

Advances in Welding and Joining Technologies

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Module 1

Fundamentals of Welding and Joining

- ✓ Classification
- ✓ Physics of welding
- ✓ Fusion welding
- ✓ Brazing and soldering
- ✓ Adhesive bonding
- ✓ Physics of welding arc
- ✓ Surface active elements and allied welding processes
- ✓ Magnetically impelled arc welding

Introduction

Electrification

Automobile

Airplane

Water Supply and
Distribution

Electronics

Radio and Television

Agricultural
Mechanization

Computers

Telephone

Air Conditioning
and Refrigeration

Highways

Spacecraft

Internet

Imaging

Household Appliances

Health Technologies

Petroleum and
Petrochemical
Technologies

Laser and Fiber Optics

Nuclear Technologies

High-performance Materials

Introduction

What is welding and joining?

Critical technologies in manufacturing

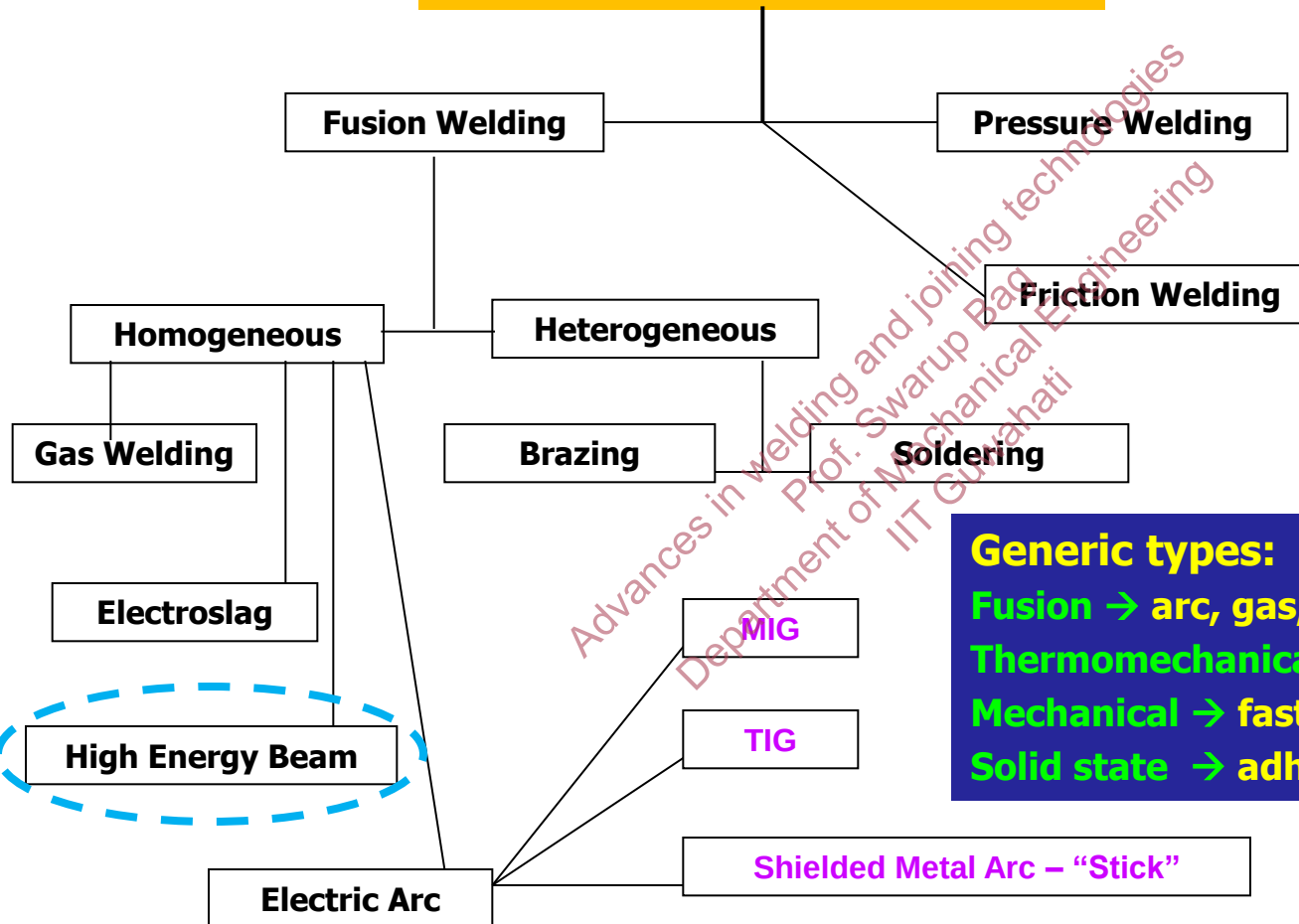
- mainly construction and mining industries in large scale

Weld Defects => Catastrophic Failure
=> loss of property and human life

Advances in welding and joining technologies
Prof. Swapnil B. Joshi
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Welding and joining

Types of Welding



Generic types:

Fusion → arc, gas, power beam, resistance

Thermomechanical → friction, flash, explosive

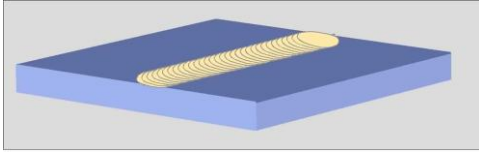
Mechanical → fasteners

Solid state → adhesive, soldering, brazing

Welding and joining

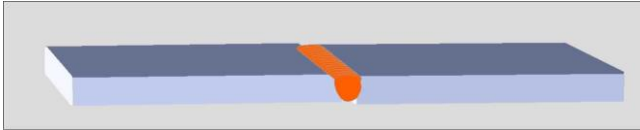
Three Types of Welds

Surface



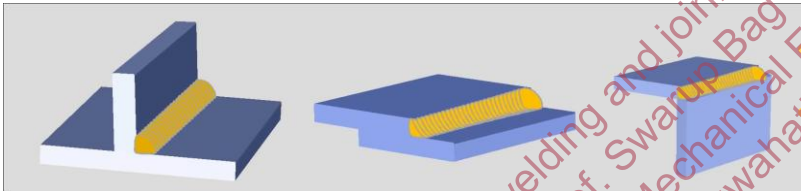
Two common applications are for hard surfacing

Groove



The primary use of groove welds is to complete butt joints

Fillet



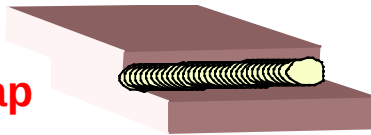
have a triangular cross section used that are at a 90 degree angle

Five Types of Joints

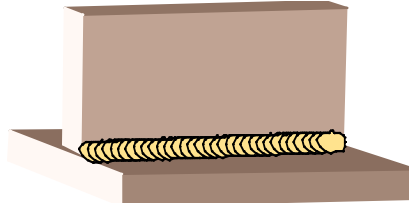
Butt



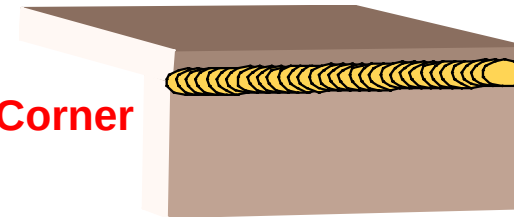
Lap



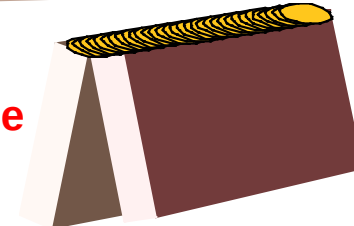
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Corner



Edge



Classification of Welding and Joining

Joining Processes

✓ Permanent

- Welded Joint
- Soldering
- Brazing
- Riveted Joint

✓ Non-permanent

- Bolted Joint
- Screw Joint

✓ Semi-permanent

- Adhesive Bonding

Classification of Welded Joints

Joining Processes

□ Fusion welding

- Gas welding
- Arc welding
- High energy beam
- Thermit welding

□ Metal Deposition Process

- Soldering
- Brazing
- Adhesive Bonding

□ Pressure welding

- Friction welding
- Ultrasonic welding
- Explosive welding
- Diffusion welding
- Resistance welding
- Magnetic impelled arc welding

Physics of welding

- Is that possible to bring together metallic surfaces together?
- Only grain boundary separate them, adherence with large force is possible
 - Ideal case to conduct welding
 - Practically metal surfaces contaminated with layer of oxides
 - Deals with the phenomena associated with welding processes
 - The formation of weld bonds (fusion welds and solid-state weld, commonly differentiated by the physics of the metallic bonding mechanism)

Physics of welding

Principles of fusion welding

- **Fusion welds** are created by the coalescence of molten base metals mixed with molten filler metals
- Metals must be heated to melting point for fusion welds to be produced
- Phase transitions inherent to these processes, a heat-affected zone is created
- The cooling of fusion zone is associated distortion, residual stress and metallurgical changes

Principles of Solid-state welds

- ✓ at temperatures below the melting point
- ✓ are created by either the macroscopic or microscopic coalescence of the materials in the solid state

Physics of arc welding

Voltage – The electrical potential or pressure that causes current to flow

Current – The movement of charged particles in a specific direction

Polarity DC- (Direct Current Electrode Negative) **Heat generation**
DC+ (Direct Current Electrode Positive) **in electrode**
AC (Alternating Current) **GTAW/GMAW**

Electrical circuit

Electricity flows from the power source

Through the electrode and across the arc

Through the base material and back to the power source

Electrical - Thermal energy

- ✓ Arc created by the electric current: converted into heat because of the resistance of electron flow
- ✓ The heat melts the metal to fuse it together

Enthalpy of Melting

Q = Heat required to melt a given volume of weld
= Heat required to melt the solid + Latent heat of fusion

$$Q = \rho C_p (T_m - T_o) + L$$

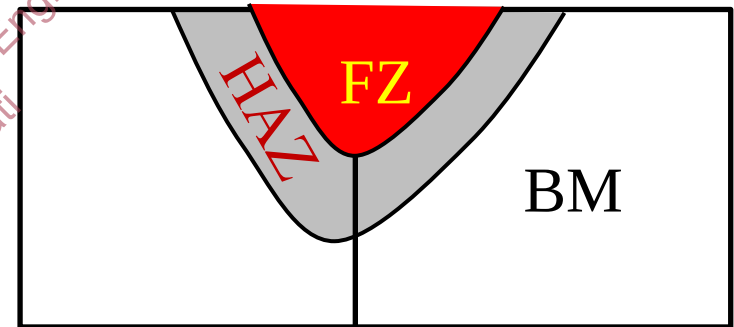
ρ = Density (mass/volume)

C_p = Heat capacity

T_m = Melting temperature

T_o = Initial temperature

L = Latent heat of fusion



Fusion zone (FZ)

Heat affected zone (HAZ)

Base material (BM)

Energy Sources for Welding

Energy to produce bonds: in form of heat to melt the metals

Categorization of energy sources

Electrical sources

Uses the electrical energy available from AC or DC source
Ex. Arc welding, Resistance welding, Electro-slag welding

Chemical sources

Chemical energy stored in a wide variety of forms can be converted to useful heat.

Ex. Oxyfuel gas welding, Thermite welding

Energy Sources for Welding

Optical Sources

Focused beams of electron or Laser is operated according to the laws of optics, achieve high power densities

Ex. Laser beam welding, Electron beam welding

Mechanical Sources

Involve some type of mechanical movement which produces the energy

Ex. Friction welding, Ultrasonic welding, Explosion welding

Solid State Sources

Characterized by a lack of motion in contrast of mechanical sources

Ex. Diffusion welding

Physical Properties of Metals

Physical properties of materials influence the applicability of the various joining processes

Electrical resistivity

it has the maximum affect in resistance welding and significant role in other processes like GMAW

Thermal conductivity

pure metals have the highest conductivity, and the addition of alloying elements tends to decrease the values of this property

Coefficient of expansion

The thermal expansion coefficient in welding of the materials is critically important in analyzing the distortion of the welded samples

Physical Properties of Metals

Specific heat

It is the measure of the ability of a body or gas to absorb or store heat

Ionization Potentials

Ease of arc initiation and its stability are related to the ionization potential – minimum possible

Metal oxides

The oxidation rate and the refractory stability of the metal oxides formed during welding affects the transfer of alloying elements across the arc

Arc Welding Power Sources

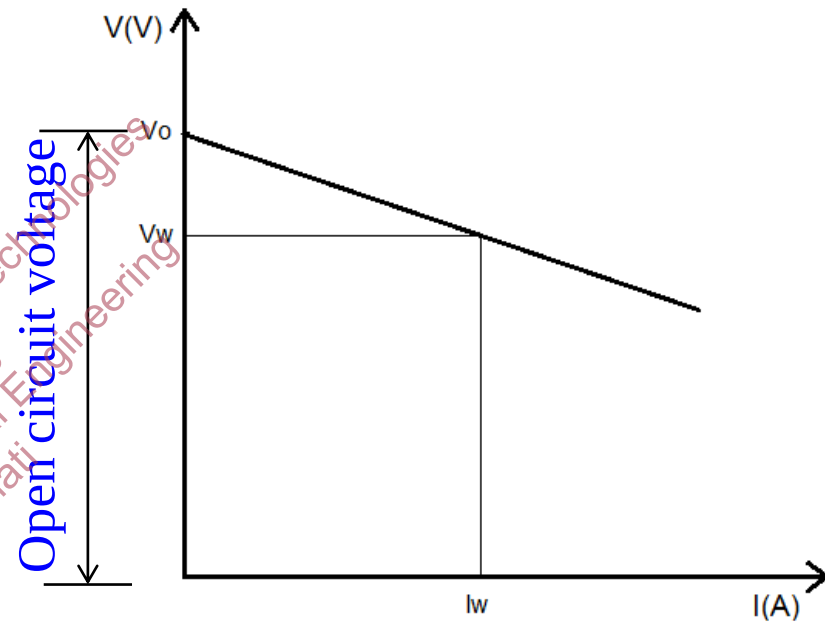
Requirement of a power source is to deliver controllable current at a voltage according to the welding process being used

Power sources can be classified in two categories

- ✓ Constant current or falling characteristic power source
- ✓ Constant voltage or flat characteristic power source

Constant voltage power source

- Downward or negative slope - sufficient internal electrical resistance and inductance in the circuit
- Change in current to melt the electrode at the required rate
- Speed of electrode control the average welding current
- Constant electrode wire feed results in a self regulating or self adjusting arc length system
- Any change in welding current occurs, it will automatically increase or decrease the electrode melting rate to regain the desired arc length



Maintain the preset voltage
or Relative arc length

Desirable for semi-
automatic arc welding

Constant current power source

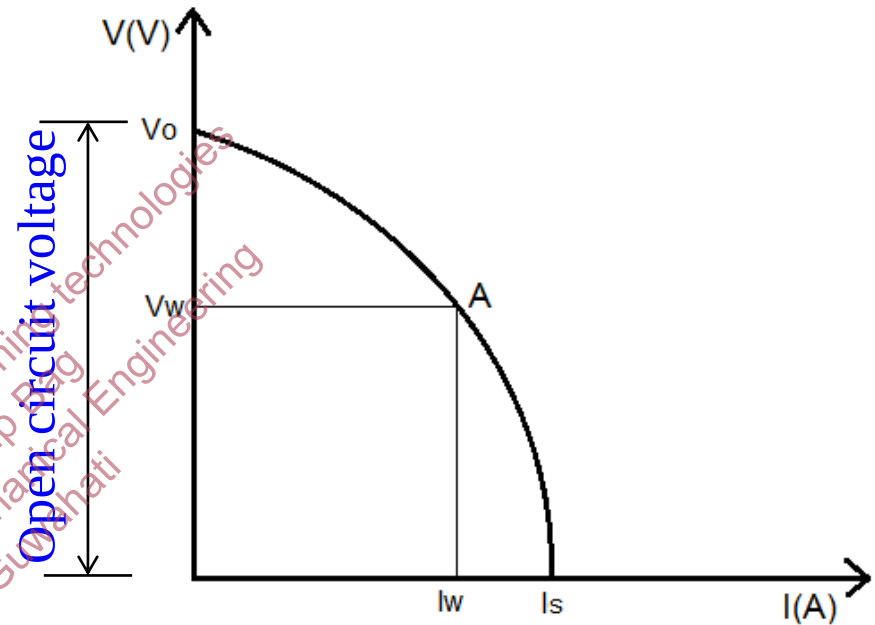
Non-linear negative slope of the curves (sharply dropping characteristics)

Desirable for manual arc welding

Efficient striking of arc - open circuit voltage should be high

High frequency unit supplies high voltage (kV) along with high frequency (kHz) with low current

Ionizes the medium between electrode and workpiece/nozzle starting pilot arc which ultimately leads to the start of main arc



A change in power source (open circuit voltage adjustment and output current control) will change the slope of the volt ampere curve

Role of shielding gas

Protecting the arc and molten weld pool from contamination by the atmosphere

- ✓ Directly use shielding gas
- ✓ Slag coverage by chemical reactions in the arc

Common shielding gases:

Argon, helium, carbon dioxide and oxygen

- 100 % for certain applications
- Mixed together in different combinations

Properties:

Reactivity, ionization potential and thermal conductivity

Fusion welding

Fusion (Non-Pressure) Pressure (Non-Fusion)

✓ Gas Welding

- Oxy-Acetylene
- Air-Acetylene
- Oxy-Hydrogen

✓ High Energy Beam

- Electron Beam Welding
- Laser Beam Welding

✓ Chemical Based

- Thermit Welding

✓ Arc Welding

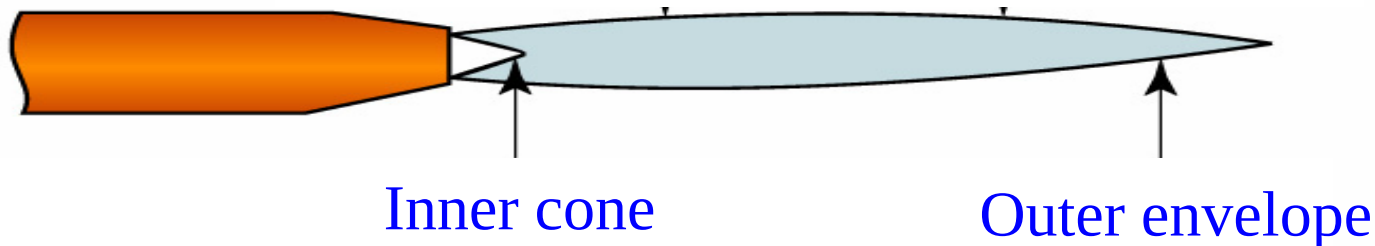
- Consumable Electrode
 - SMAW – Shielded Metal Arc Welding
 - GMAW – Gas Metal Arc Welding
 - SAW – Submerged Arc Welding
 - ESW – Electroslag Welding
- Non-Consumable Electrode
 - GTAW – Gas Tungsten Arc Welding
 - PAW – Plasma Arc Welding
 - Carbon Arc Welding²¹

Oxy-Acetylene Gas Welding

- ✓ Mixing of acetylene gas and oxygen in the welding nozzle
- ✓ Proportional of gases decided the nature of flame

Neutral Flame: Ratio of oxygen to acetylene, in the mixture leaving the torch, is almost exactly one-to-one.

Ex. Welding of mild steel, stainless steel, copper, aluminum

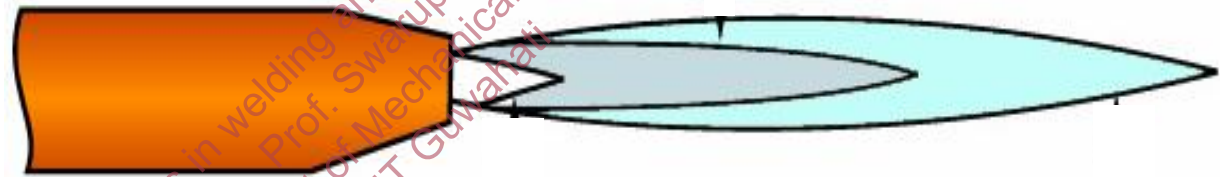


Oxy-Acetylene Gas Welding

Carburizing Flame: Proportion of acetylene in the mixture is higher than that required to produce the neutral flame.

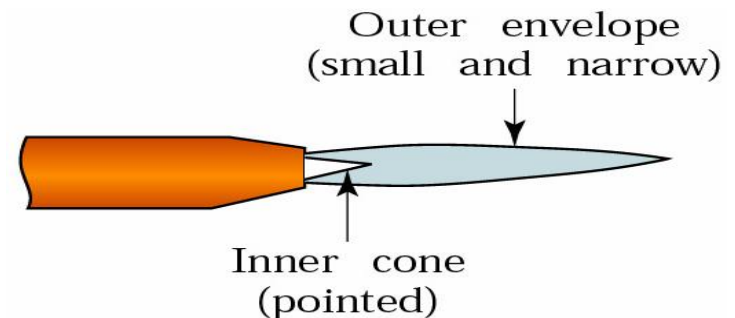
Lower temperature than neutral flame (excess carbon)

Ex. Welding of iron and steel produces very hard and brittle **iron carbide**



Oxidizing Flame: Contains more oxygen than required for a neutral flame

Used for Copper base metals and zinc base metals



Shielded Metal Arc Welding

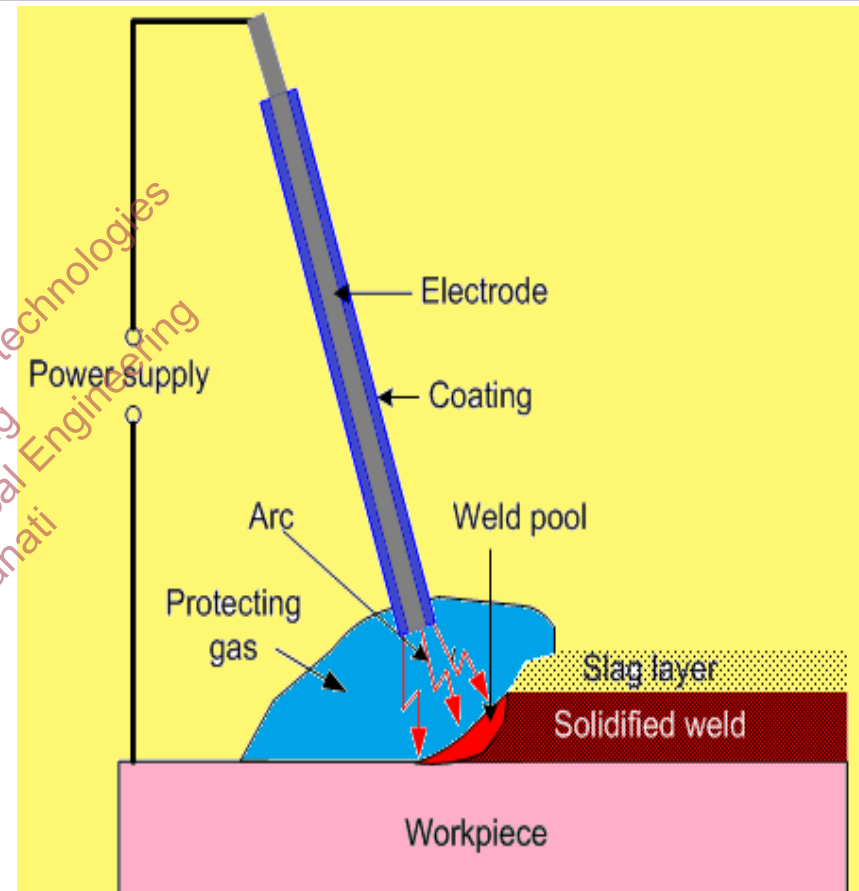
- Consumable electrode (coated with a shielding flux)
- Flux produces protective gas around weld pool
- Flux coated rod
- Slag keeps oxygen off weld bead during cooling

✓ Advantages

- Simple, portable and inexpensive equipment

✓ Disadvantages

- Process is discontinuous due to limited length of the electrodes
- Weld may contain slag inclusions
- Fumes make difficult the process control



Gas Metal Arc Welding

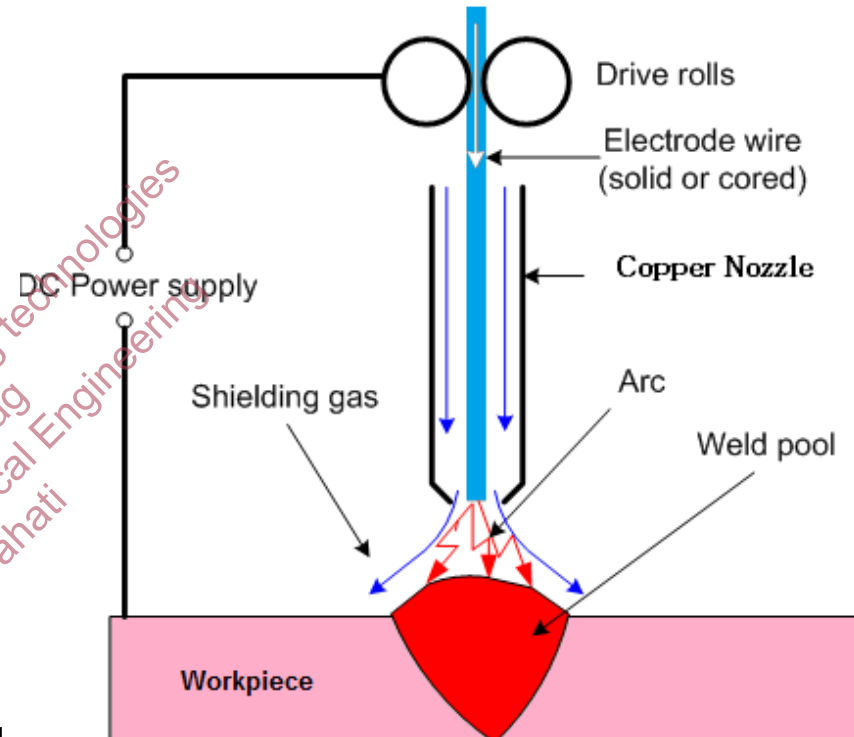
- Consumable wire electrode
- Shielding provided by gas (Ar, He, CO₂, Ar + O₂ or other gas mixtures)

✓ Advantages

- Continuous weld may be produced (no interruptions)
- Slag removal is not required (no slag)

✓ Disadvantages

- Expensive and non-portable equipment is required



Submerged Arc Welding

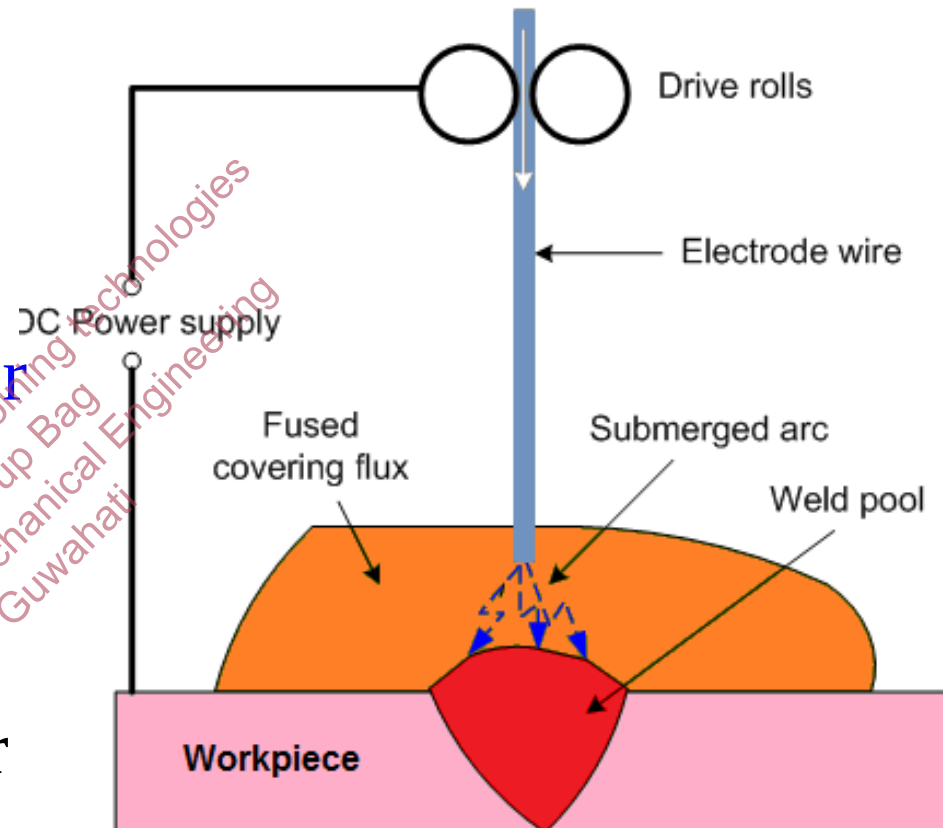
- Consumable wire electrode
- Shielding provided by flux granules
- Low UV radiation & fumes
- Flux acts as thermal insulator
- Suitable for thick plates

✓ Advantages

- Very high welding rate
- The process is suitable for automation
- High quality weld structure

✓ Disadvantages

- Weld may contain slag inclusions
- Mostly for welding horizontally located plates



Electroslag Welding

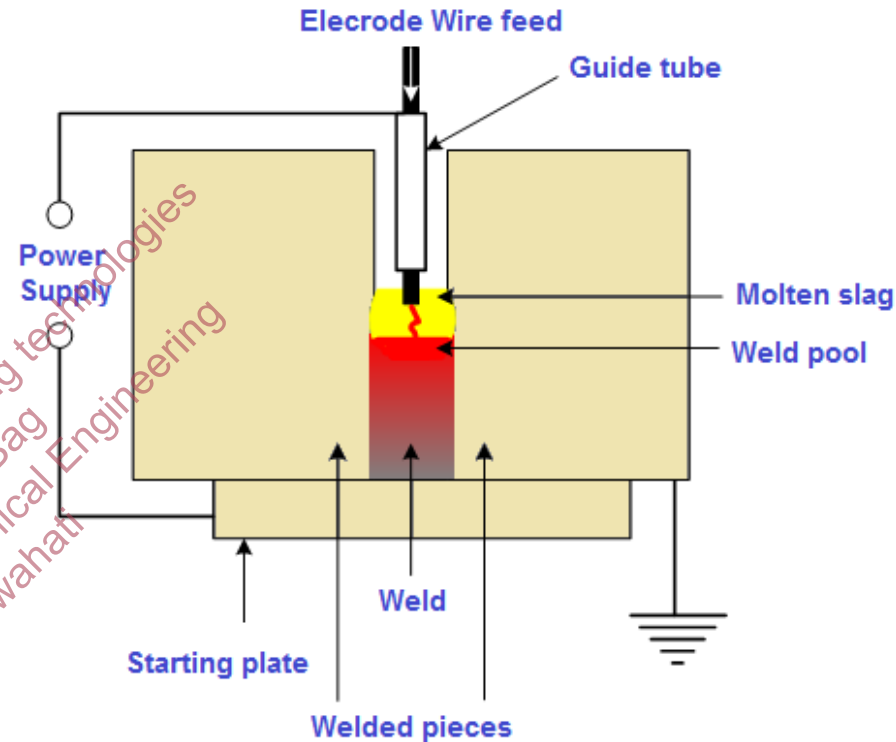
- Workpiece is filled with a welding flux
- At start, arc is created to melt the flux powder and forms molten slag
- Molten flux short circuits the arc
- Heat is generated due to ohmic heating of the slag
- Slag circulates and melt the consumable electrode and workpiece edges

✓ Advantages

- High deposition rate
- Welding of thick plates
- Low slag consumption
- Low distortion

✓ Disadvantages

- Coarse grain structure of the weld
- Low toughness of the weld
- Only vertical position is possible

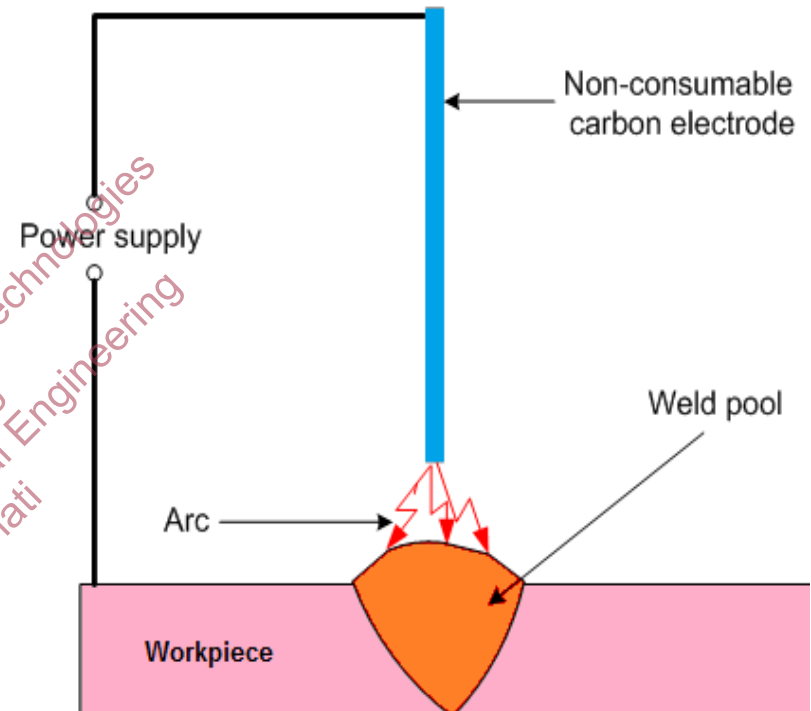


Carbon Arc Welding

- Oldest welding process
- Shields (neutral gas, flux) may be used for weld pool protection depending on type of welded metal.

✓ Advantages

- Low cost of equipment and welding operation
- High level of operator skill is not required
- The process is easily automated
- Low distortion of work piece



✓ Disadvantages

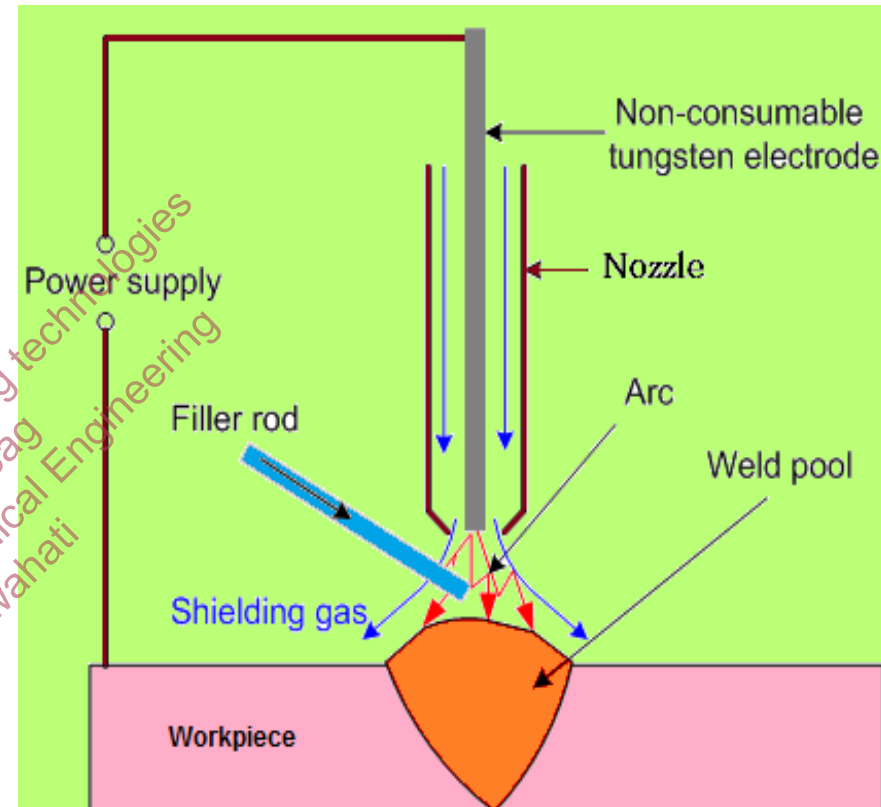
- Unstable quality of the weld (porosity)
- Carbon of electrode contaminates weld material with carbides

Gas Tungsten Arc Welding

- Non-consumable electrode
- With or without filler metal
- Shielded by inert gas (Ar, He, N₂)
- Used for thin sections of Al, Mg, Ti

✓ Advantages:

- Weld composition is close to that of the parent metal
- Relatively high quality weld structure
- No slag formation
- Thermal distortions of work pieces are minimal due to concentration of heat in small zone



✓ Disadvantages:

- Low welding rate
- Relatively expensive
- Requires high level of operators skill

Gas Tungsten Arc Welding

- ✓ Workpiece in a protective inert gas atmosphere
- ✓ Any filler material supplied externally
- ✓ To increase melting point of electrode – thorium or zirconium is added to tungsten
- ✓ DCEN is normally used
- ✓ Welding Al and Mg – AC is used
- ✓ Ar is most commonly used shielding gas
- ✓ N₂ is used for welding copper

Plasma Arc Welding

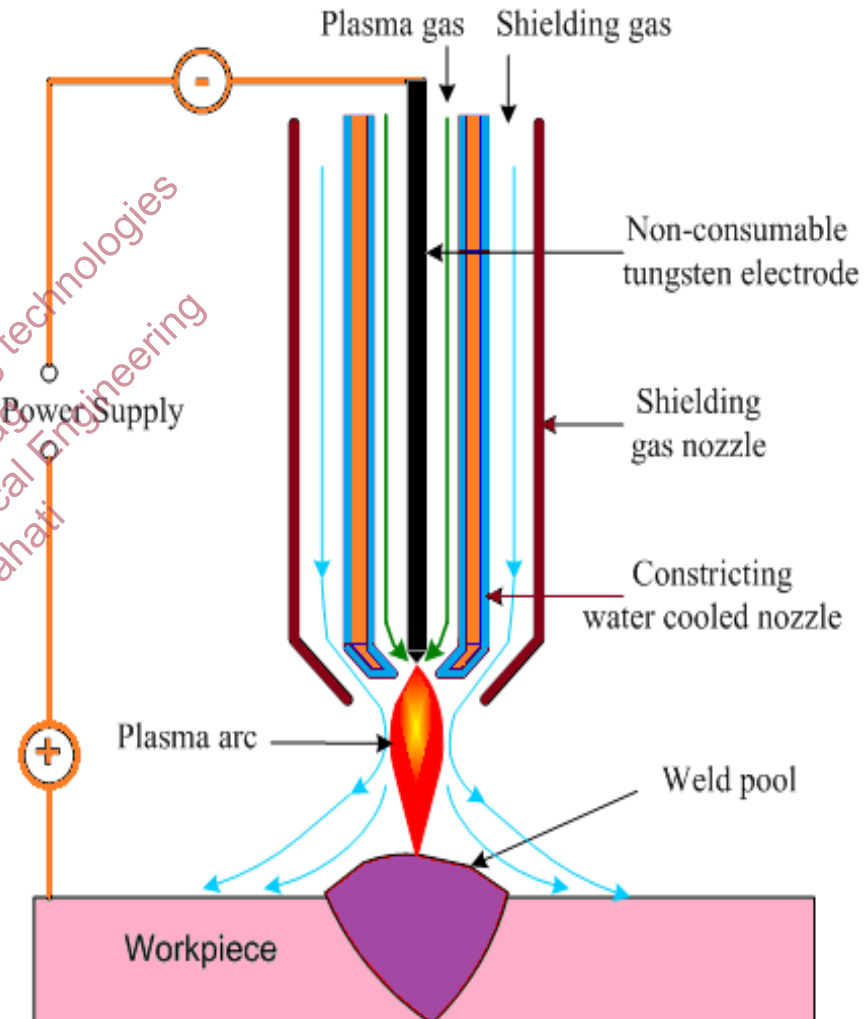
- Plasma is a gaseous mixture of positive ions, electrons and neutral gas molecules
- Non-consumable electrode

✓ Advantages

- Good tolerance of arc to misalignments
- High welding rate
- Keyhole effect produces high penetrating capability

✓ Disadvantages

- Expensive equipment
- High distortions and wide welds as a result of high heat input



Modes of Plasma Arc Welding

Transferred arc

- ✓ Workpiece being welded is part of the electrical circuit
- ✓ Plasma arc transfers from the electrode to the workpiece
- ✓ May be used for high speed welding

Non-Transferred arc

- ✓ Arc occurs between the electrode and the nozzle
- ✓ High temperature is carried to the workpiece by the plasma gas
- ✓ Thermal energy-transfer mechanism is similar to that for an oxy-fuel
- ✓ It is used for welding of various metals and for plasma spraying (coating)

LASER Beam Welding

- Heat is generated by a high energy laser beam
- Can be conduction more or keyhole mode welding
- Shielding gas is used

✓ Advantages

- Very narrow weld may be obtained
- Relatively high quality of the weld structure
- Very small heat affected zone
- Dissimilar materials may be welded
- Micro and nano-scale welding
- Vacuum is not required
- Low distortion of work piece

✓ Disadvantages

- High cost equipment
- Not completely free from contamination

Electron Beam Welding

- Beam of high energy electrons
- Carried out in a vacuum chamber
- Formation of keyhole

✓ Advantages

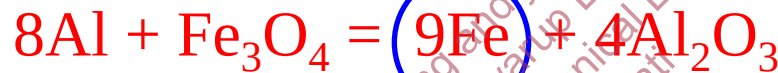
- Deep penetration weld
- Narrow weld and narrow heat affected zone
- Low distortion
- Filler metal is not required

✓ Disadvantages

- Expensive equipment
- High production expenses
- X-ray irradiation

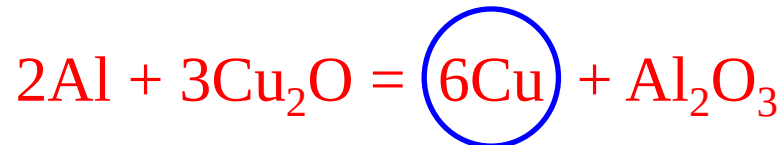
Thermit Welding

- Utilizes heat generated by exothermic chemical reaction between the components of the thermit (a mixture of a metal oxide and aluminum powder)
- The molten metal, produced by the reaction, acts as a filler material joining the work pieces after solidification



- Reaction produces Al_2O_3 , free elemental iron and large amount of heat
- The exothermic reaction occurs via reduction and oxidation
- Al_2O_3 is much less dense

Other metal oxides:



Thermit Welding

✓ Advantages

- heat of chemical reaction is utilized
- No external power source is required
- Large heavy section may be joined

✓ Disadvantages

- Only ferrous (steel, chromium, nickel) materials can be welded
- Relatively slow welding rate
- High temperature process may cause distortions and changes in Grain structure in the weld region
- Weld may contain gas (mainly H_2) and slag contaminations

Summary

- ✓ Heat generation in electrode depends on DC polarity
- ✓ Welding of aluminum AC is preferred
- ✓ Thermal conductivity of material is important parameter for FZ and HAZ dimensions
- ✓ Flat characteristic of V-I curve is suitable for semi-automatic arc welding
- ✓ Sharp dropping characteristic is suitable for manual arc welding
- ✓ Inert gas is most suitable shielding gas
- ✓ Non-transferred arc in PAW is suitable for thermal spraying or coating
- ✓ LBW or EBW is preferred for high depth of penetration is required (formation of keyhole)

**Thank you
for your kind attention**

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Welding v/s Brazing or Soldering

Difference: Brazing and Welding

Metallic components are joined through fusion or recrystallization of the base metal by **applying heat, pressure or both**

In brazing, where only the filler metal melts during processing

Difference: Soldering and Brazing

Soldering - joining process wherein metals are bonded together using a non-ferrous filler metal with a melting temperature lower than 450 °C

Brazing - the filler metal melting point is greater than 450 °C - it is considered to be a brazing process rather than a soldering process

Brazing

- ✓ Brazing is production and cost efficient
- ✓ Component distortion is minimized or eliminated
- ✓ Base metal dilution is low
- ✓ Joining of dissimilar materials can be achieved
- ✓ Different geometric sizes can be joined
- ✓ Small and wide gap sizes can be filled
- ✓ Specialized labor is not required

Principle of Brazing

- ✓ **Brazing** is when a filler metal or alloy is heated to its melting temperature above 450 °C
- ✓ It is then distributed in liquid form between two or more close-fitting parts by capillary action
- ✓ The filler metal is brought slightly above its melting temperature
- ✓ It then interacts with a thin layer of the base metal (known as wetting) and is then cooled quickly to form a sealed joint

Capillary action pull the melted brazing alloy into the space between the parts being joined

An air/acetylene torch is used

Advantages and Limitations of Brazing

- ✓ Join virtually any dissimilar metals
- ✓ The bond line can be very neat in appearance
- ✓ Brazing does not melt the base metal
- ✓ It allows much tighter control over tolerances without the need for secondary finishing
- ✓ There is almost no distortion
- ✓ Possible to join non-metals, i.e. ceramics can be easily brazed to each other or to metals
- ✓ Brazed parts may not be put in an environment which exceeds the melting point of the filler metal (typically bronze)
- ✓ Brazed joints require a high degree of base-metal cleanliness
- ✓ Creating an aesthetic disadvantage - joint color is often different from that of the base metal

Common Brazing Techniques

Heat Sources for Brazing

Torch brazing: fuel gas flame - acetylene, hydrogen or propane

Application: braze a tube into a fitting using copper or silver brazing filler metals

Induction brazing: Electric coils used to heat the part and the brazing filler metal

Application: tube to tube assembly - brazing with copper and silver alloys

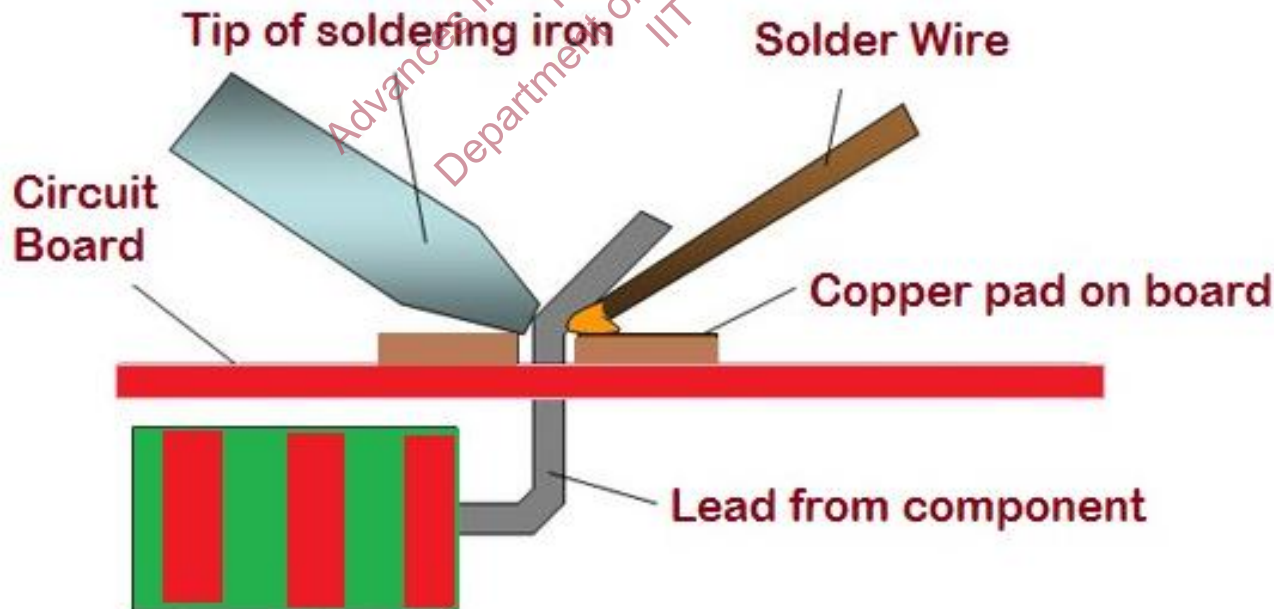
Common Brazing Techniques

Continuous furnace: Through preheating, heating and post-heating zones where the braze alloy reaches melting temperature, then resolidifies during cooling
Silver and copper based brazing filler metals are most commonly used in these processes

Vacuum furnace: A furnace with electrically heated elements heat the brazing filler metal to the melting state
Flow and capillary attraction are achieved
Brazing of alloys that are **sensitive to oxidation** at high temperatures - pumping system removes oxygen
Application: Gold, copper, nickel, cobalt, titanium and ceramic based filler metals are vacuum brazed

Principle of Soldering

- ✓ **Difference from Brazing** - filler metal used in case of soldering should have the melting temperature lower than 450°C
- ✓ Flux must be applied to the faying surfaces and then surfaces are heated
- ✓ Solder is added to the joint - distributes between the closely fitted surfaces
- ✓ Strength of soldered joint is much lesser than welded joint and less than a brazed joint



Advantages and Limitations of Soldering

- ✓ A low-temp heat source can be used – not necessary to melt base metals
- ✓ Parts can be dis-assembled at any time by simply supplying heat
- ✓ Dissimilar metals can be easily joined - aluminum to brass, and copper to steel
- ✓ Low Strength
- ✓ Damaged under high temperature conditions
- ✓ Careful removal of the flux residuals is required in order to prevent corrosion
- ✓ Large sections cannot be joined
- ✓ Fluxes may contain toxic components

Soldering Tools

Soldering iron, fluxes, solder wire or stick and spelter

Soldering Iron: Consists of a copper bit attached to iron rod at its one end, and a wooden handle at the other end

- used to melt the filler metal and paste it to make the joint

- ✓ Most of the solder metals are the alloy of **tin** and **lead**
- ✓ Percentage of **lead** is kept **least** due to its **toxic properties**
- ✓ A solder is selected on the basis of its melting point
- ✓ Solder of high melting point provides better strength of the joint
- ✓ Tin promotes the wetting action required for making the joint

Types of Solders

Soft soldering: Used for joining small intricate parts having low melting points

- ❑ tin-lead alloy as filler material
- ❑ melting point of the filler material should be below 400°C
- ❑ It uses gas torch as the heat source

Hard soldering (also called Brazing): Joins two pieces of metals by expanding into the pores of the work piece opened by high temperature

- ❑ The filler material possess high temperature above 450°C
- ❑ It comprises of two parts namely silver soldering (used for most nonferrous metals and alloys) and brazing

Soldering Techniques

Touch soldering, furnace soldering, resistance soldering, dip soldering and infrared soldering - methods are common to both soldering and brazing processes

Methods for only soldering

Hand Soldering: Small joints are made in very short time
Done **manually** using solder iron (mainly repairing)

Wave Soldering: Large-scale soldering process

Electronic components are soldered to a printed circuit board (electronic assembly)

Reflow Soldering: Also widely used in electronics to make print circuit boards

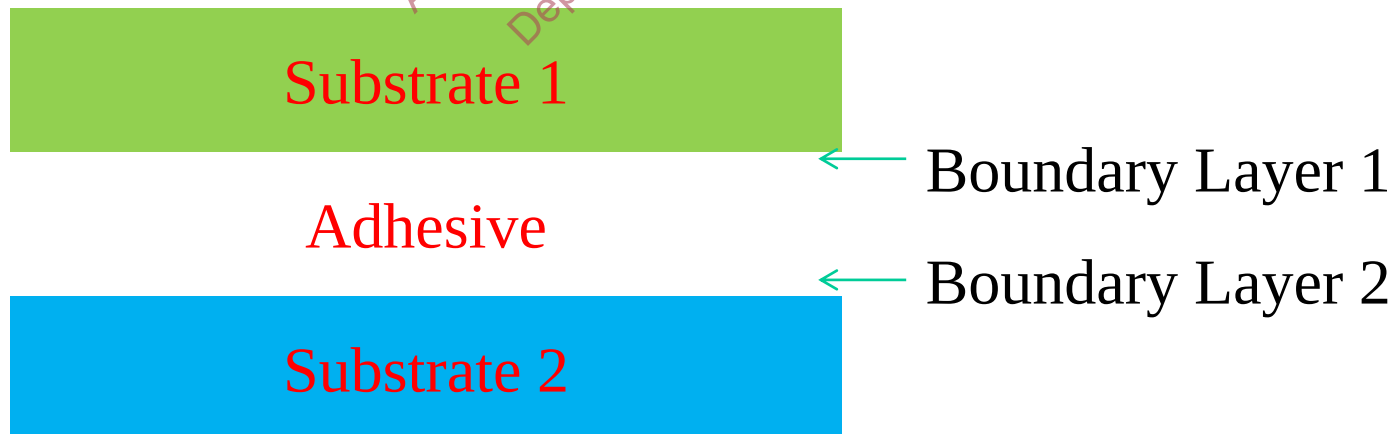
A solder paste (solder powders + flux) is applied to spots on the board the board is heated to melt the solder, forming mechanical and electrical bonds between the component

Principle of Adhesive Bonding

Joining process in which a filler material is used to hold two (or more) closely-spaced parts together by **surface attachment**

An adhesive must

- wet the surfaces
- adhere to the surfaces
- develop strength after it has been applied
- remain stable



Surface Preparation and Curing

Surface Preparation: Part surfaces must be extremely clean
Bond strength depends on degree of adhesion between adhesive and parts – links with the cleanliness of surface

For metals - solvent wiping often used for cleaning, and roughening surface by sandblasting improves adhesion

For nonmetals - surfaces are sometimes mechanically roughened or chemically etched to increase roughness

Curing: Process by which physical properties of the adhesive are changed from **liquid to solid** (usually by chemical reaction)

- Curing often aided by **heat and/or a catalyst**
- If heat used, temperatures are relatively low
- Curing takes time - **a disadvantage in production**
- Pressure sometimes applied to activate bonding process

Methods of Application of Adhesive

✓ Brushing

Performed manually; coating is often uneven

✓ Manual rollers

Similar to paint rollers

✓ Silk screening

Brushing through open areas of a screen to coat selected areas

✓ Flowing

Using manually operated flow guns; more consistent control than brushing

Failure of Adhesive Bonding

Three possible mechanisms:

- ✓ **Structural failure** - internal failure of a substrate material in a region close to the joint
- ✓ **Adhesive failure** - interfacial failure resulted in separation of one of the substrate from the adhesive layer
- ✓ **Cohesive failure** - internal failure of the adhesive layer.



Structural failure



Adhesive failure



Cohesive failure

Classification of Adhesives

Classification is based on **load carrying capability**

Structural, semi-structural, or non-structural

Glass transition temperature - an important property for polymeric materials, above which polymers are rubbery and below which they are glassy

Structural adhesives: Relatively strong adhesives that are normally used well below their glass transition temperature

Two groups - thermoplastic and thermosetting

The thermoplastic adhesives get soften at high temperatures

Common examples: epoxies and acrylic adhesives

Semi-structural - applications where failure would be less critical

Non-structural - applications for aesthetic purposes

cost-effective required for assembly of finished products

Advantages and Disadvantages

- Ability to join dissimilar materials
- Sealing properties (adhesive fills gaps and voids)
- Provides thin and invisible joint
- Joints may be electrically/thermally conductive or insulating
- Eliminates galvanic corrosion
- Requires careful substrate (adherent) surface preparation
- Service temperature (Most are unstable above 180°C) and environment limitation
- Changing properties during service
- Long mixing and curing time may be required
- Difficult to disassembly of joined parts
- Necessity to hold together the joined parts during curing

Applications of Adhesive Bonded Joints

- ✓ Automotive, aircraft, building products, ship building
- ✓ Packaging industries
- ✓ Footwear
- ✓ Furniture
- ✓ Book binding
- ✓ Electrical and electronics

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Physics of Welding Arc

- ✓ Welding arc and electron emission mechanism
- ✓ Zones in welding arc
- ✓ Electrical aspects
- ✓ Initiation of arc
- ✓ Forces acting on arc
- ✓ Effect of electrode polarity
- ✓ Efficiency of arc
- ✓ Modes of metal transfer

Basics of Welding Arc

- ✓ Arc develops due to flow of current - charged particles should have reasonably good electrical conductivity

Charged particles are generated by

Thermo-ionic emission

Increase in temperature of metal increases the kinetic energy of free electrons

When it crosses the limit, electrons are ejected from the metal surface

Tungsten and carbon - having high melting point exhibit thermo ionic electron emission tendency

Field emission

Free electrons are pulled out of the metal surface by high potential difference between the work piece and electrode

Secondary emission

High velocity electrons also collide with other gaseous molecules - results in decomposition of gaseous molecules into atoms and charged particles (electrons and ions)

Zones in Arc Gap

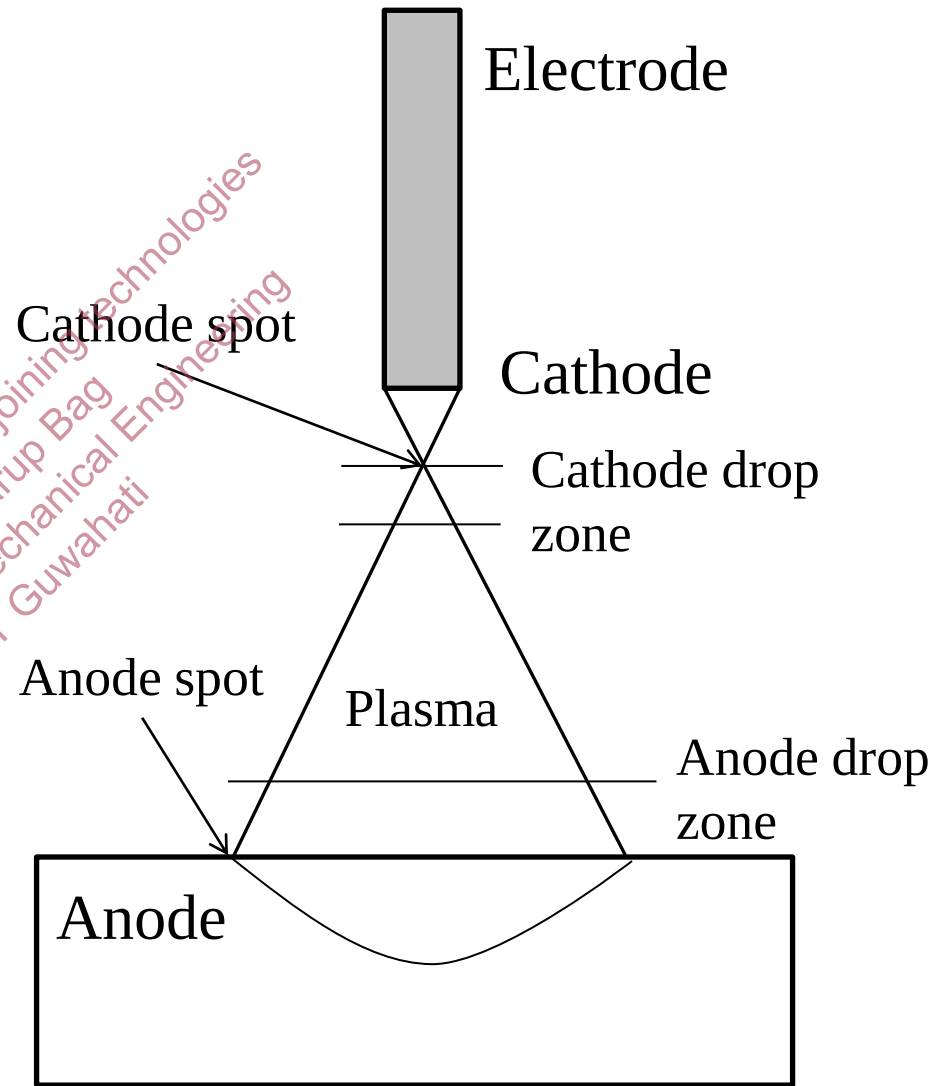
Cathode spot: Region where from electrons are emitted

Cathode drop region: Voltage drop affects the heat generation and melting rate of the electrode

Plasma: flow of charged particles i.e. free electrons and positive ions takes place

Anode drop region: Voltage drop affects the heat generation and melting of anode

Anode spot: Electrons get merged and their impact generates heat for melting



Electrical Aspects of Welding Arc

Welding arc – effective resistance for flow of current in an electric circuit

Resistance - is a function of temperature

- inversely proportional to the density of charge particles

$$V = V_c + V_p + V_a \text{ (cathode drop + plasma drop + anode drop region)}$$

Power of the arc = $V \cdot I$ where I = current

- ✓ Variation of arc length mainly affects plasma heat
- ✓ Shielding gas influences the heat generation in the cathode and anode drop zones

Initiation of Arc

Touch start: in case of all common welding processes

Field start: automatic welding operations (TIG, PAW)

Touch start

- ✓ Electrode - contact with the work piece and then pulled apart to create a very small gap
- ✓ Causes short-circuiting resulting in flow of heavy current - leads to heating, partial melting and slight evaporation of the metal at the electrode tip
- ✓ Pulling up of the electrode - maintain the arc

Field start

- ✓ High strength electric field is applied - leads to ejection of electron from cathode spots
- ✓ Once the free electrons are available in arc gap - normal potential difference maintain a welding arc
- ✓ Commonly used where direct contact between electrode and work piece is not preferred

Effect of Electrode Polarity

Generation of Heat

$\frac{2}{3}$ rd of heat is generated at the anode and $\frac{1}{3}$ rd at the cathode

Mass of electron is less than mass of ions - it gets accelerated at high velocity and more heat is generated at anode

DC Welding - DCSP/DCEN

- used for non-consumable electrode and for deep penetration
- DCRP/DCEP
- used for consumable electrode welding process and thin sheets

AC Welding

- Polarity changes in every half cycle of current

Arc Stability

- SMAW provide better arc stability with DCEN than DCEP.
- GTAW commonly uses DCEN
- When cleaning action is required, AC is more preferable

Arc Efficiency

Heat loss due to

conduction to base metal

by convection and radiation to surrounding

Only a part of heat generated by the arc to be used for melting purpose

- ✓ Arc efficiency - ratio of the heat generated at anode and total heat generated in the arc (using non-consumable materials)
- ✓ In consumable arc welding process - heat generated both at cathode and anode for melting of filler and base metal
- ✓ In general, consumable arc welding processes offer higher arc efficiency than non-consumable arc welding process

Forces Acting on Arc Zone

Influence the mode of metal transfer

Gravity force - acts on molten metal drop $F_g = \rho Vg$

Surface tension force - tends to resist the detachment of molten metal drop from electrode tip and usually acts against gravitational force

Force due to impact of charge carriers – acts by charged particles on to the molten metal drop at the tip of electrode tends to delay the detachment

Force due to metal vapours - due to upward movement of metal vapours from the weld pool act against the molten metal drop at the tip of the electrode

Force due to electro magnetic field - Interaction of electromagnetic field with that of charge carriers produces a force which tends to pinch the drop at the tip of the electrode also called pinch force

Modes of metal transfer

Transfer of molten metal from the tip of a electrode to the weld pool

Factors

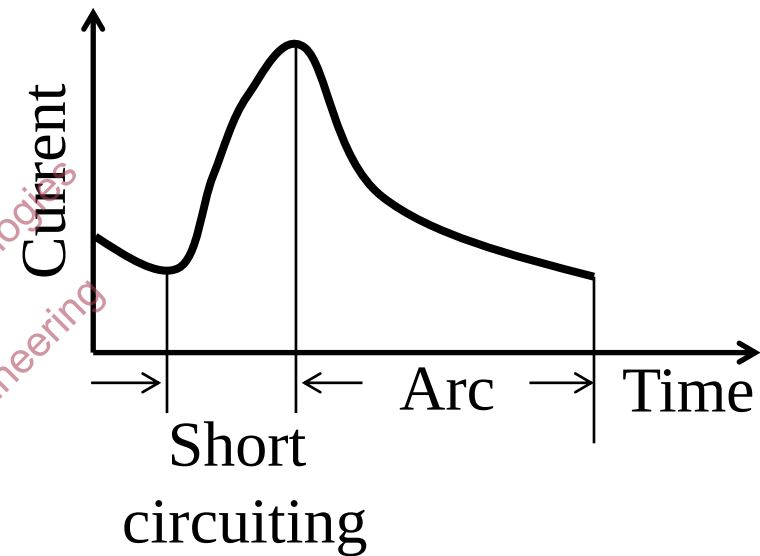
Shielding gas, composition of the electrode, diameter of the electrode

Types of metal transfer

- Short Circuit Transfer
- Globular Transfer
- Spray Transfer
- Dip Transfer

Modes of metal transfer - Short Circuit Transfer

- ✓ Low welding current - droplet grows slowly
- ✓ When drop touches weld pool, short-circuiting takes place
- ✓ Due to narrow arc gap, molten drop does not attain a size big enough to fall under gravitational force
- ✓ After short circuit - welding current flow increases abruptly and results in excessive heat generation
- ✓ The molten metal of droplet becomes thinner (low surface tension)
- ✓ Molten metal is transferred to the weld pool
- ✓ An arc gap is established that increases arc voltage abruptly



Arc
Short circuiting
Pinching

Finally, re-ignites arc and flow of current starts

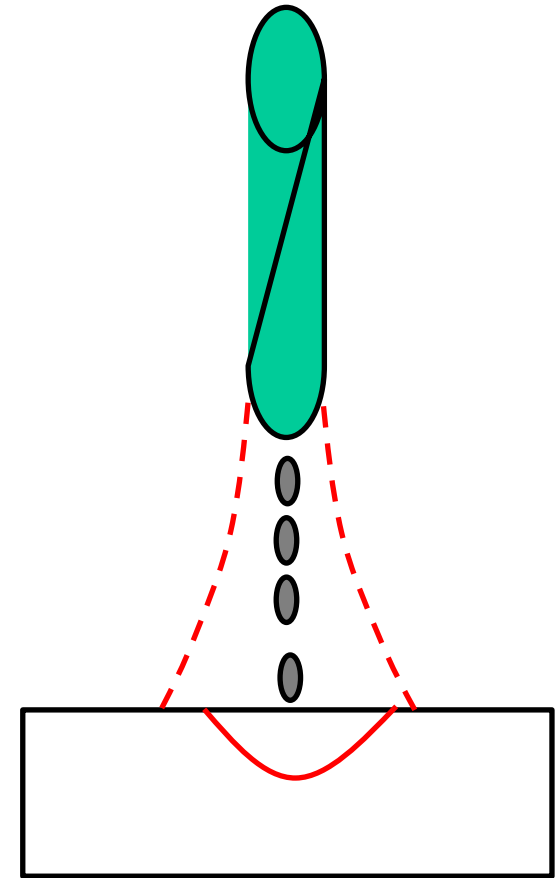
Repeated over cycle

Modes of Metal transfer – Globular transfer

- ✓ Welding current is low (more than short circuit transfer) and arc gap is large - droplet can grow slowly
- ✓ Droplets continues to grow until gravitational force exceeds the surface tension force
- ✓ As soon as drop attains large size enough and so gravitational force becomes more than other drop-holding-forces
- ✓ Drop separates from the electrode tip and is transferred to the weld pool
- ✓ The droplet transfer occurs when it attains size larger than the electrode diameter
- ✓ No short-circuit takes place

Modes of Metal transfer – Spray transfer

- ✓ Welding current density is higher than globular transfer
- ✓ High welding current density results in high melting rate and greater pinch force
- ✓ Droplets are formed rapidly and pinched off quickly by high pinch force
- ✓ Droplets are of very small in size
- ✓ High welding current increases temperature that lowers the surface tension force
- ✓ Decreases the resistance to detachment of drops



Required especially in difficult to access areas

Modes of metal transfer – Dip transfer

Dip Transfer: Welding current is very low and feed rate is high

- ✓ Electrode is short-circuited with weld pool that leads to the melting of electrode and transfer of molten drop
- ✓ Dip transfer differs from short-circuiting – in terms of arc gap
- ✓ Low welding current and narrow arc gap (at normal feed rate) results in short circuit mode of metal transfer
- ✓ Dip transfer is primarily caused by abnormally high feed rate

Summary

- ✓ Brazing and soldering can be used for joining dissimilar materials, however, joint strength may not be high like fusion welding
- ✓ Curing in adhesive bonding takes considerable time - hence the process is slow
- ✓ In automatic welding process field start is used for initiation of arc
- ✓ DCEN polarity creates maximum heat at the workpiece
- ✓ Consumable arc welding processes offer higher arc efficiency than non-consumable arc welding process
- ✓ When welding current density is high, the metal transfer mode is spray transfer

Thank you for your kind attention

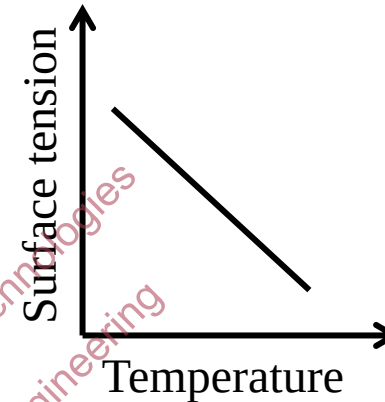
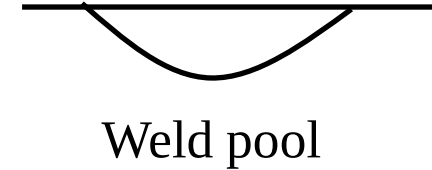
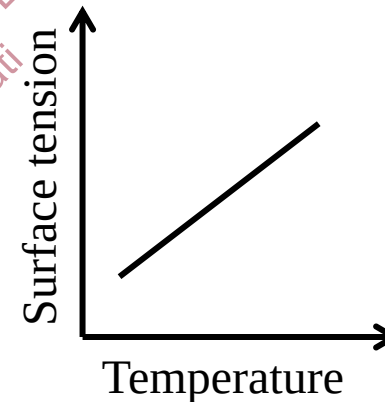
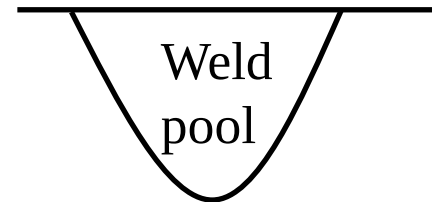
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Surface Active Elements

- ✓ Fluid flow - major factor determining fusion zone shape
- ✓ The dominant driving force for fluid flow - surface tension gradient
- ✓ Small concentrations of surface active elements affect weld pool shape
 - by altering surface tension gradients
 - Changes the direction of fluid flow in the weld pool
- ✓ Impurities (not surface active elements) may affect weld pool shape
 - By reacting with surface active impurities
 - Prevent the action of surface active impurities
- ✓ Surface tension is temperature dependent

Marangoni Convection Mode

- ✓ Magnitude and direction of surface tension gradients - Marangoni convection
- ✓ Surface tension decreases with increase in temperature – negative slope
- ✓ Small addition of surface active element - change the surface tension temperature coefficient to a positive value
- ✓ Overall, affect the direction of the liquid material flow
- ✓ Surface tension of most liquid metals is substantially altered by the presence of small amounts oxygen and Sulphur

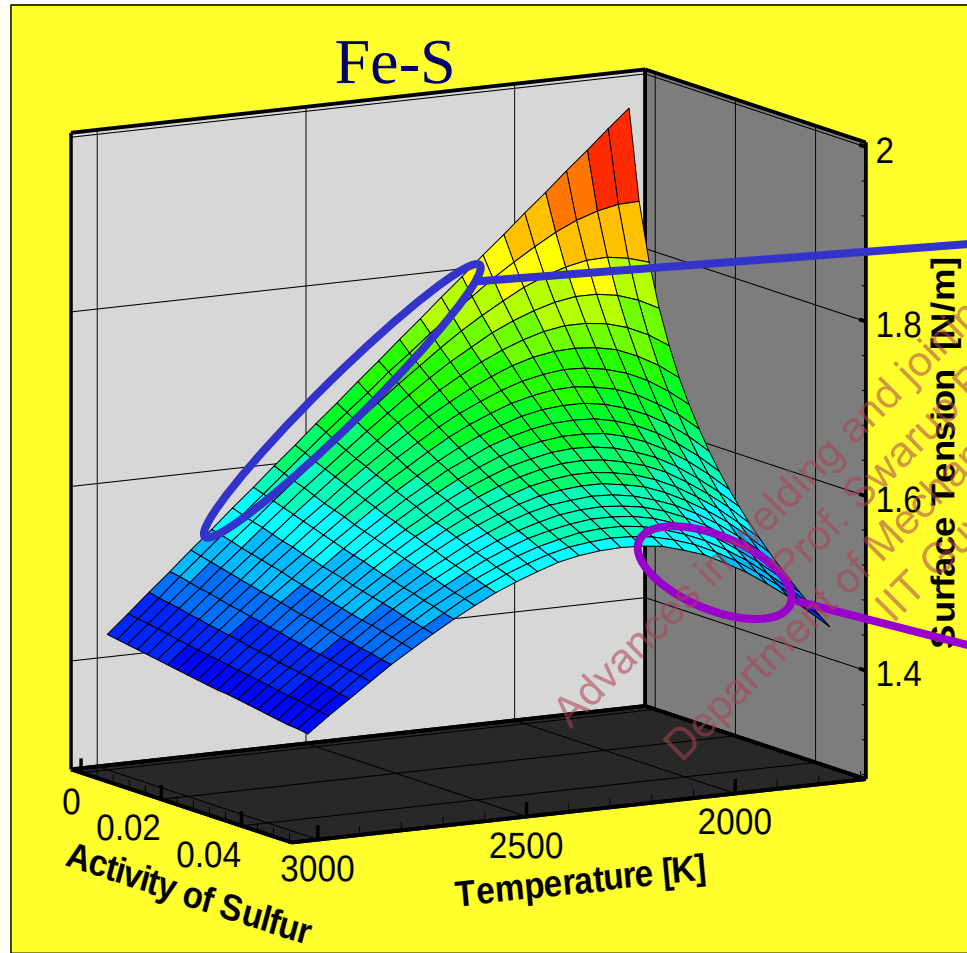
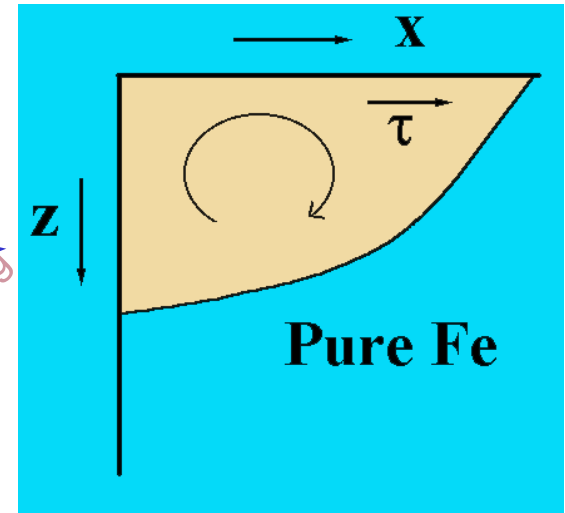
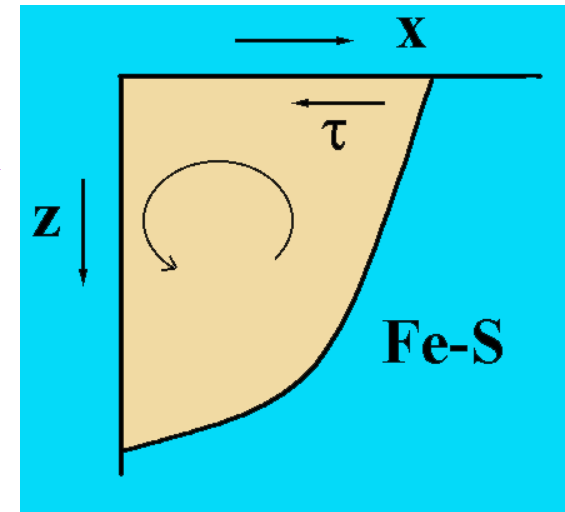


Marangoni convection mode
in weld pool

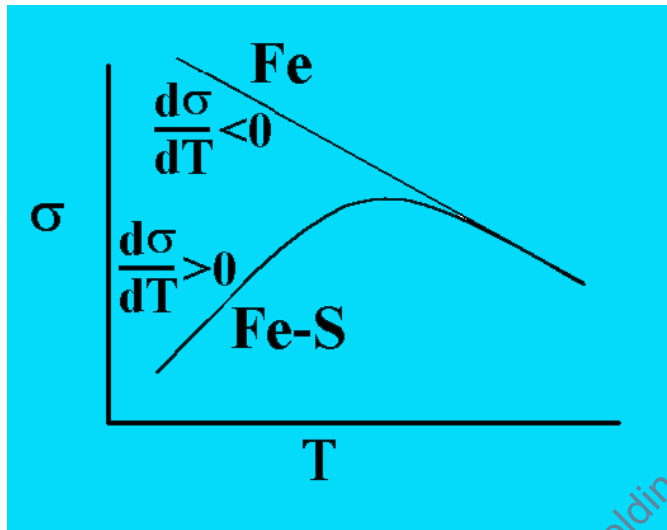
Surface active elements in welding

- Presence of surface-active agent in the liquid metal in significant amount, $\partial\sigma / \partial T$ can be changed from negative to positive
- Marangoni convection influence the weld pool
- Presence of Sulphur and oxygen in Stainless Steel acts as surface active elements
- **Example:** 180 – 600 ppm oxygen in SS304 produce maximum weld penetration

Surface tension force in weld pool model



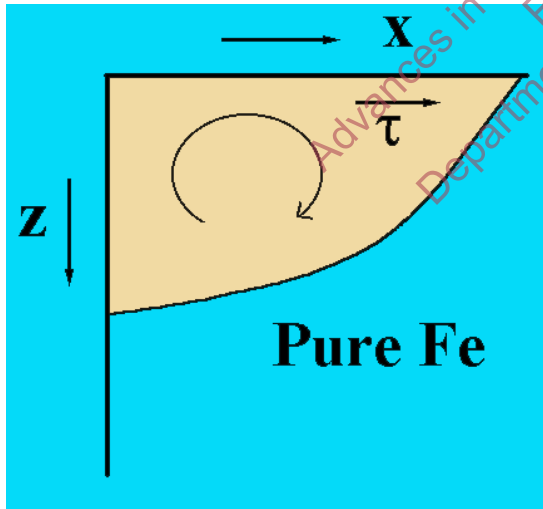
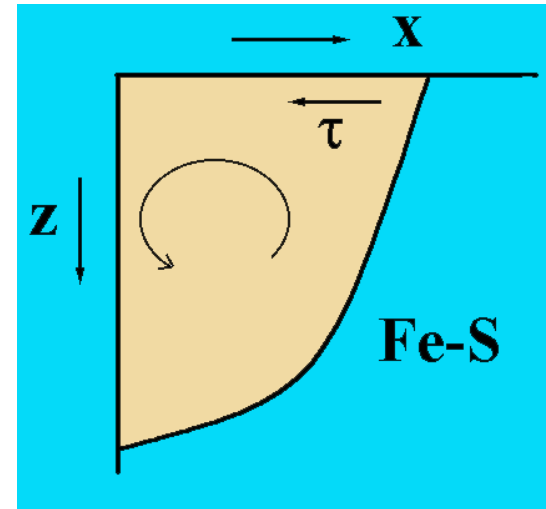
Surface tension force in weld pool model



$$\tau = \frac{d\sigma}{dx} = \frac{d\sigma}{dT} \cdot \frac{dT}{dx}$$

Negative or positive

Negative



Allied welding process using surface active elements

Minor elements can be added to the weld pool by adjusting

- ✓ Chemical composition of the base material
- ✓ Spreading fluxes (halides or oxides) on the substrate material
- ✓ Using active gaseous addition (CO_2) to the argon shielding gas

Overall, addition of a small amount of minor elements to the base material significantly changes the weld penetration

Industrially A-TIG process has been developed

Activated TIG Welding Process

- ✓ A-TIG is a variant of TIG Welding which involves application of thin coating (10-15 μm thick) of activated flux on the joint area prior to welding
- ✓ Results in increase in penetration in single pass welding
- ✓ Overcomes the limitations of the conventional TIG welding process

Advantages

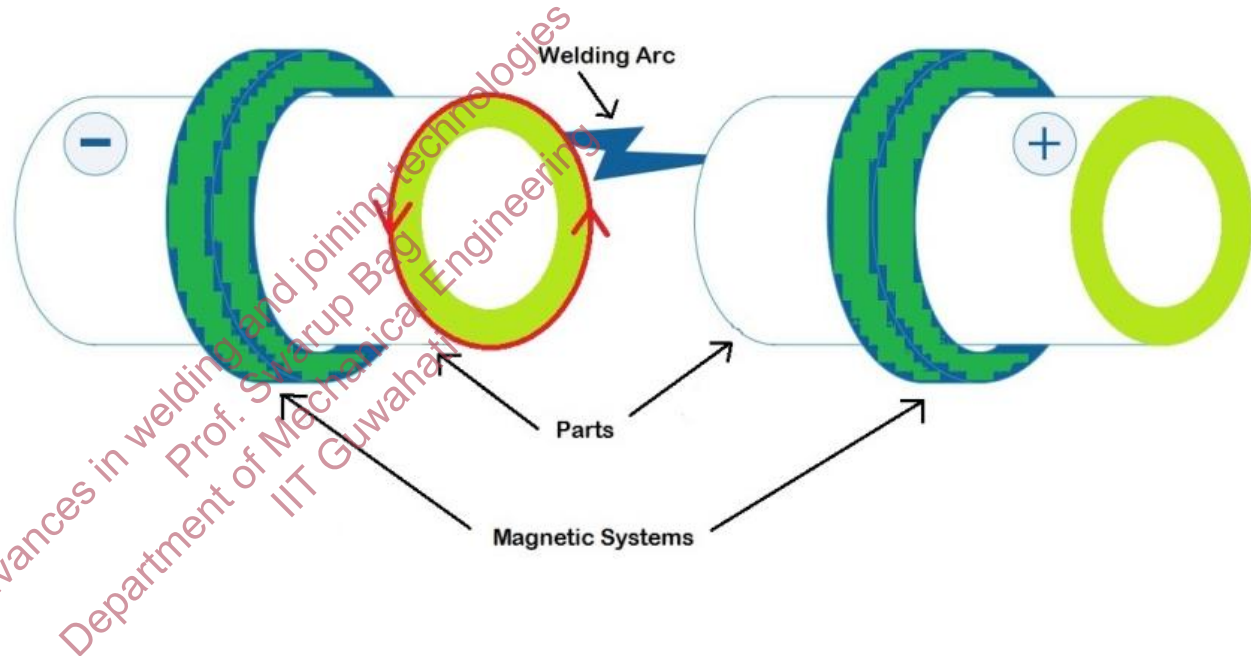
- Enables single pass welding of higher thickness plates
- Enhance productivity and reduce consumption of filler wire
- Residual stresses reduced significantly ($> 70\%$) and the weld joints are almost distortion free
- Significant reduction in the cost of fabrication ($> 50\%$)

Magnetic Impelled Arc Butt Welding

Is a forge welding process that relies on an electric arc to generate necessary heating the surfaces being welded

The arc rotate due to the presence of external magnetic field

Generated permanent electromagnets with or



Creates very uniform heating at the joint

The heated parts are rapidly brought under pressure

Forging action produces the final solid-state joint

Stages in MIAB Welding

Arc initiation - Arc stabilization - Arc rotation - Upsetting

- ✓ Arc is initiated when the closed joints are slightly spaced with the applied voltage
- ✓ The arc rotation starts due to the interaction of magnetic and electric fields
- ✓ The momentum of the arc gets established
- ✓ The arc velocity is stabilized and results in a visible arc ring around the gap between the joints
- ✓ A thin layer of molten metal appears at the tube end
- ✓ The upsetting force to be applied to fuse the metal joints

Advantages and Limitations

✓ Advantages

- Less metal loss
- Uniform welding
- Low power consumption
- No edge preparation
- No filler material
- Less internal flash
- Reduced machine maintenance

✓ Limitations

- High wall thicknesses (more than 6 mm) difficult to weld due to non-uniform heating

Applications

✓ Applications of MIAB welding

- Butt welding of thin-walled tubes
- Butt welding of thick-walled tubes
- Butt welding of solid parts
- Tube to plate welding
- Tube to flange welding

✓ Optional Features of MIAB

- Can weld tube to tube or tube to flange, and can weld irregular or non circular components as easily as circular
- One of the fastest methods of welding tube

Issues and challenges in welding processes

Different variants of electric arc welding facilitate more than 70% of the demand from the fabrication industries

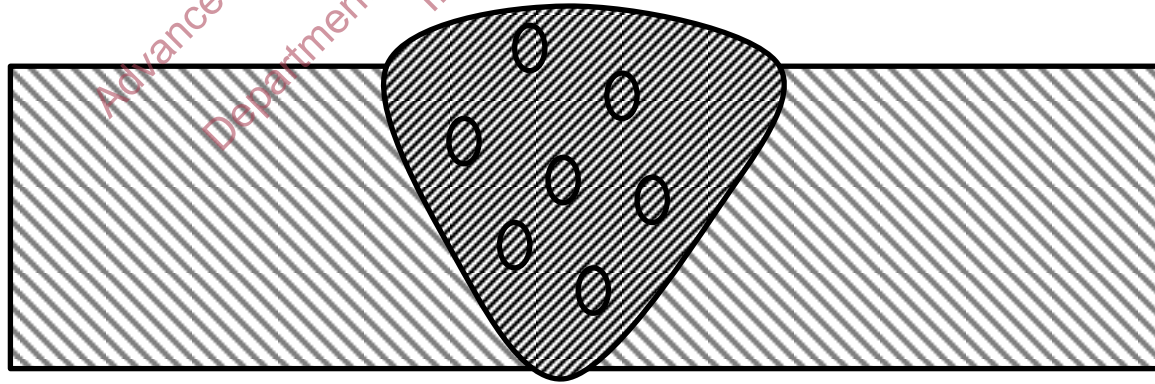
Welding with High Intensity Beam

Welds made with high intensity beams are characterized with exceptionally high rate of solidification and cooling

Issues and challenges in welding processes

Porosity in aluminium welds is the major challenge

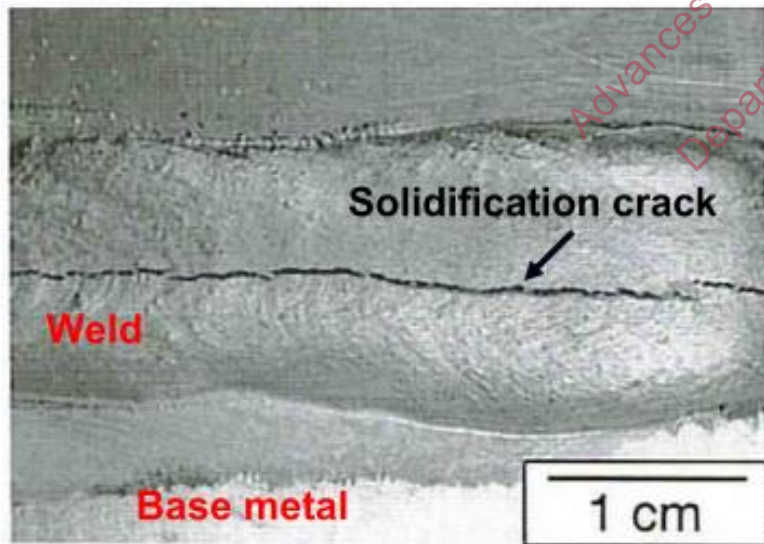
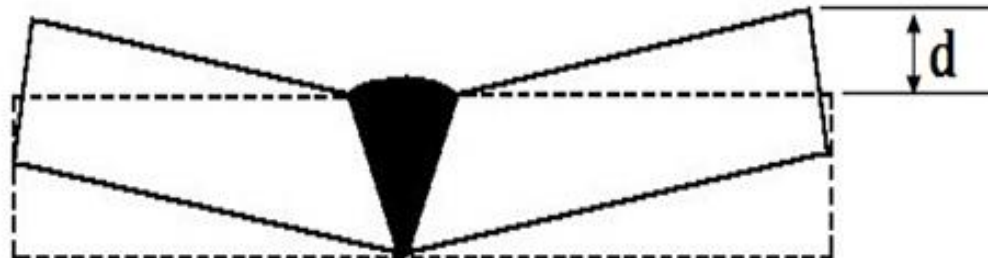
Aluminium exhibits 20% greater solubility of H_2 in liquid state leading to gas entrapment and porosity in solidified weld



Issues and challenges in welding processes

High distortion and cracks are other problems

High coefficient of thermal expansion and volume shrinkage during solidification result in severely distorted weld joints or cracks during solidification



Issues and challenges in welding processes

Welding of titanium alloys is also challenging

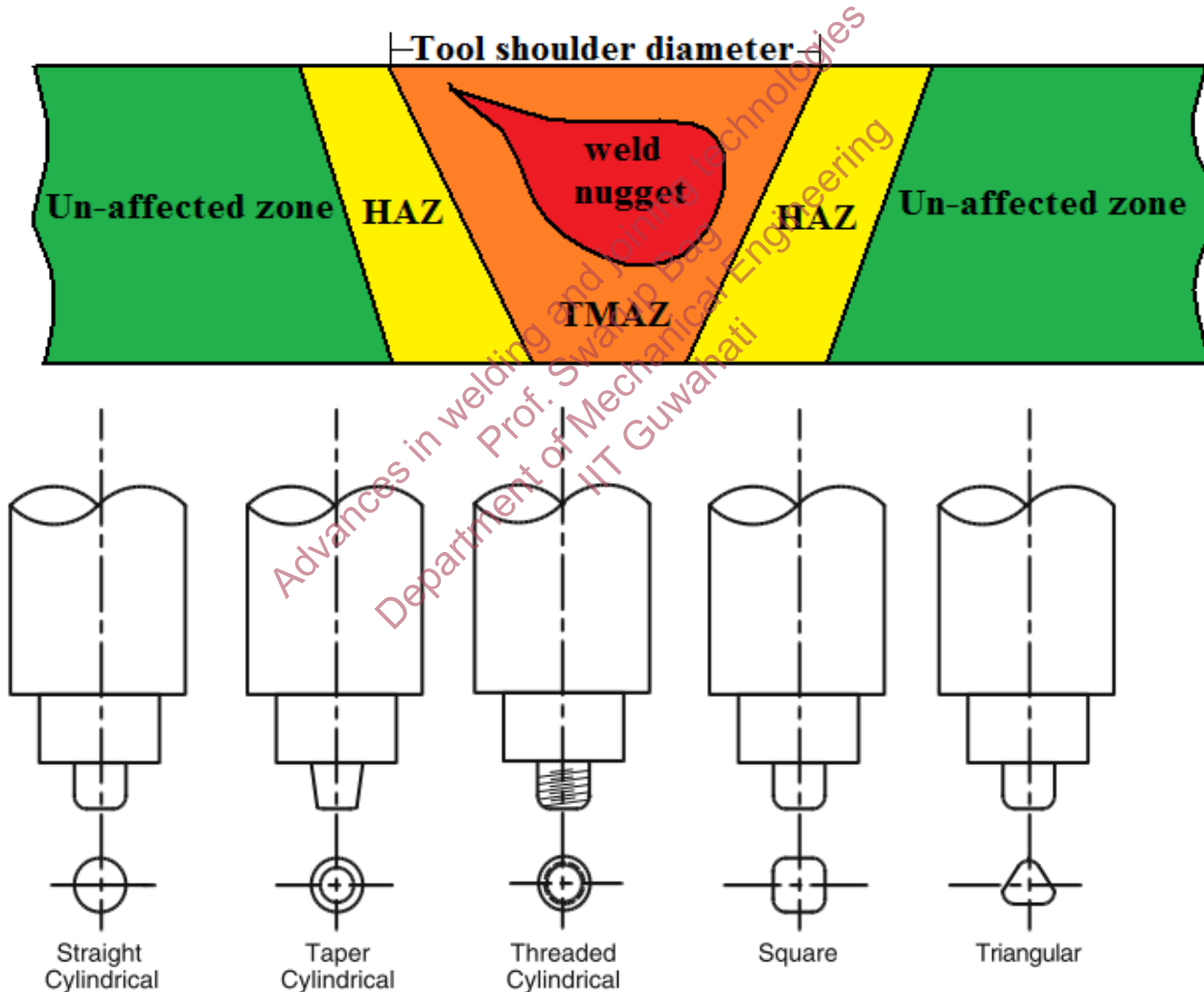
Titanium starts reacting with O_2 , N_2 and H_2 above 260°C . The molten weld pool must be protected from atmospheric contamination till it cools below 470°C .

Welds contaminated with O_2 are very brittle and hard. Usually, welding is carried out inside a chamber.



Issues and challenges in welding processes

Friction Stir Welding – A solid state joining



Issues and challenges in welding processes

Many problems of fusion welding are avoidable by friction stir welding

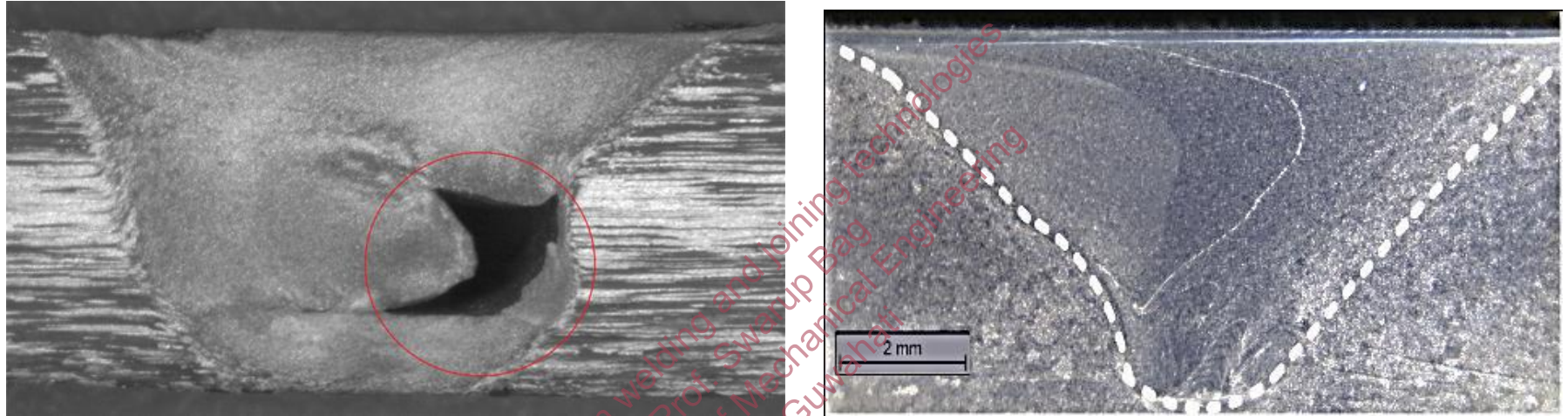
Since workpiece does not melt, problems such as porosity, solidification cracks and thermal distortion are non-existent.

The harder the workpiece material, the stronger has to be the tool material.

The weld evolves as function of tool geometry, tool rotational speed, and welding speed

Issues and challenges in welding processes

Challenges of FSW Process – Bad material flow



It is extremely important to identify appropriate combinations of tool geometry, tool rotational speed and welding speed to ensure proper material flow.

Because the tool experiences severe atmosphere of stress and temperature, commercial use of FSW for hard alloys still remains elusive.

Issues and challenges in welding processes

Friction welding of nickel based superalloys and of titanium alloys

Fusion welding of Nickel based superalloys and Titanium alloys are difficult due to their high melting temperature and high reactivity at high temperature

Friction Welding is by far the most efficient method for joining these materials in critical applications

Issues and challenges in welding processes

Laser beam welding of Al- and Ti-alloys is another attractive alternative

The Laser Beam, produced by a solid state laser (Nd:YAG) or a gas (CO_2) laser, is focussed and directed through optical lens to achieve high power density.

Laser Beam Welding can produce deep and narrow weld with minimum heat affected zone and distortion of final weld joint.

Laser Beam Welded Large Panel for Fuselage (main body of aircraft)

Simultaneous welding from both sides minimize distortion in large spherical or cylindrical panels used for fuselage structure.

Issues and challenges in welding processes

Electron beam welding in aerospace

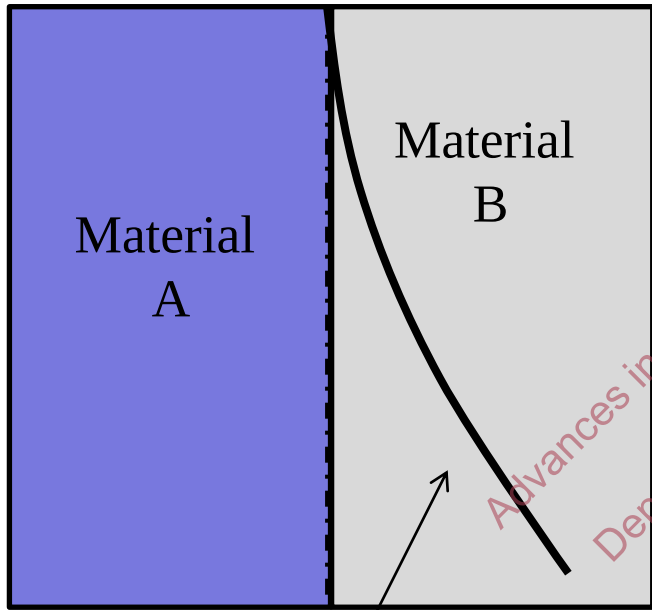
- ✓ Welding in a vacuum ensures no gas contamination.
- ✓ Provides deepest penetration irrespective of type of material or surface conditions.
- ✓ Proven track record and widely accepted for critical aerospace materials.

Critical aerospace components such as spiral bevel gear, and compressor rotors rotate at very high speeds under high loads and thus, need totally defect free welds.

Electron beam welding is the only approved joining process

Issues and challenges in welding processes

Challenges in electron beam welding



Thermoelectric magnetic field

Cu - Steel

Issues and challenges in welding processes

Micro scale welding process

Resistance

Arc (TIG, MIG and plasma)

Laser

**Electron beam welding - modification of
Scanning Electron Microscope (SEM) optics**

The geometric precision and cost of equipment is main challenge for mass production

- Fixture design and handling (robotic arm)
- Development under microscope

**Thank you
for your kind attention**

End of Module 1

Fundamentals of Welding and Joining