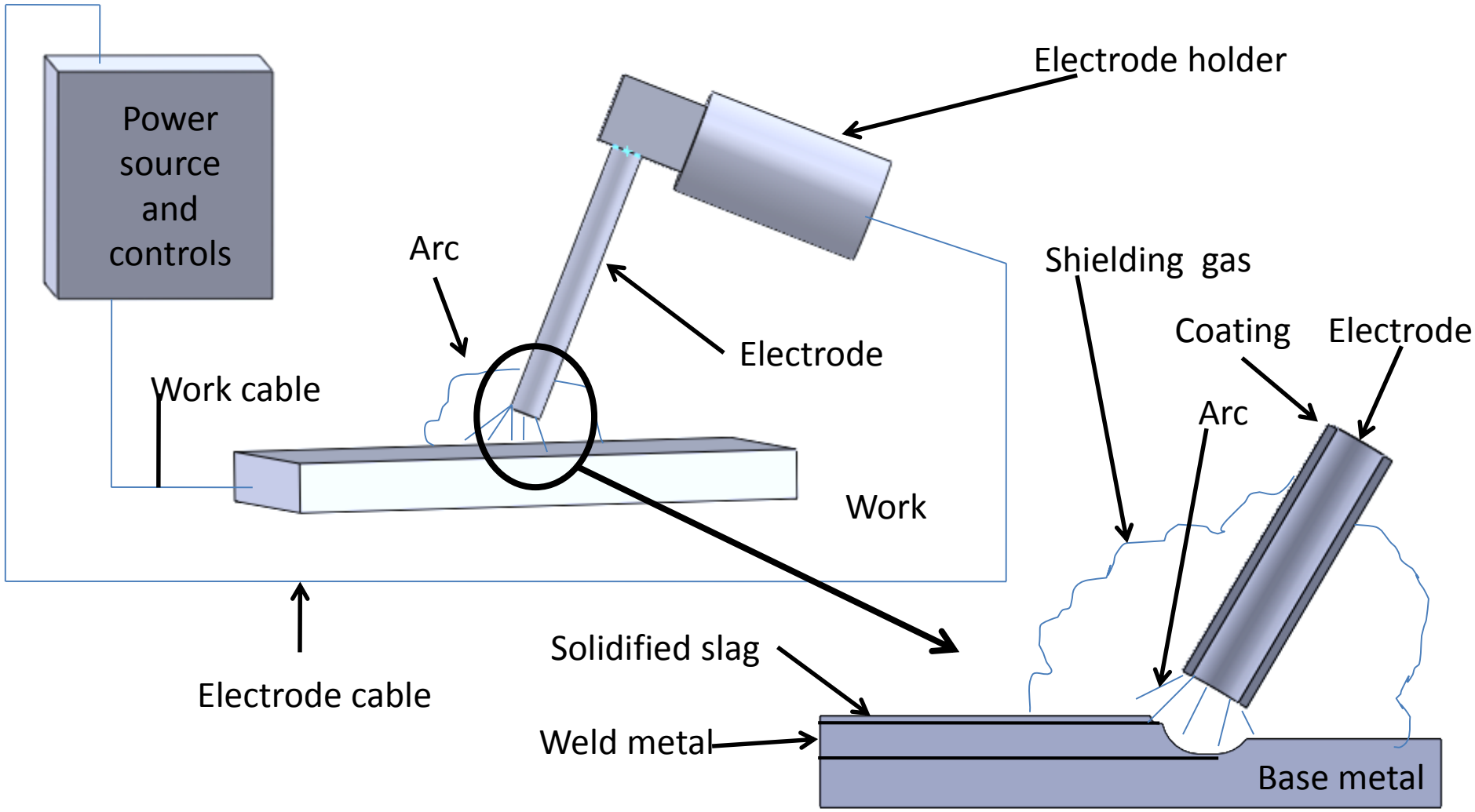


Square Wave

Spatial-temporal characteristics of arc

- Voltage, Current, Efficiency
- Wave form : flat, square, sine, unbalanced sine etc.
- Pulsing effects (Peak value, base value)
- Frequency (Hz)
- Traverse rate (m/s)
- Electrode path : arc oscillation, frequency and amplitude etc.

Shielded metal arc welding

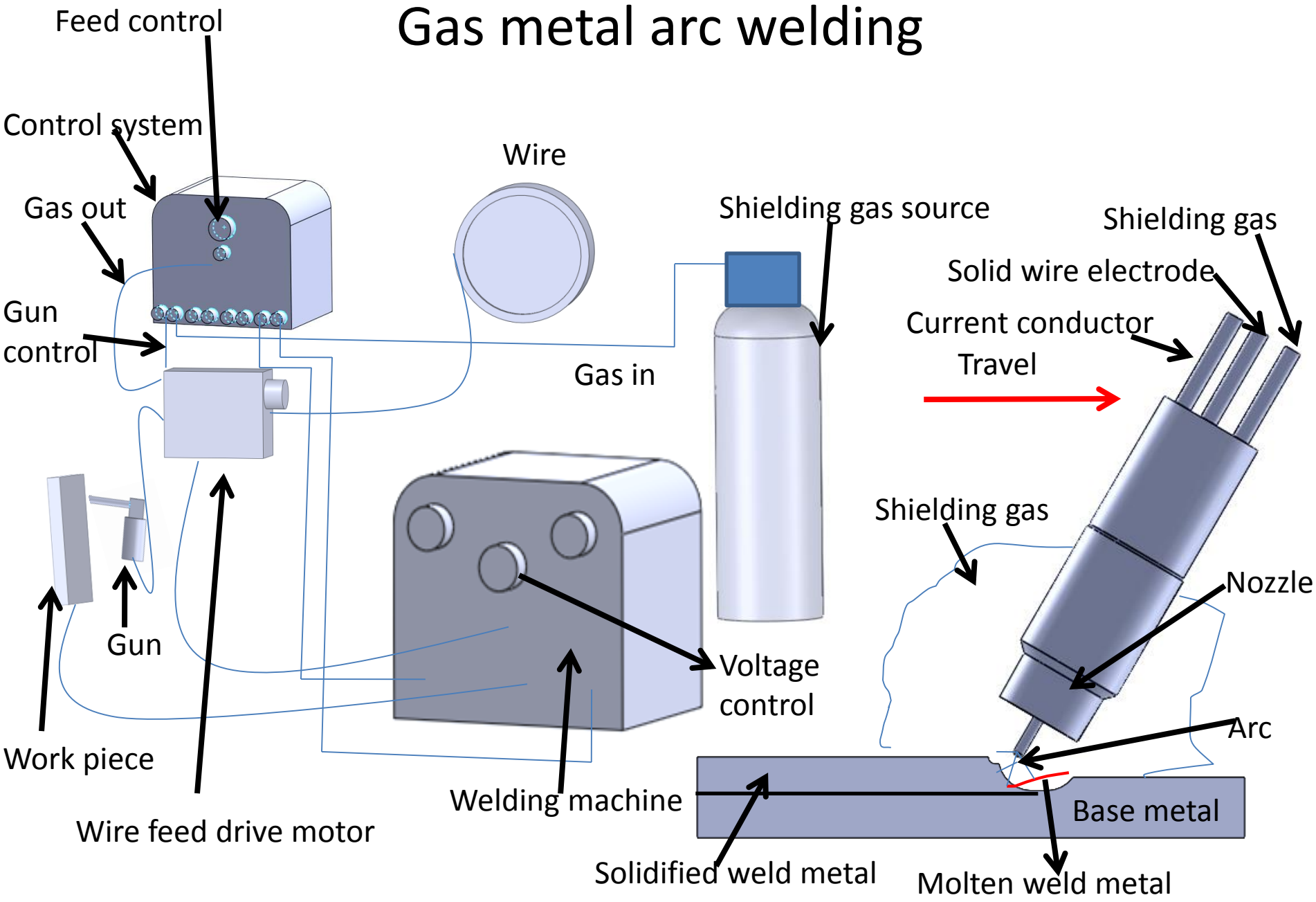


What is in the Flux?

Role of a Flux : Protection, Deoxidation, Stabilization and Metal Addition

Constituent	Role
Iron oxide	Slag former, arc stabilizer
Titanium oxide	Slag former, arc stabilizer
Calcium fluoride	Slag former, fluxing agent
Potassium silicate	Arc stabilizer, Binder
Magnesium oxide	Fluxing agent
Cellulose	Gas former
Calcium carbonate	Gas former, Arc stabilizer
Ferro-manganese, Ferro-chrome	Alloying changes
Ferro-silicon	Deoxidizer

Gas metal arc welding

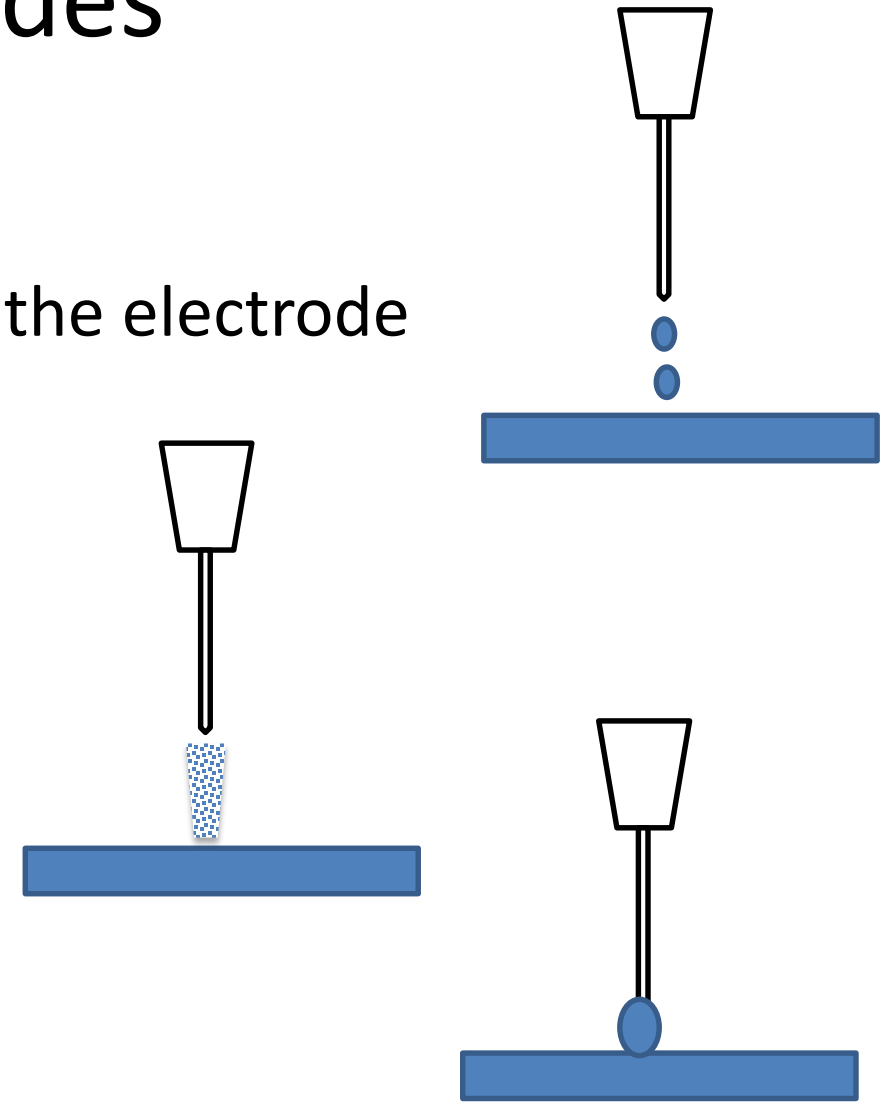


GMAW

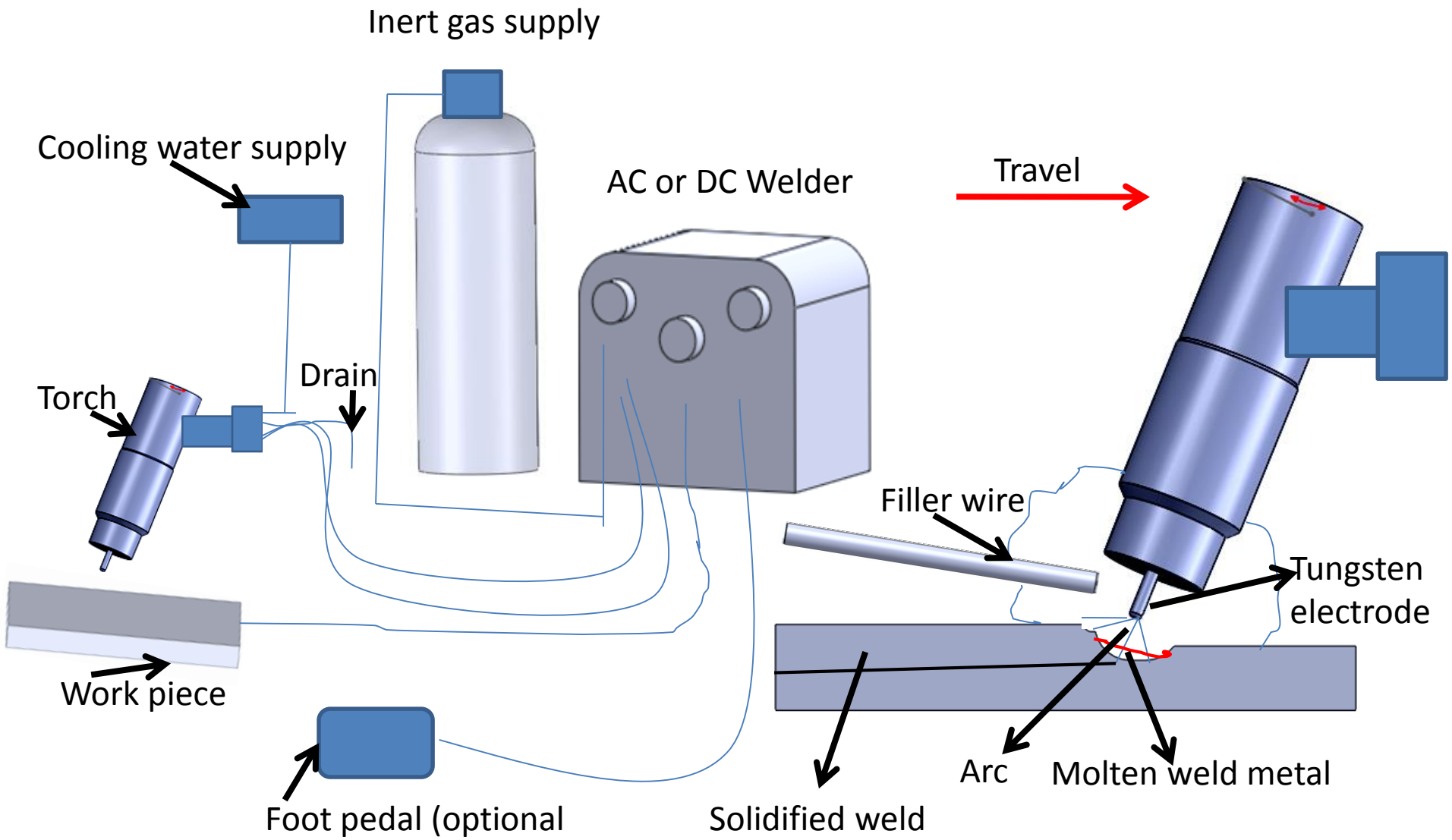
Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras

Metal transfer modes

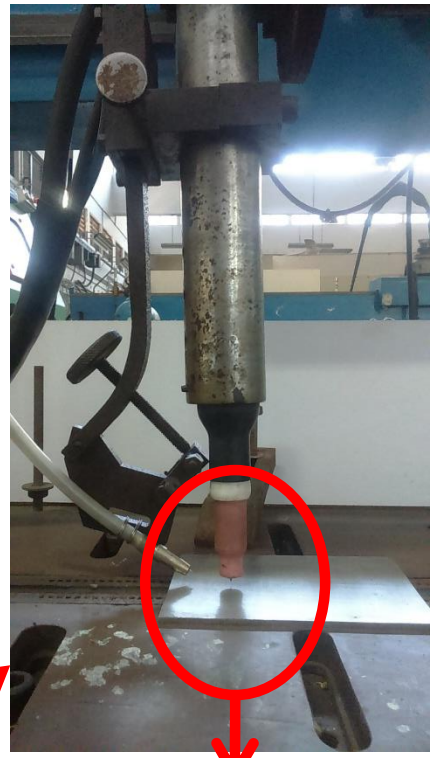
- Globule transfer
  - Droplets close to or larger than diameter of the electrode
  - Reach base material by gravity
  - Leads to spatter
- Spray transfer
  - Fine droplets
  - Reach base material by EM force
- Short-circuit transfer
  - Small and fast solidifying weld pools

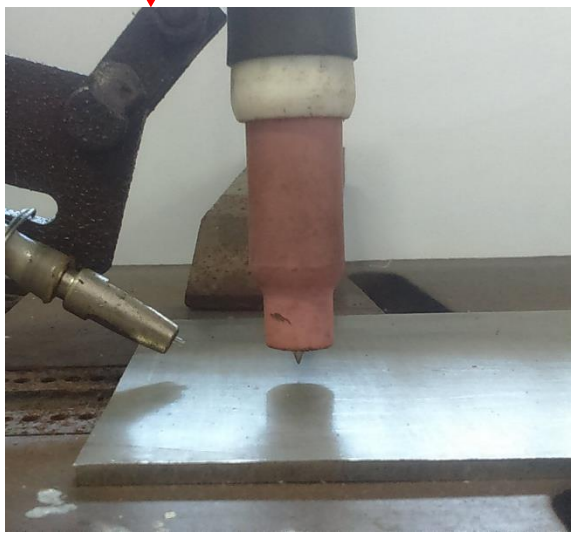


Gas tungsten arc welding



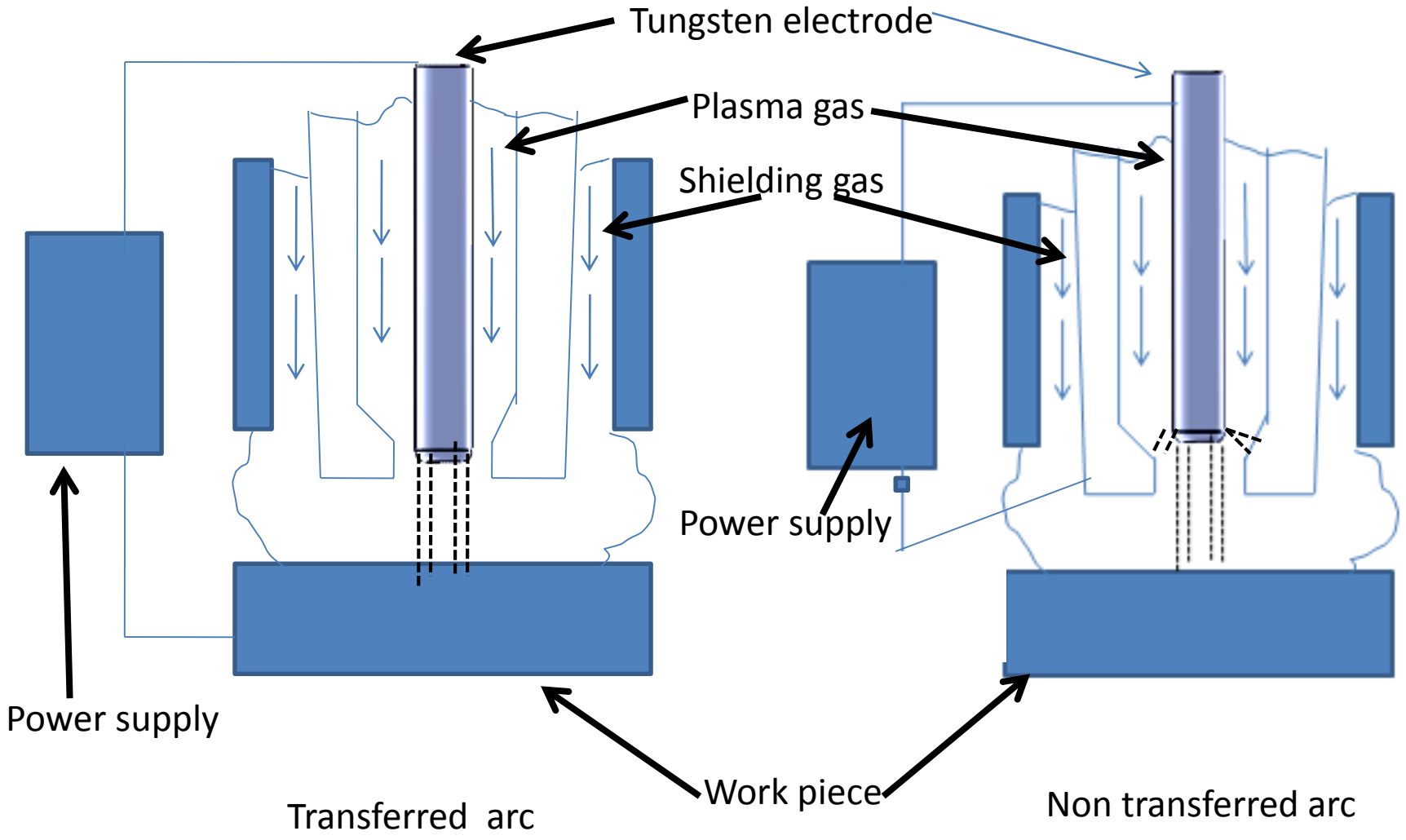
TIG





Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras

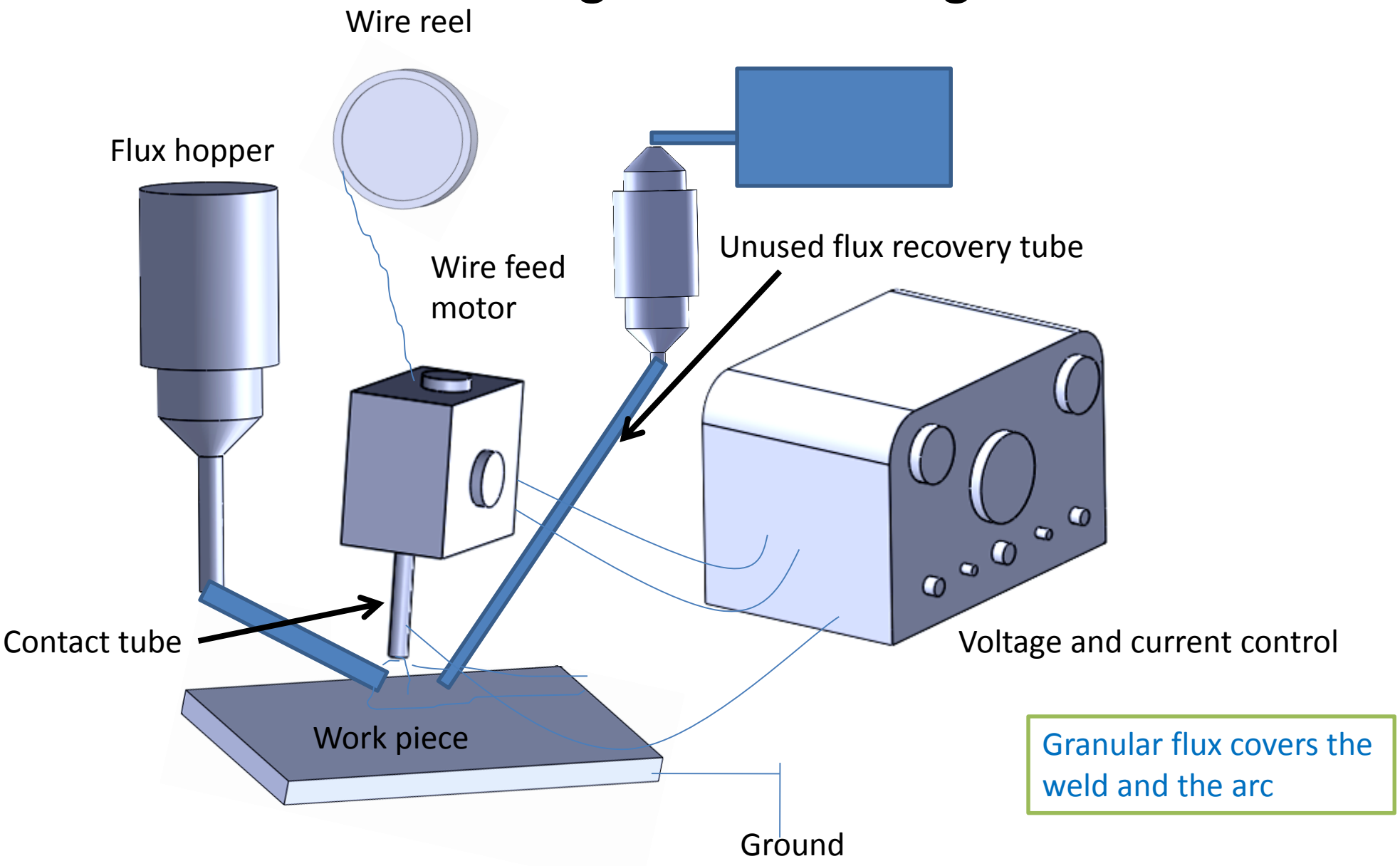
Plasma arc welding



PAW

Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras

Submerged Arc welding

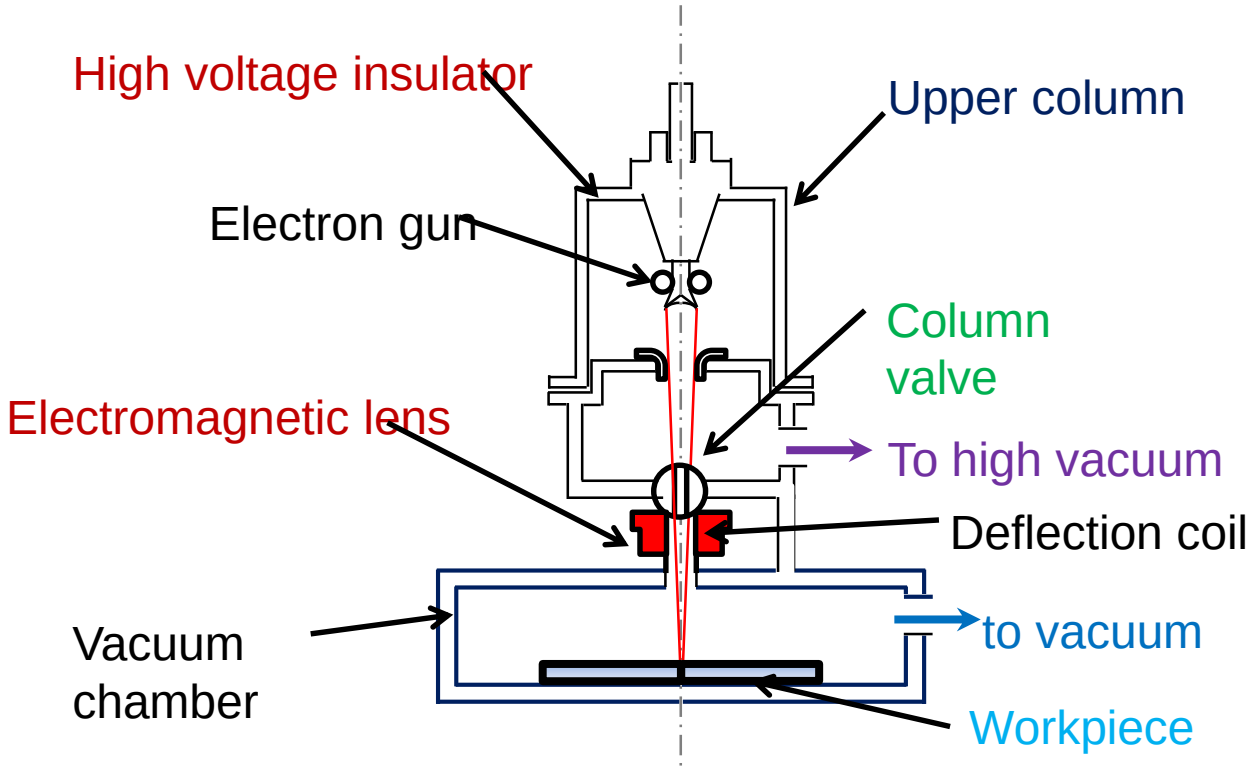


Granular flux covers the weld and the arc

SMAW

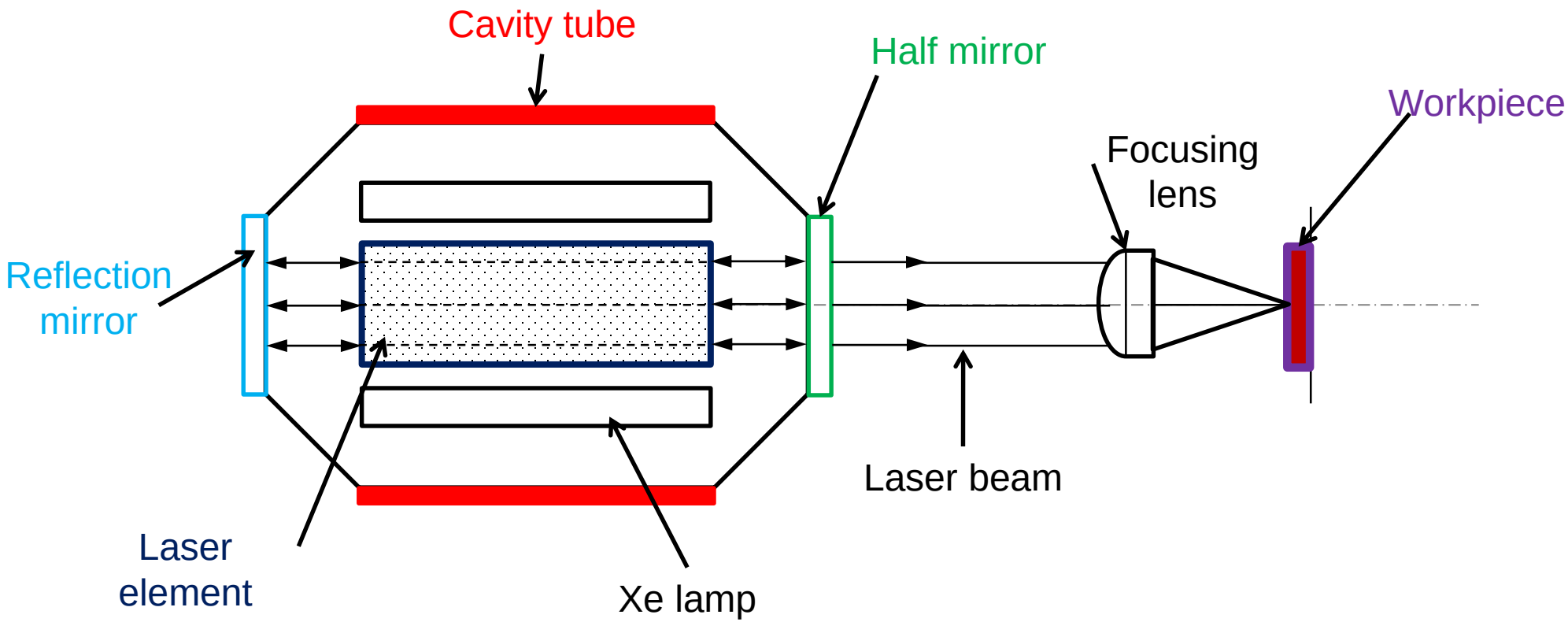
Photographs from the facilities in Materials Joining Laboratory, Department of MME, IIT Madras

Electron beam welding



Schematic of a typical EBW gun

Laser beam welding



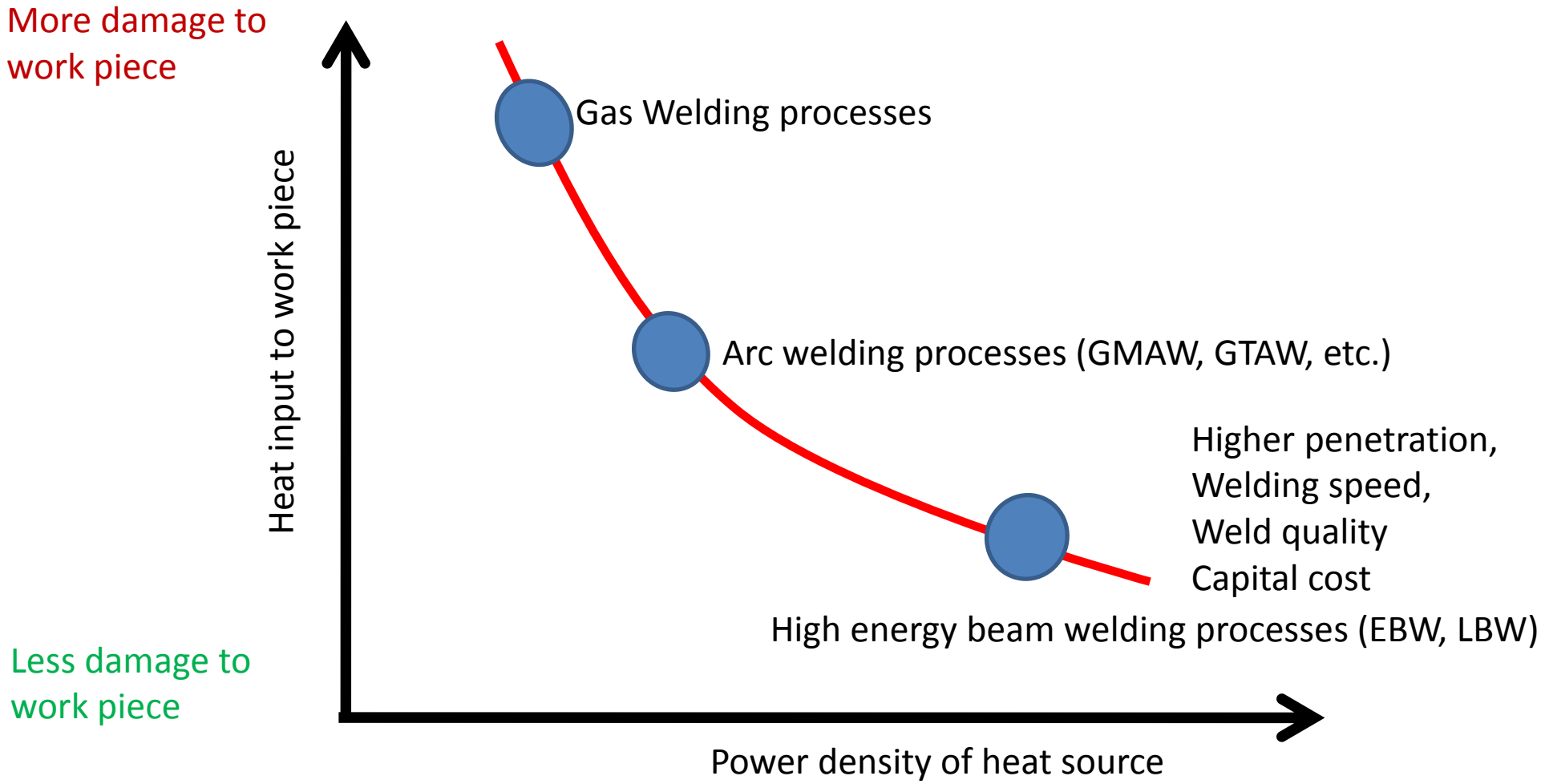
Basic features of an Nd : YAG laser

Intensity of heat sources

Process	Heat source intensity (W/m^2)
SMAW, FCAW	$5x10^6 – 5x10^8$
GTAW, GMAW	$5x10^6 – 5x10^8$
PAW	$5x10^6 – 10^{10}$
LBW, EBW	$10^{10} – 10^{12}$

Ref: Principles of Welding by Robert W. Messler, Wiley-VCH (2004) ISBN: 0471253766

Heat input vs power density



Ref: Welding Metallurgy, 2nd Edition by Sindo Kou, Wiley-Interscience ISBN: 0471434914

Summary of features

Feature/Process	GTAW	GMAW	PAW	LBW	EBW
Heat Source	Arc	Arc	Plasma Arc	Laser beam	Electron beam
Protection	Shielding gas	Shielding gas	Shielding gas	None / Shielding gas	Vacuum
Rate of Heat Input	Medium	Medium	High	High	Very High
Aspect Ratio of Weld	1	1	3	5	20
Max Penetration	3 mm	5 – 10 mm	Up to 20 mm	25 mm	150 mm
Advantages	High quality weld	Continuous and Automated	Longer arc length	Any location where light can reach, high speed, accuracy	Precision, accuracy, deep and narrow welds
Materials Joined	Most common metals	Most common metals	Most common metals	Reflectivity Issues	Vacuum Issues

Ref: Materials and Processes in Manufacturing, 9th Edition by E. Paul DeGarmo et al., Wiley. ISBN: 9812530703

End of Introduction