Casting, Forming & **Welding**
(ME31007)

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Dept. of Mechanical Engineering

CFW- Welding marks distribution

CFW Total Marks = 100
Casting =33, Forming = 33, Welding =33

End semester exam – 50 %
Mid semester exam – 30 %
Class test 1 (Before midsem) – 7 %
Class test 2 (After midsem) – 7 %
Attendance + Assignments - 6 %

Course details: Welding

	Topic	Hours	
1.	Introduction to welding science & technology	3	
2	Welding Processes	4	
3	Welding Energy sources & characteristics	2	
4	Welding fluxes and coatings	1	
5	Physics of Welding Arc	3	
6	Heat flow in welding	2	
7	Design of weld joints	1	
8	Defects, Testing and inspection of weld joints	2	
9	Metallurgical characteristics of welded joints, Weldability, Brazing, soldering, adhesive joining	2	
	Total	20	

References

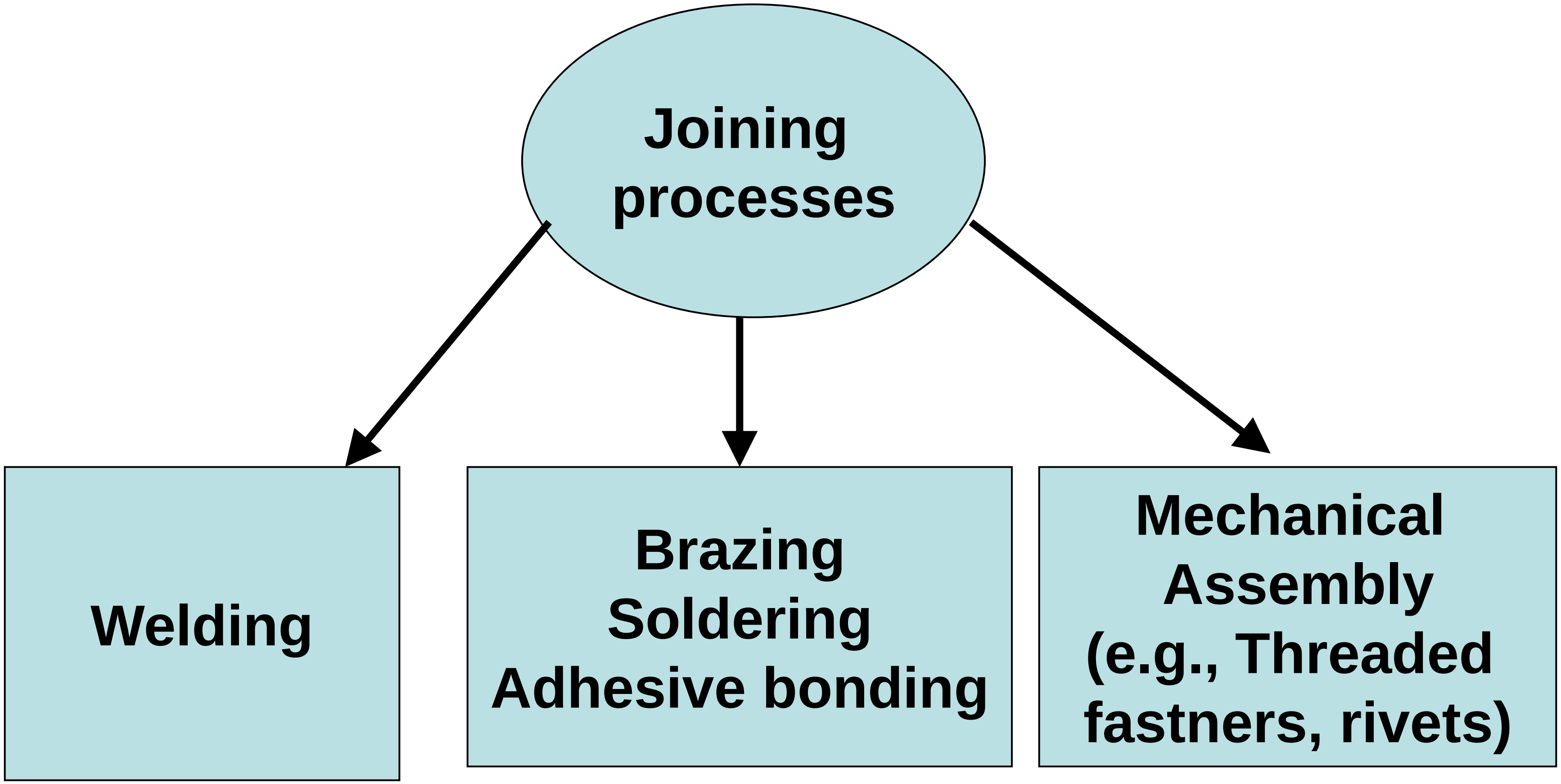
- Principles of Welding, Robert W Messler
- Metallurgy of Welding, J.F. Lancaster
- Welding Science and Technology, Md. Ibrahim Khan
- Welding Technology-O.P. Khanna
- Manufacturing Engineering and Technology, S. Kalpakjian

Lecture 1

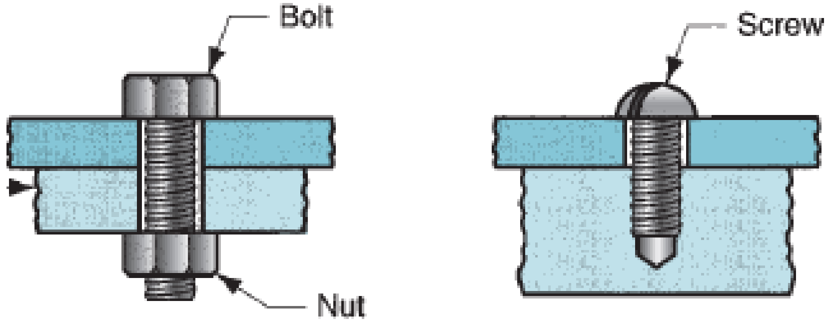
19 July 2018, Thursday, 8.00 am -9.00 am

Introduction to welding

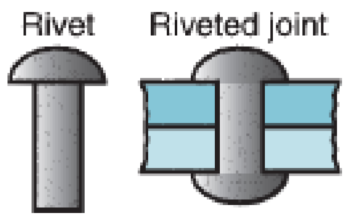
Overview of Joining processes



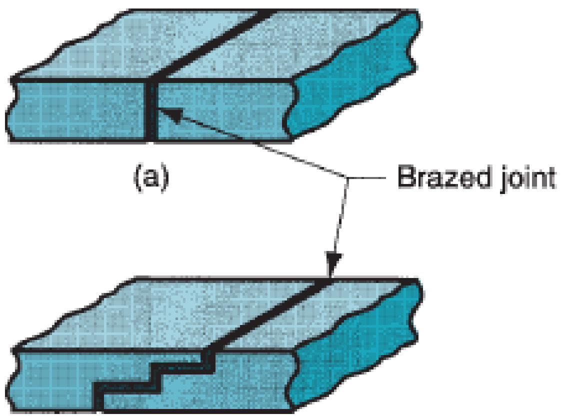
Joining processes-overview



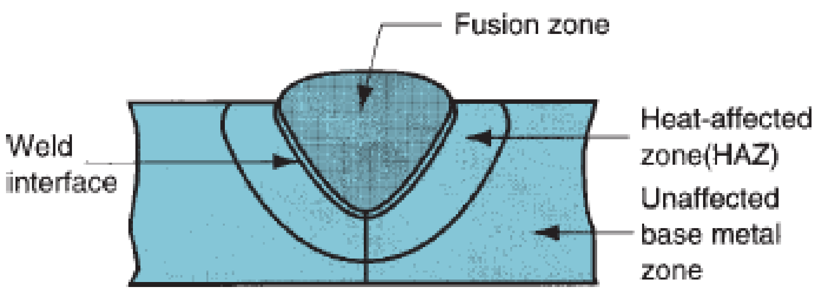
Threaded fastner



Riveted Joint



Brazed Joint



Welded Joint

What are the joints that were used in the Eiffel Tower?

Some application areas of welding

Aircraft industry

Ship building

Automotive industry

Welding: Application areas

- Applications in Air, Underwater & Space
- Automobile industry, aircraft industry, ships and submarines
- Buildings, bridges, pressure vessels, girders, pipelines, machine tools, offshore structures, nuclear power plants, etc.
- House hold products, farm, mining, oil industry, jigs & fixtures, boilers, furnaces, railways etc.

Welding process-Features

- Permanent joining of two materials through localized coalescence resulting from a suitable combination of Temperature & Pressure
- Formation of Common metallic crystals at the joints/interface
- With or Without filler material

Welding process-Features

- Continuity: absence of any physical disruption on an atomic scale
- Not necessarily homogeneous but same in atomic structure, thereby allowing the formation of chemical bonds

Material (similar/dissimilar)	Metals	Ceramic	Polymer
Type of bond	Metallic	Ionic/covalent	Hydrogen, van der Waals, or other dipolar bonds

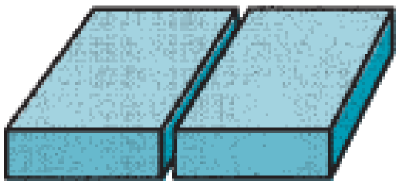
Welding Process: Advantages

- Exceptional structural integrity, continuity, fluid tightness, portable equipments
- Strength of joints can approach or exceed the strength of the base material(s)
- Wide range of processes & approaches
- Can be performed manually, semi automatically or completely automatically
- Can be performed remotely in hazardous environments (e.g., underwater, areas of radiation, outer space) using robots

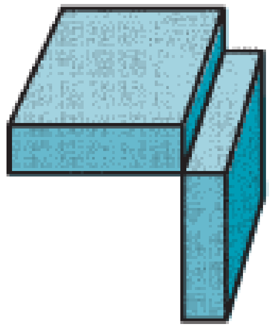
Welding Process: Disadvantages

- Precludes disassembly
- Requirement for heat in producing many welds can disrupt the base material microstructure and degrade properties; may induce residual stresses
- Requires considerable operator skill
- Capital equipment can be expensive (e.g., laser beam, vacuum chambers etc.)

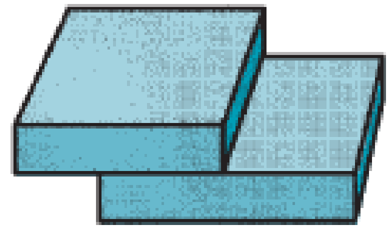
Types of joints in welding



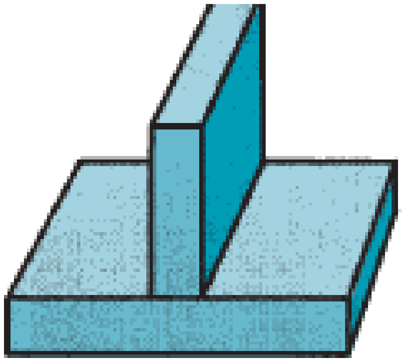
Butt joint



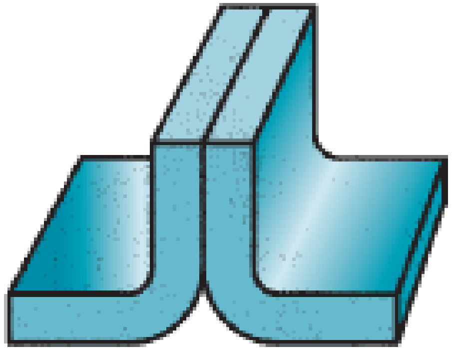
Corner joint



Lap joint



Tee joint

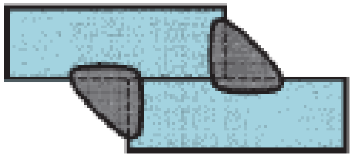


Edge joint

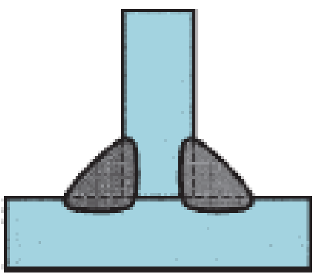
Types of welds

1) Fillet weld

Fillet weld on corner joint



Fillet weld
on lap joint



Fillet weld
on T-joint

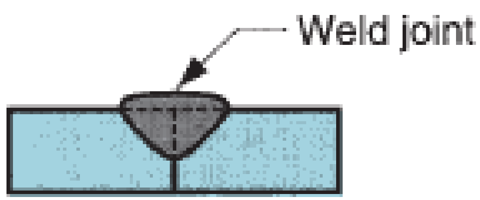
Types of welds

2) Groove weld

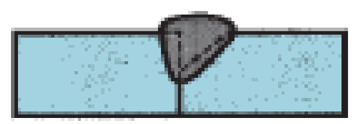
(a) square groove weld,

(b) single bevel
groove weld

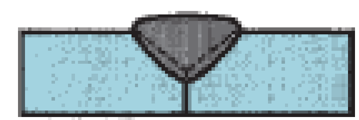
(c) single
V-groove weld



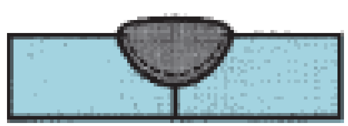
(a)



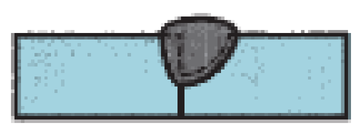
(b)



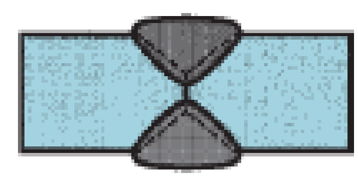
(c)



(d)



(e)



(f)

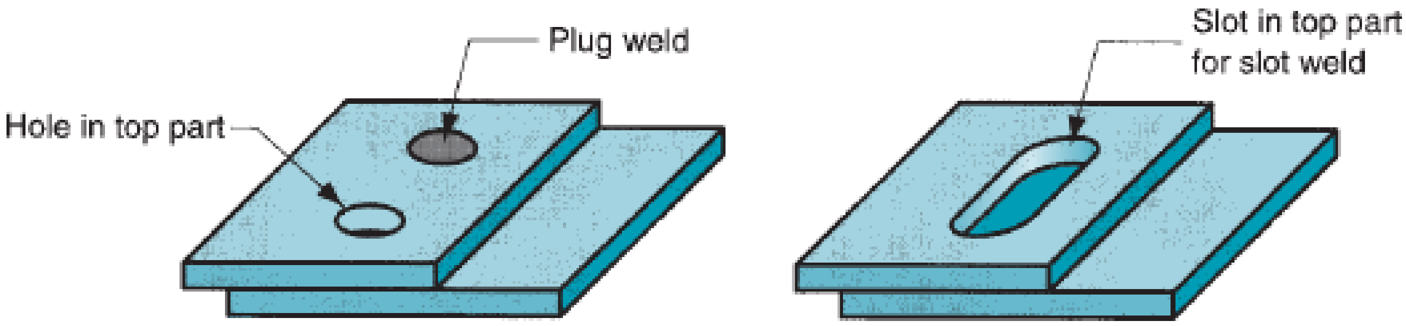
(d) single
U-groove weld

(e) single
J-groove weld

(f) Double V- groove
weld for thicker
sections

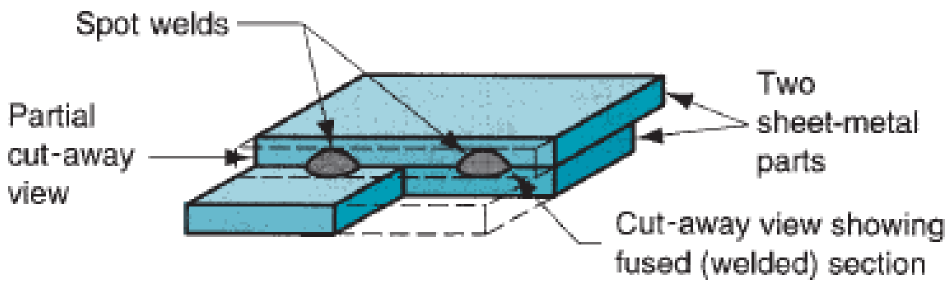
Types of welds

3) Plug & slot weld

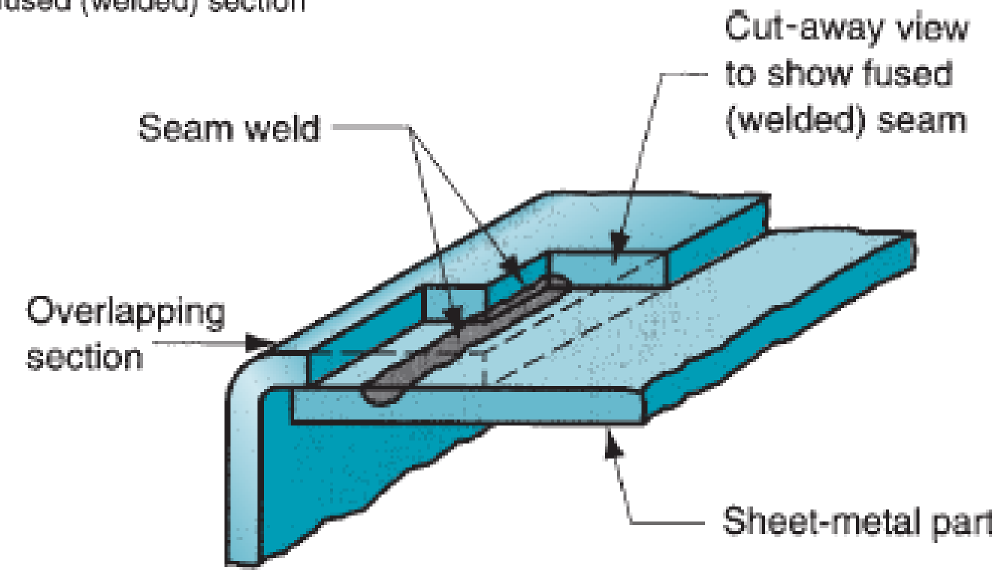


- Drill hole/slot on the top plate only
- Hole/slot is filled with filler metal

Types of welds



4) Spot weld

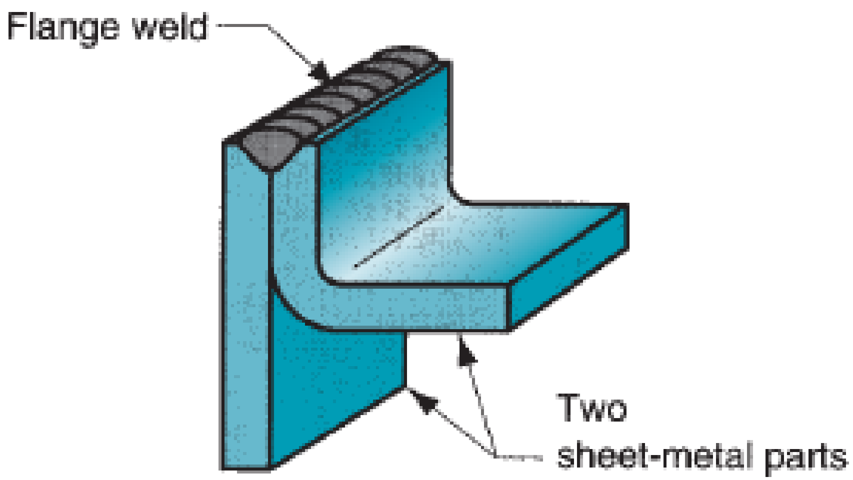


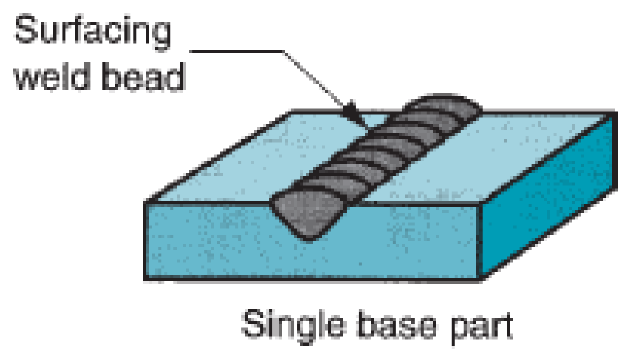
5) Seam weld

- Fused section between the surfaces of two sheets
- Mostly associated with resistance welding

Types of welds

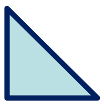
6) Flange weld & Surfacing weld





- Surfacing weld is not for joining parts
- The purpose is to increase the thickness of the plate or to provide a protective coating on the surface.

Weld symbols



Fillet weld

Square Butt

Single V Butt

Double V Butt

Single U

Single Bevel Butt

Flush/Flat contour

Convex contour

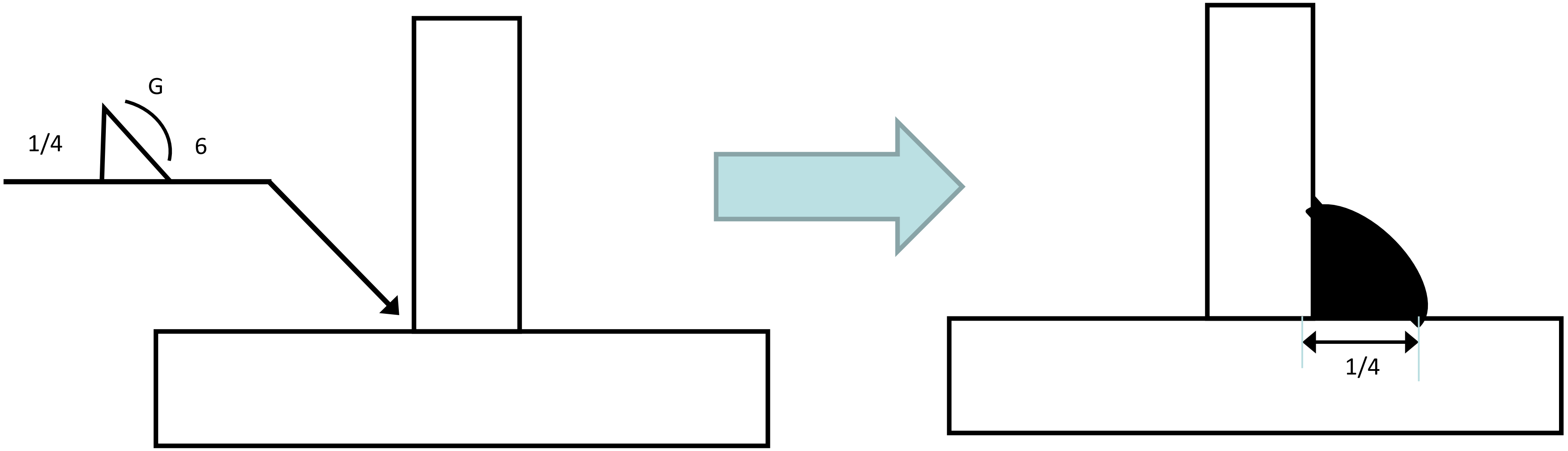
Concave contour

G Grinding Finish

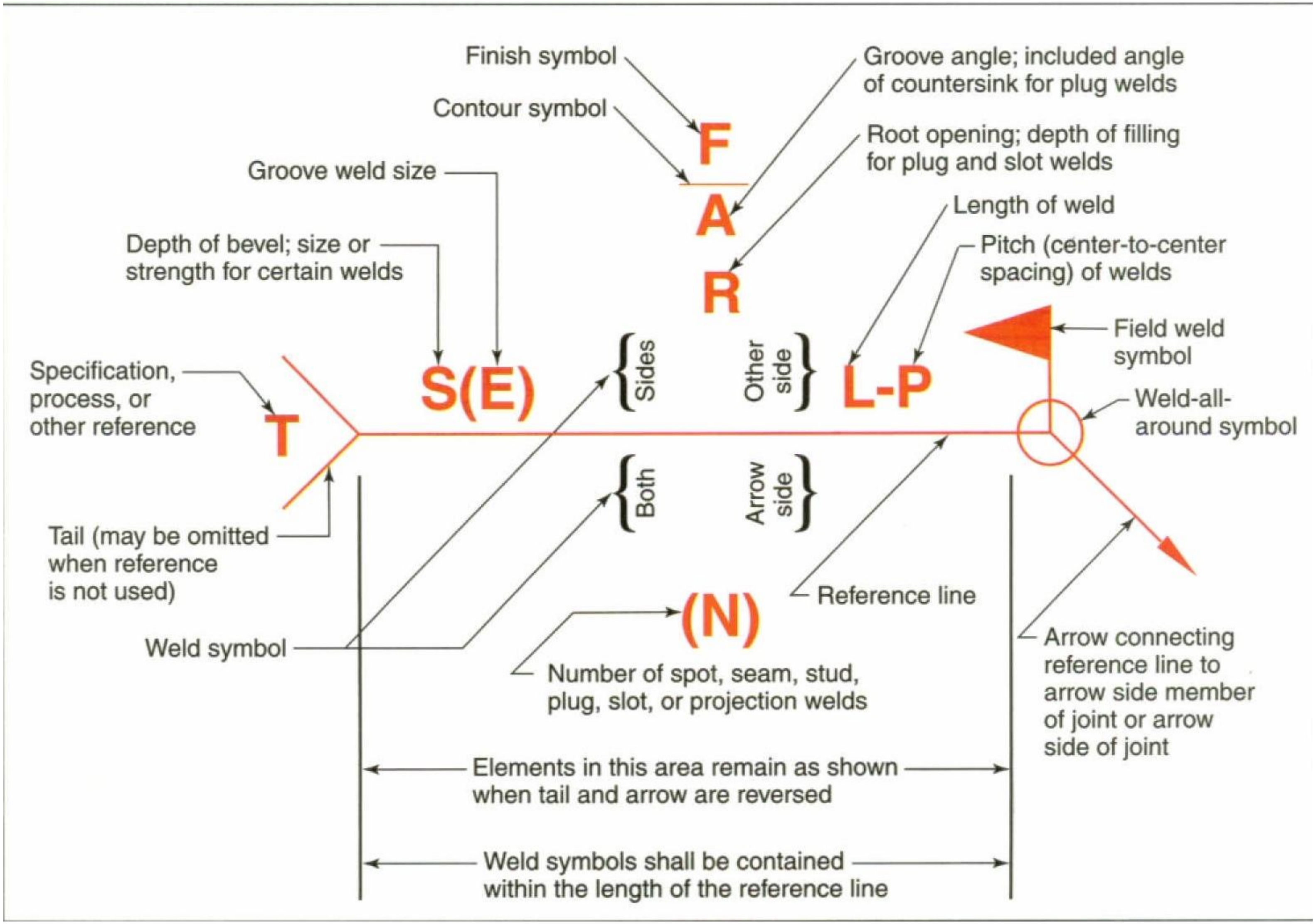
M Machining Finish

C Chipping Finish

Weld Specification-Example



Weld Specification



Lecture 2

26 July 2018, Thursday, 8.00 am -9.00 am

Introduction to welding

Basic elements of a welding setup

1. Energy source to create union by pressure/heat
2. Method to remove surface contaminants
3. Protect metal from atmospheric contamination
4. Control of weld metallurgy

1. Energy source

Classification of Fusion welding based on energy source

Energy source	Types of welding
Chemical	Oxy fuel gas welding, Exothermic welding/ Thermite welding, Reaction brazing/Liquid phase bonding
Radiant energy	Laser beam welding, Electron beam, Infrared welding/ brazing, Imaging arc welding, Microwave welding,
Electric-Perm. electrode arc	Gas tungsten arc welding, plasma arc welding, Carbon arc welding, atomic hydrogen welding, Stud arc welding
Electric-Consumable electrode	Gas metal arc welding, Shielded metal arc welding, Submerged arc welding, Electrogas welding, Electroslag welding, Flux cored arc welding
Electric-Resistance	Resistance spot, resistance seam, projection welding, flash/ upset welding, Percussion, Induction welding

1. Energy source

Classification of solid state welding based on energy source

Energy source	Types of welding
Mechanical	Cold welding, Hot pressure welding, Forge welding, Roll welding, Friction welding, Ultrasonic welding, Friction stir welding, Explosion welding, Deformation diffusion welding, Creep isostatic pressure welding, Super plastic forming
Chemical + Mechanical	Pressure gas welding, Exothermic pressure welding, Pressure thermit forge welding
Electrical + Mechanical	Stud arc welding, Magnetically impelled arc butt welding, resistance spot welding, resistance seam welding, projection welding, flash welding, upset welding, percussion welding, resistance diffusion welding

2. Removal of Surface contaminants

- Surface contaminants may be organic films, absorbed gases or chemical compounds of the base metals (usually oxides)
- Heat when used as source of energy removes organic films and absorbed gases
- Fluxes are used to clean oxide films and other contaminants to form slag
- Slag floats and solidifies above weld bead protecting the weld from further oxidation

3. Protection from atmospheric contamination

- Shielding gases are used to protect molten weld pool from atmospheric contaminants like O_2 & N_2 present in air
- Shielding gases could be Ar, He,CO_2
- Alternatively, welding could be carried out in an inert atmosphere.

4. Control of weld metallurgy

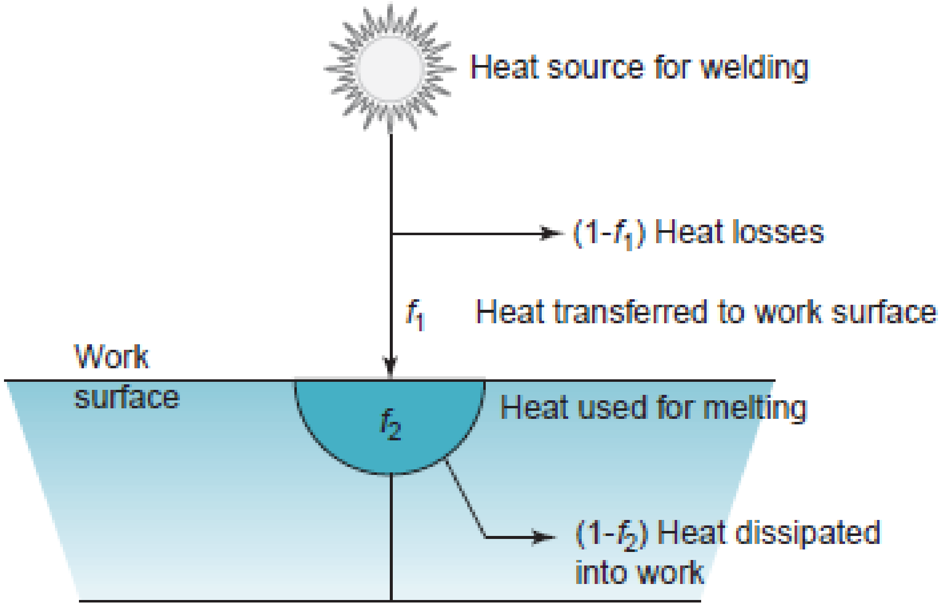
- Microstructures formed in the weld and HAZ determines the properties of the weld
- Depends on heating, cooling rates (power, weld travel speed)
- Can be controlled by preheating/ post heat treatment
- De-oxidants, alloying elements etc. added to control weld metal properties

Power density

- Defined as the power transferred to work per unit surface area (W/mm^2)
- Time to melt the metal is inversely proportional to power density

Welding Process	Approx. Power density (W/mm^2)
Oxy-fuel welding	10
Arc welding	50
Resistance welding	1000
Laser beam welding	9000
Electron beam welding	10,000

Heat transfer mechanisms in Fusion Welding



Heat transf. factor f_1= Heat transf. to work / Heat gen. by source

Melting Factor f_2 = Heat used for melting / Heat tranf. to work

Useful heat or energy = $f_1.f_2$

Example No: 1

The power source in a particular welding setup generates 3500 W that can be transferred to the work surface with a heat transfer factor $f_1 = 0.70$. The metal to be welded is low carbon steel, whose melting temperature is 1760K. The melting factor in the operation is 0.50. A continuous fillet weld is to be made with a cross-sectional area of 20 mm^2. Determine the travel speed at which the welding operation can be accomplished?

Heat capacity of low carbon steel (C_p)=480 J/Kg.K

Latent heat of melting L_m =247 kJ/Kg

Density ρ = 7860 kg/m^3

Initial sample temperature T_0 = 300 K

Example 1-Solution

Rate of heat input to the weld bead = $3500 \times f_1 \times f_2$

$= 3500 \times 0.7 \times 0.5 = 1225$ J/s

Heat input = Energy used for heating to T_m + Energy used for melting

$1225 = [C_p(T_m - T_0) + L_m]\ \rho \times A \times v$

$1225 = [480(1760-300) + 247 \times 10^3] \times 7860 \times 20 \times 10^{-6} \times v$

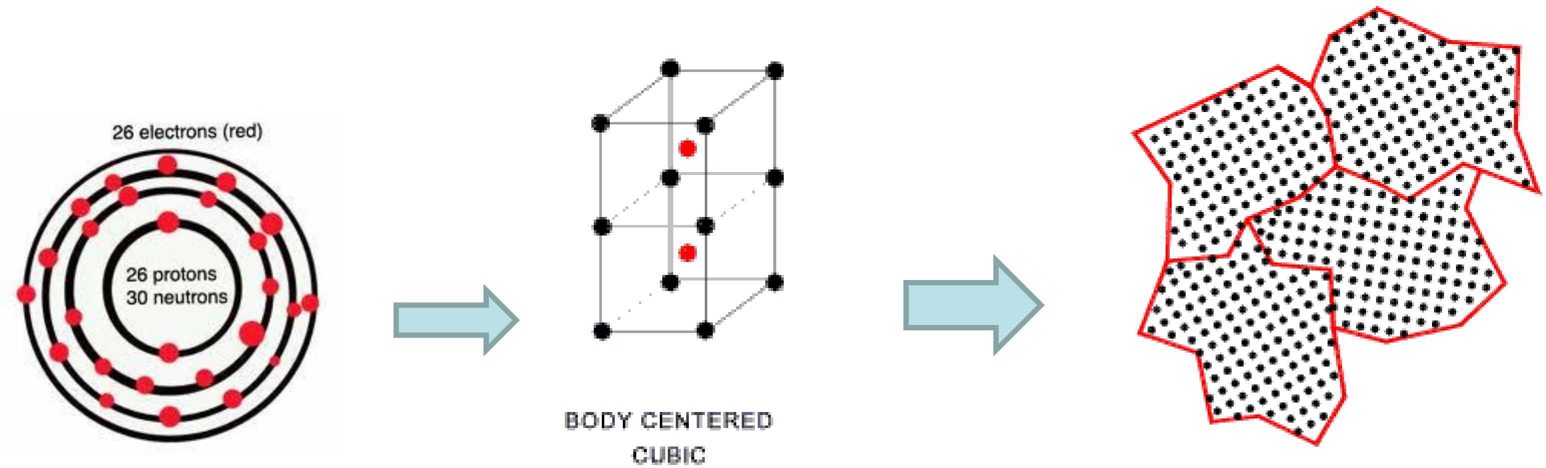
Travel speed v = 0.0082 m/s = **8.2 mm/s**

Lecture 3

02 August 2018, Thursday, 8.00 am -9.00 am

Introduction to welding

Some material science basics…



Atoms Lattice Grains

- Grain size, Grain boundaries,
- **Recrystalization** ~0.4-0.6 T_m $\rightarrow$ Atoms remain in lattice, but new grains will be formed
- **Melting** $\rightarrow$ Atoms displaced from lattice, free to move

Some material science basics…

- Metals are crystalline in nature and consists of irregularly shaped grains of various sizes
- Each grain is made up of an orderly arrangement of atoms known as lattice
- The orientation of atoms in a grain is uniform but differ in adjacent grains

Basic Classification of welding

(a) Fusion welding (b) solid-state welding

a) Fusion Welding

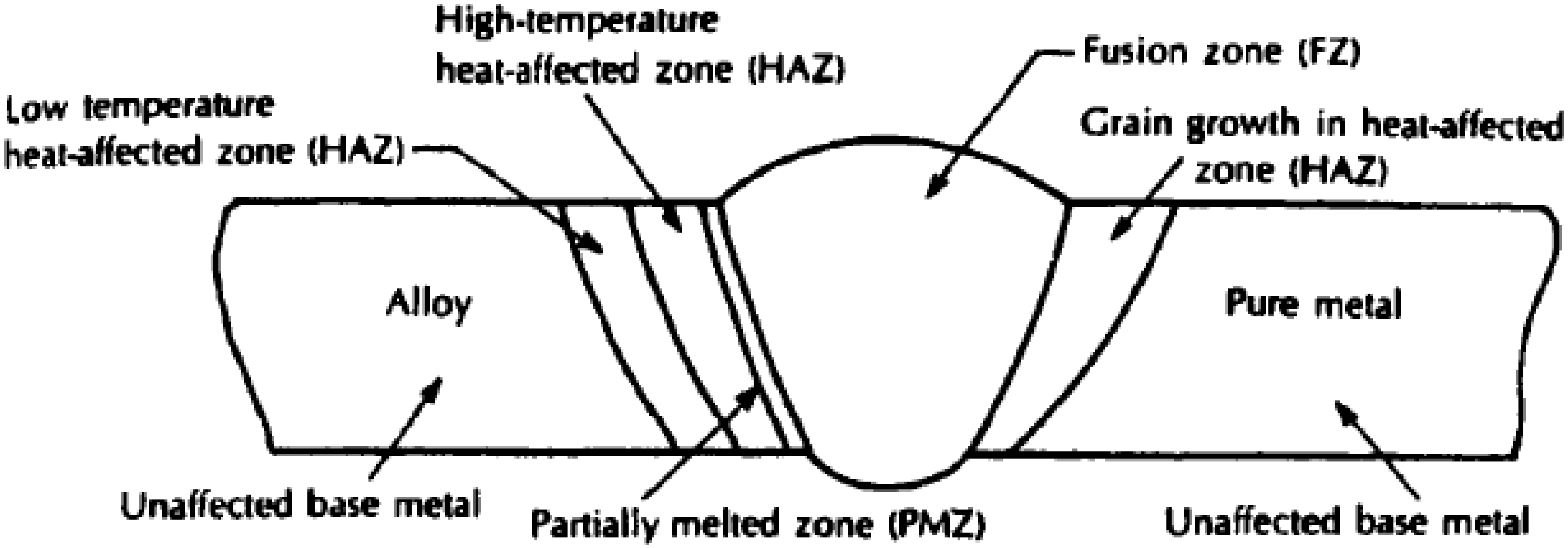
- Uses heat to melt the base metals
- A filler metal is mostly added to the molten pool to facilitate the process and provide bulk and strength to the welded joint.
- e.g., Arc welding, resistance welding, Gas welding, Laser beam welding, Electron beam welding

Basic Classification of welding

b) Solid state Welding

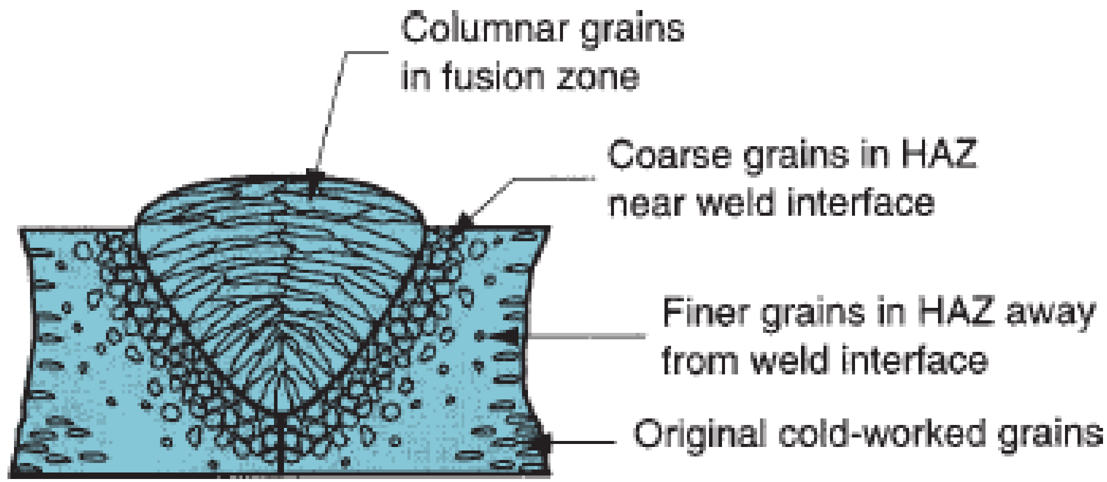
- Coalescence results from application of pressure alone or a combination of heat and pressure
- If heat is used, the temperature in the process is below the melting point of the metals being welded
- No filler metal is used
- e.g., Diffusion welding, friction welding, ultrasonic welding

Micro-structural zones in Fusion welding



1) Fusion zone 2) Weld interface/partially melted zone
3) Heat affected zone 4) Unaffected base metal

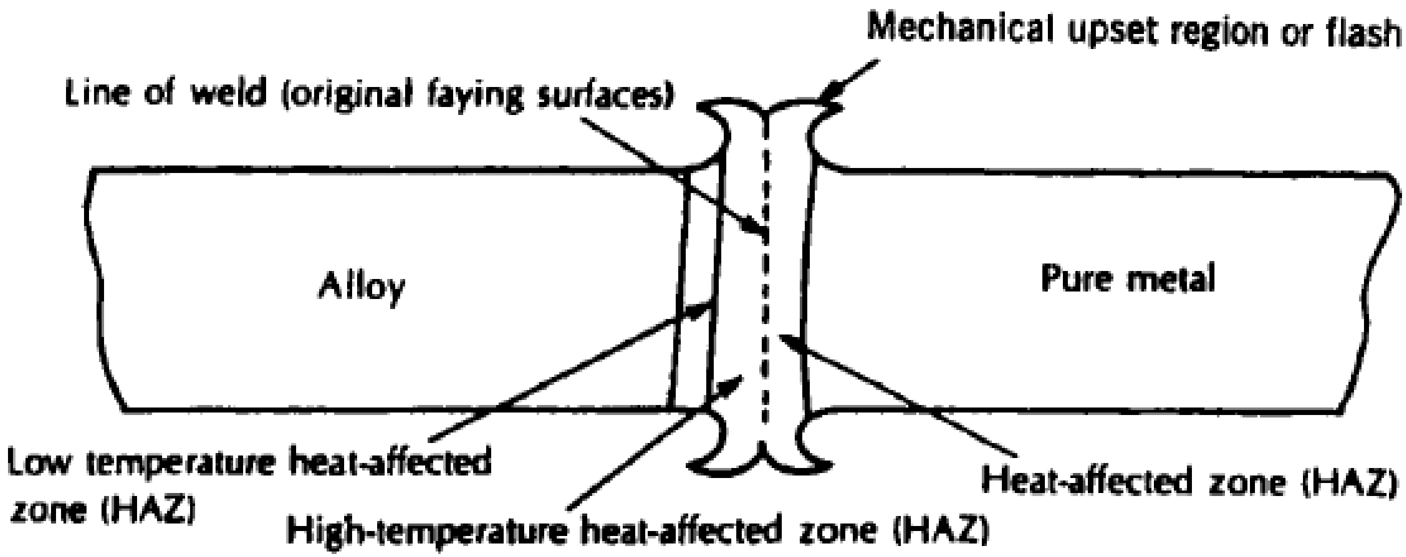
Grain growth in Fusion welding



(b)

- Fusion Zone → Directional solidification → Epitaxial grain growth → Columnar grains
- HAZ → Possible recrystallization/ grain refinement or phase change
- Slow cooling →Coarse grains; Fast cooling → Fine grains
- Shrinkage of fusion zone → Residual stress on the base metal surrounding HAZ

Micro-structural zones in Solid state welding



- No Fusion zone
- Little or no HAZ
- Mechanically upset region (Flash)
- Plastic deformation at the interface

Role of Temperature in Fusion/ solid state welding

- Drives off volatile adsorbed layers of gases, moisture, or organic contaminants
- Breaks down the brittle oxide through differential thermal expansion
- Lowers yield/flow strength of base materials$\rightarrow$ helps plastic deformation
- Promotes dynamic recrystallization during plastic deformation (if $T > T_r$)
- Accelerates the rates of diffusion of atoms
- Melts the substrate materials, so that atoms can rearrange by fluid flow (if $T > T_m$)

Role of Pressure in solid state welding

- Disrupts the adsorbed layers of gases/organic compound or moisture by macro- or microscopic deformation
- Fractures brittle oxide or tarnish layers to expose clean base material atoms
- Plastically deform asperities (lattice) to increase the number of atoms that come into intimate contact (at equilibrium spacing)

Mechanisms for obtaining material continuity

(1) Solid-phase plastic deformation, without or with recrystallization $\rightarrow$ Solid state welding

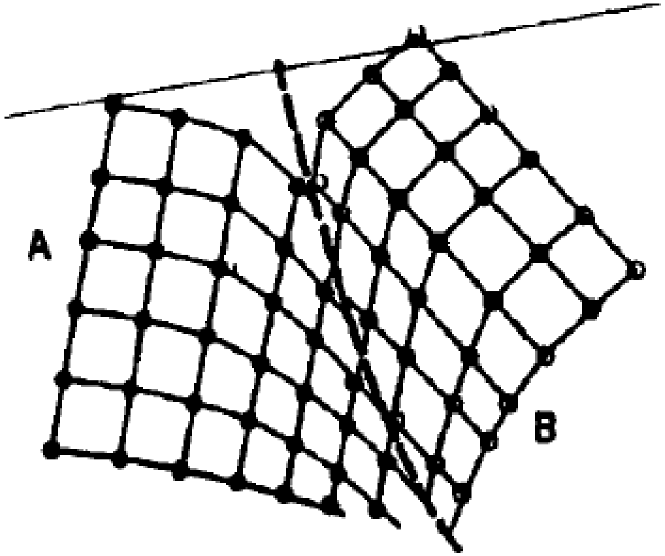
(2) Diffusion, $\rightarrow$ Brazing, Soldering

(3) Melting and solidification $\rightarrow$ Fusion Welding

Obtaining continuity

1a) Solid-phase plastic deformation (**with no heat**)

- Atoms are brought together by plastic deformation
- Sufficiently close to ensure that bonds are established at their equilibrium spacing
- Significant lattice deformation
- Lattices are left in the strained state (distorted) in cold deformation



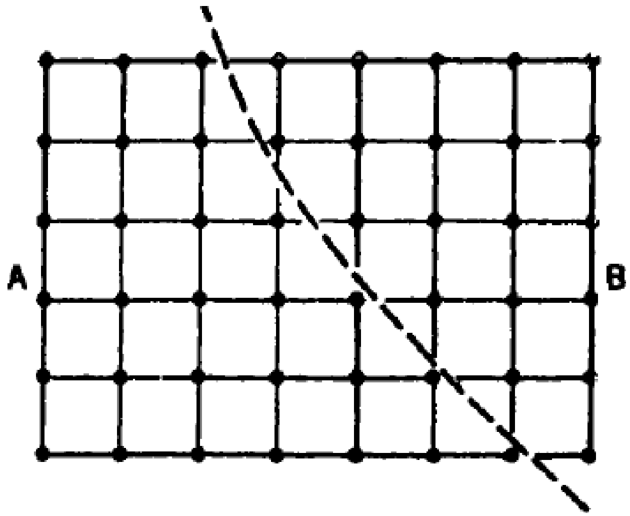
(1a) Cold deformation and lattice strain

Prevailing mechanism in solid state welding with out heat

Obtaining continuity

1b) Solid-phase plastic deformation (**with heat**)

- In hot state (0.4-0.5 T_m), the strained lattice recover from the distorted state
- Atomic rearrangement & Recrystallization
- Grain growth across original interface
- Eliminates the original physical interface



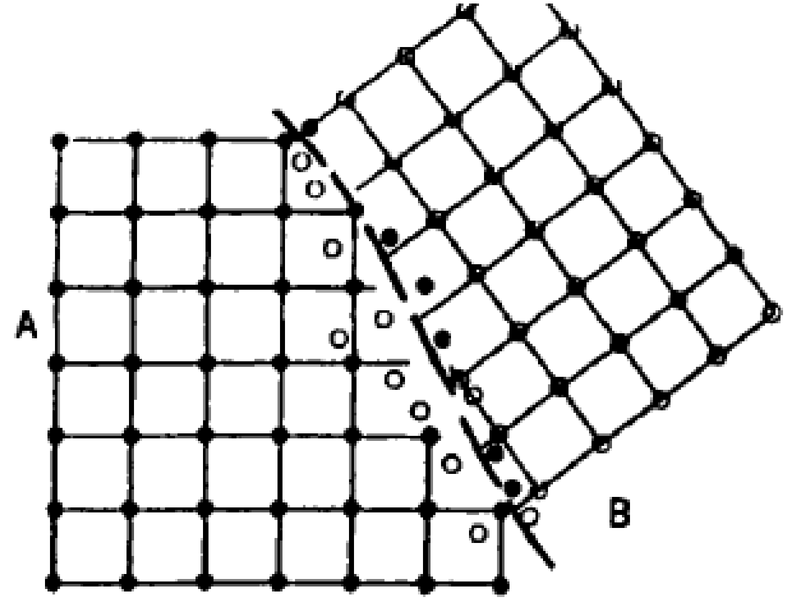
(1b) hot deformation and dynamic recrystallization

Prevailing mechanism in solid state welding with heat

Obtaining continuity

2) Diffusion

- Transport of mass through atom movement
- Can occur entirely in solid phase or with liquid phase
- For dissimilar materials $\rightarrow$ thin layer of alloy at the interface
- Rate of diffusion α Difference in composition (Fick's law), Temperature

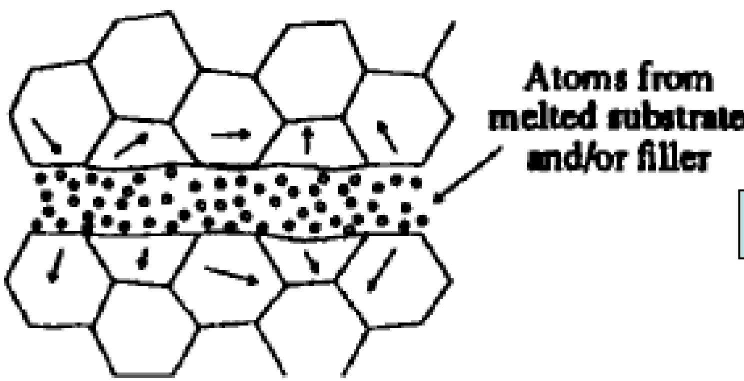


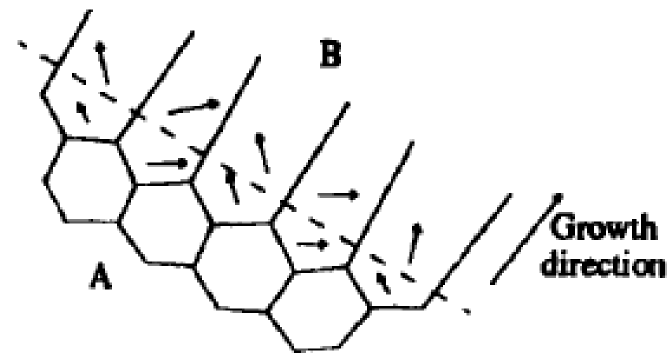
Solid-phase diffusion across the original interface (dotted line)

Prevailing mechanism in brazing/soldering

Obtaining continuity

3) Melting and solidification





Liquid provided by melting the parent materials without or with additional filler

Establishing a bond upon epitaxial solidification of this liquid

- Solidifying crystals take up the grain structure & orientation of substrate/unmelted grains
- Prevailing mechanism in most fusion welding process

Summary: Lectures 1-3

- Overview of welding, applications, advantages, Welded Joint types
- Weld specifications, Symbols
- Fusion & Solid state welding
- Elements of weld setup, Heat Balance, Power density
- **N.B:** Characteristics, micro-structural zones and concept of lattice continuity in fusion & solid state welding

Welding Processes
1) Oxy-Fuel gas welding

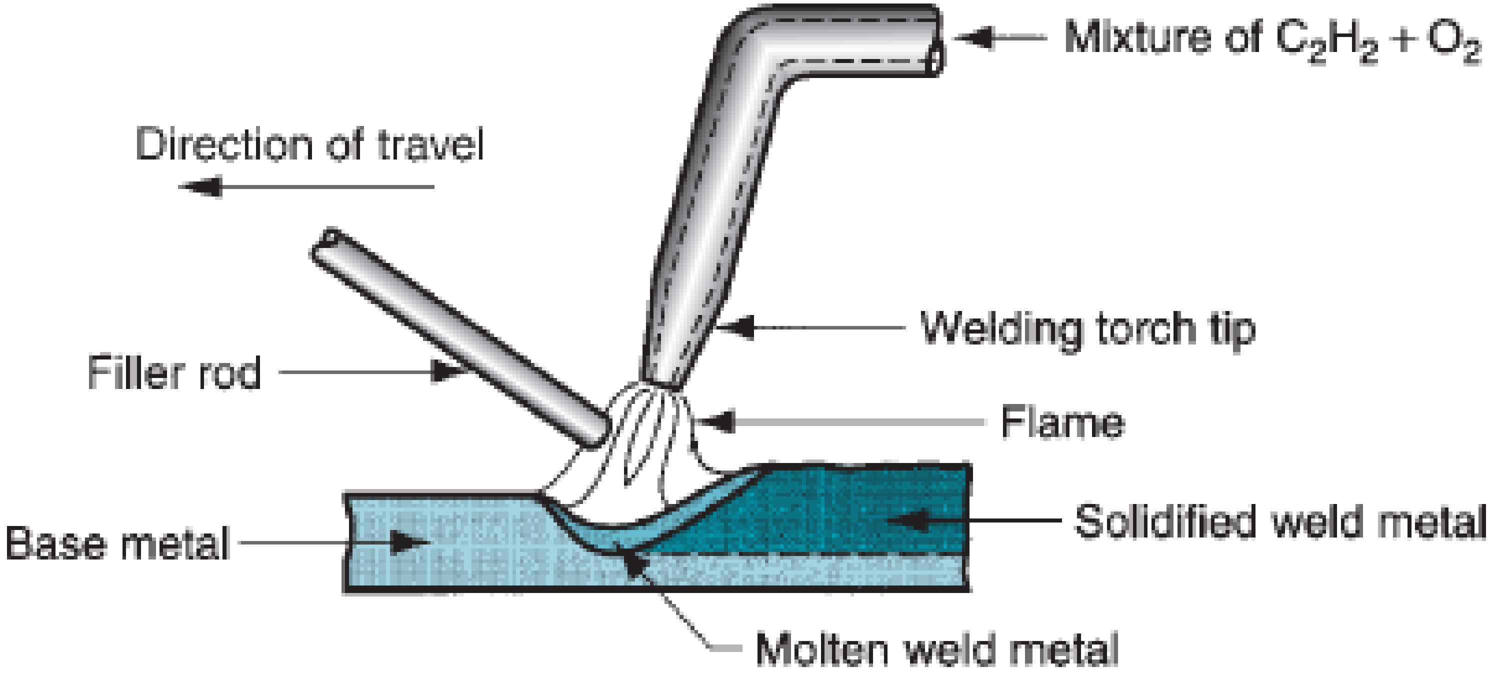
Welding Processes-
1) Oxy-Fuel gas welding

- Uses oxygen as oxidizer
- Acetylene, H_2 or Natural gas, methane, propane, butane or any hydrocarbon as fuel
- Fuel + Oxidizer $\rightarrow$ Energy
- Acetylene is preferred (high flame temperature-3500 °C)

Gases used in Oxy-gas welding

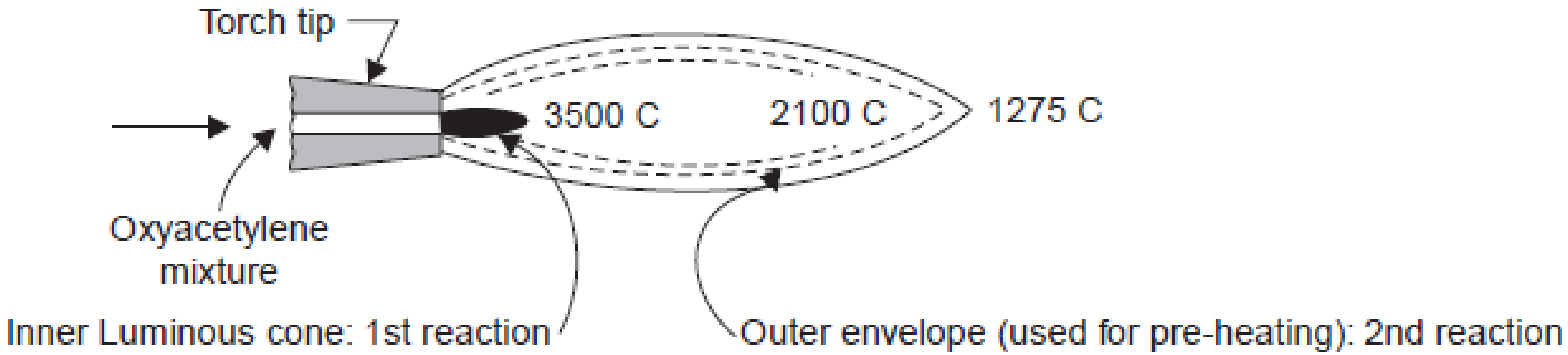
Fuel	Peak reaction Temp (C)	Heat of combustion (MJ/m^3)
Acetylene	**3500**	54.8
Methylacetylene-propadiene (C_3H_4)	2927	91.7
Hydrogen	2660	12.1
Propylene	2900	12.1
Propane	2526	**93.1**
Natural gas	2538	37.3

Oxy-acetylene welding (OAW) operation



Reactions in Oxy-acetylene welding

- Flame in OAW is produced by the chemical reaction of C_2H_2 and O_2 in <u>two stages</u>

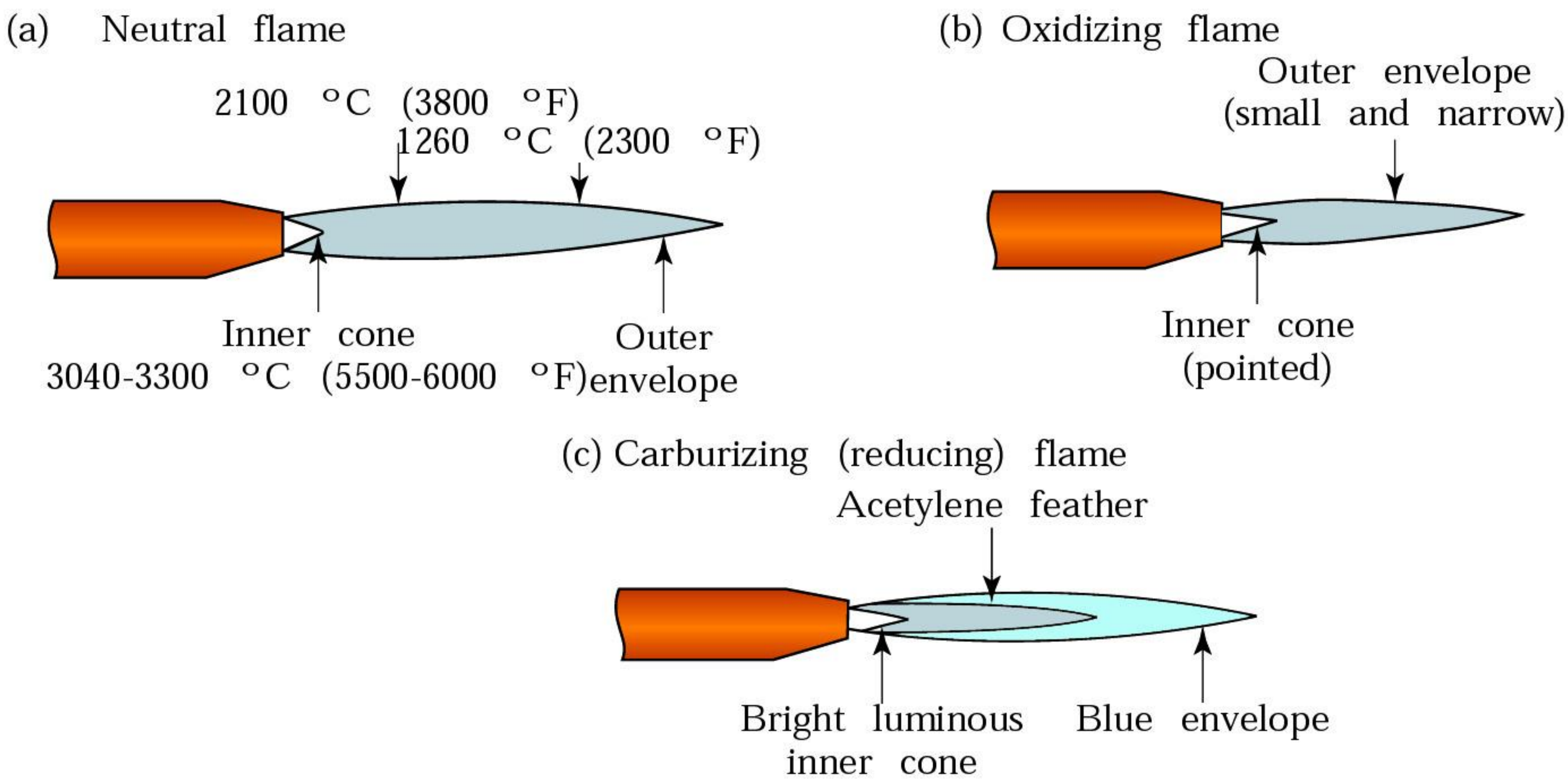


Stage 1 $C_2H_2 + O_2 \rightarrow 2CO + H_2 + \text{Heat (1)}$

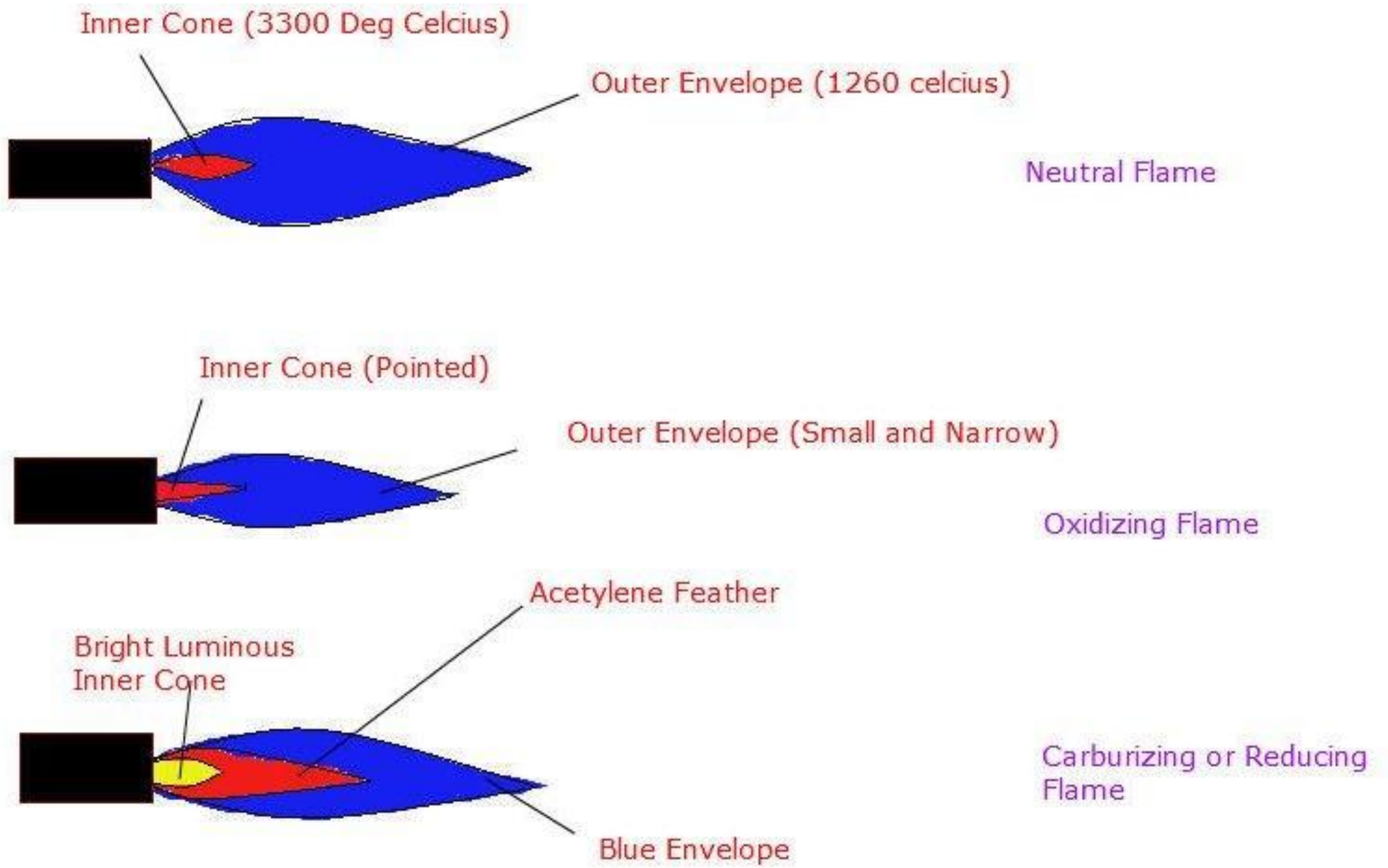
Stage 2 $2CO + H_2 + 1.5O_2 \rightarrow 2CO_2 + H_2O + \text{Heat (2)}$

Heat (1) > Heat (2)

Flames in OAW



Flames in OAW



Neutral flame is used for most applications

Flames in OAW- Reducing flame

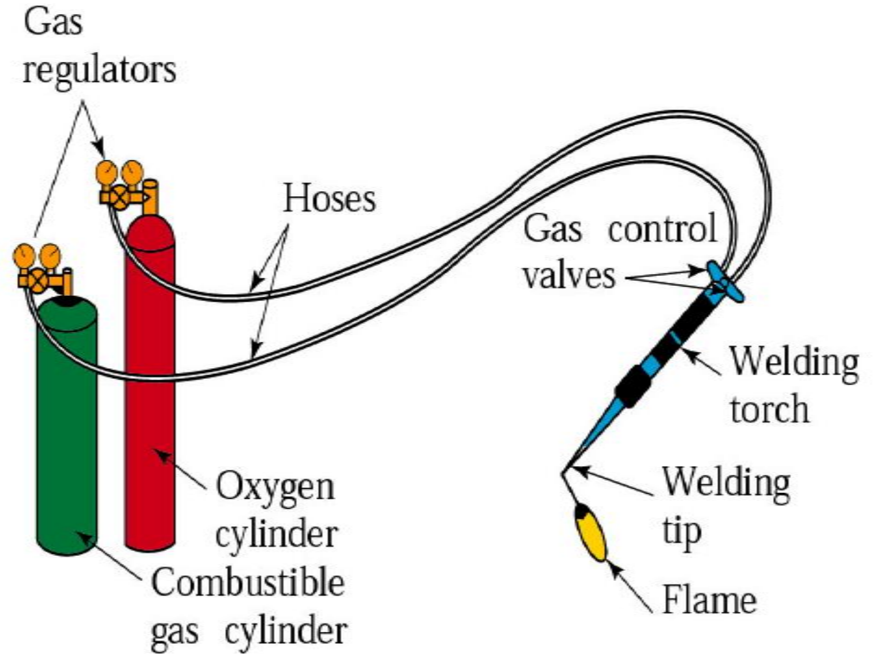
- Reducing flame for removing oxides from metals, such as aluminium or magnesium
- Preventing oxidation reactions during welding
- To prevent decarburization (i.e., C to CO,) in steels.
- Low carbon, alloy steels, monel metal (Ni+Cu+…), hard surfacing

Flames in OAW-Oxy. flame

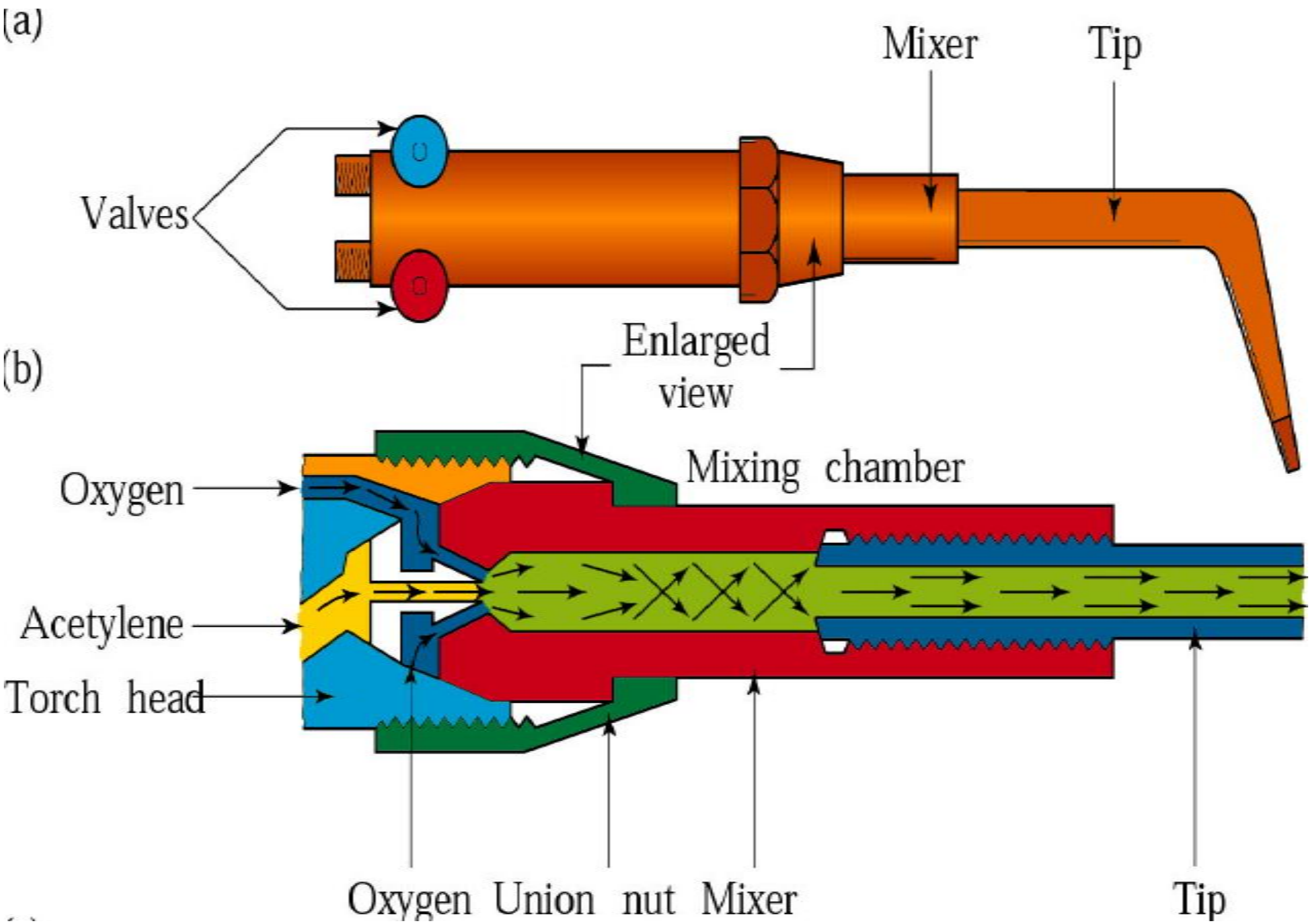
- The oxidizing flame causes the metal being welded to form an oxide.
- Useful for preventing the loss of high vapor-pressure components, such as zinc out of brass, through the formation of an impermeable “oxide skin” (here, copper oxide)
- Brass (Cu + Zn)
- Bronze, Cu, Zn & Sn alloys

OAW set up

- Pressurized cylinders of O_2 and C_2H_2
- Gas regulators for controlling pressure and flow rate
- A torch for mixing the gases
- Hoses for delivering the gases from the cylinders to the torch



OAW Torch



(a)
Mixer
Tip
Valves
Enlarged view
(b)
Mixing chamber
Oxygen
Acetylene
Torch head
Oxygen
Union nut
Mixer
Tip

Example 1 - OAW

An oxyacetylene torch supplies 0.3 m^3 of acetylene per hour and an equal volume rate of oxygen for an OAW operation on 4.5-mm-thick steel.

Heat generated by combustion is transferred to the work surface with a heat transfer factor f1 = 0.20. If 75% of the heat from the flame is concentrated in a circular area on the work surface that is 9.0 mm in diameter, find

(a) rate of heat liberated during combustion,

(b) rate of heat transferred to the work surface, and

(c) average power density in the circular area.

(Heat of combustion of Acetylene in O_2 = 55×10^6 J/m^3)

Example 1 - OAW

(a) The rate of heat generated by the torch is the product of the volume rate of acetylene times the heat of combustion: RH = (0.3 m^3/hr) ($55\times10^{6)}$ J/m3 = 16.5×10^6 J/hr or <u>4583 J/s</u>

(b) With a heat transfer factor f1 = 0.20, the rate of heat received at the work surface is
f1 × RH = 0.20×4583 = <u>917 J/s</u>

(c) The area of the circle in which 75% of the heat of the flame is concentrated is A = Pi. $(9)^2/4$ = 63.6 mm^2
The power density in the circle is found by dividing the available heat by the area of the circle:
Power density = 0.75 × 917/63.6 = <u>10.8 W/mm2</u>

OAW-Advantages

- The OAW process is simple and highly portable
- Inexpensive equipment
- Control over temperature
- Can be used for Pre-heating, cutting & welding

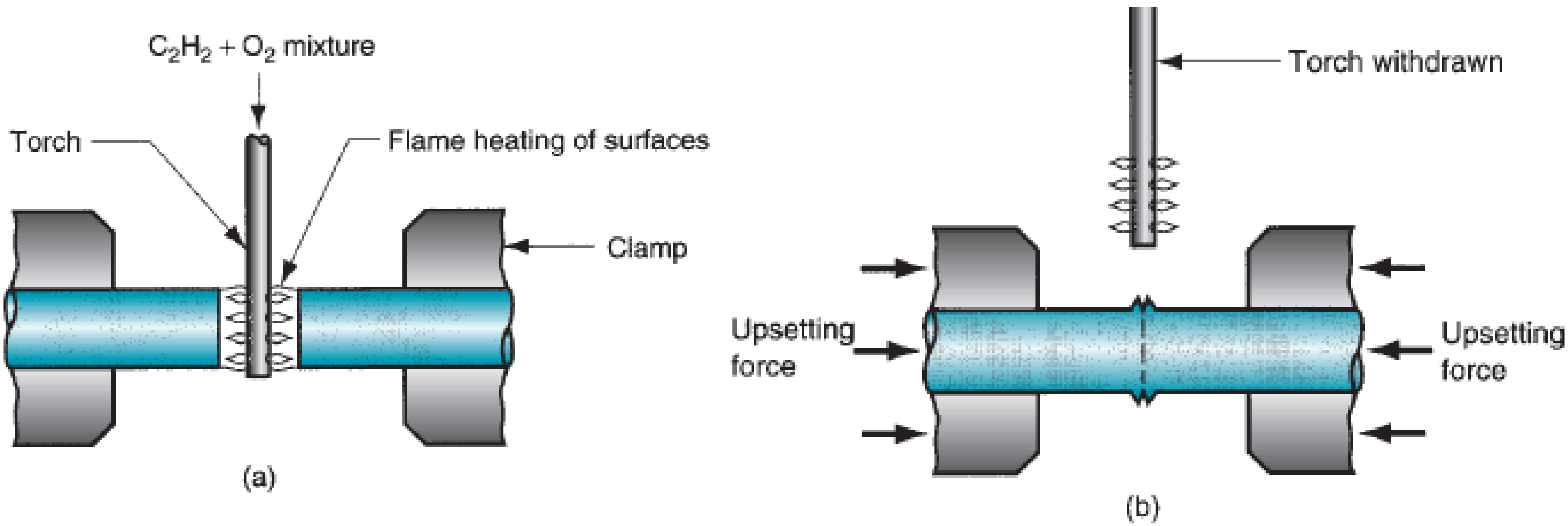
OAW-Disadvantages

- Limited energy $\rightarrow$ welding is slow
- Low protective shielding $\rightarrow$ welding of reactive metals (e.g., titanium) is generally impossible
- Low power density, Energy wastage, total heat input per linear length of weld is high
- Unpleasant welding environment
- Weld lines are much rougher in appearance than other kinds of welds $\rightarrow$ Require more finishing
- Large heat affected zones

OAW-Applications

- Preheating/post heat treatment
- Can be used for cutting, grooving, or piercing (producing holes), as well as for welding
- Oxyfuel gas processes can also be used for flame straightening or shaping
- Oxidizing flame for welding Brass, bronze, Cu-Zn and Tin alloys
- Reducing flame for low carbon & alloy steels

Pressure Gas welding
(Special case of OAW)



- Oxyfuel gas used for preheating the weld interface

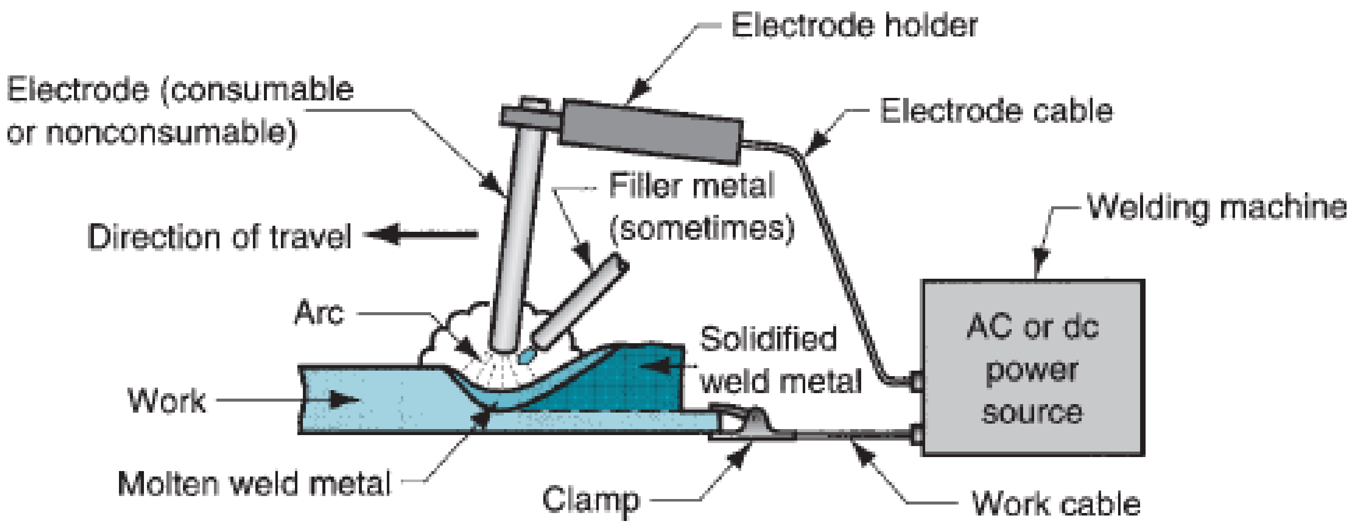
Lecture 4

08 August 2018, Thursday, 8.00 am -9.00 am

Welding Processes-

Arc welding

Arc welding (AW)- Basic configuration



	Arc welding Types
Consumable electrode	SMAW, GMAW (MIG), Submerged arc welding (SMAW)
Non consumable Electrode	GTAW(TIG)

Arc Shielding in AW process

- Accomplished by covering
  - the electrode tip,
  - arc, and
  - molten weld pool with a blanket of gas or flux,

- Common shielding gases $\rightarrow$ argon and helium,

- In the welding of ferrous metals with certain AW processes, oxygen and carbon dioxide are used, usually in combination with Ar and/or He, to produce an oxidizing atmosphere or to control weld shape

Flux in AW process

- Flux is usually formulated to serve several functions:

  (1) To remove/prevent oxide

  (2) provide a protective atmosphere

  (3) stabilize the arc, and

  (4) reduce spattering

- Flux delivery techniques include

  (1) pouring <u>granular flux </u>onto the weld

  (2) using a stick <u>electrode coated with flux </u>material in which the coating melts during welding

  (3) using <u>tubular electrodes</u> in which flux is contained in the core and released as the electrode is consumed

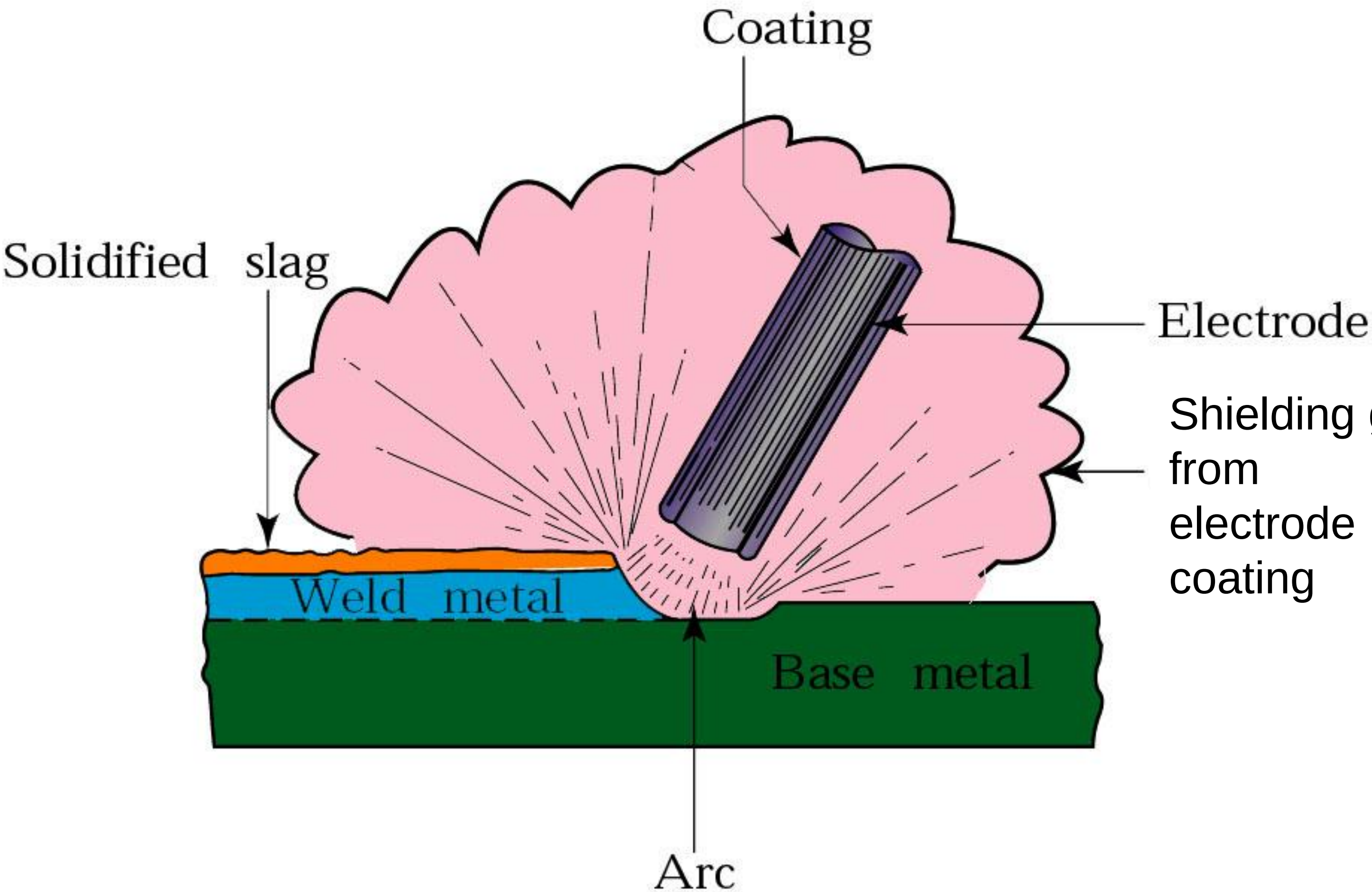
Arc Welding- Consumable Electrodes

- Consumable electrodes → Rods or wire.
- Welding rods → 225 to 450 mm long, < 10 mm dia.
- Welding rods → to be changed periodically → reducing arc time of welder
- Consumable weld wire → continuously fed into the weld pool from spools → avoiding the frequent interruptions

Arc Welding- Non-consumable Electrodes

- Made of tungsten (or carbon, rarely), which resists melting by the arc
- Slow depletion $\rightarrow$ Analogous to wearing of a cutting tool in machining
- Filler metal must be supplied by means of a separate wire that is fed into the weld pool

AW-Type 1: Shielded metal arc welding (SMAW)



Shielding gas from electrode coating

Shielded metal arc welding (SMAW)

- Consumable electrode consisting of a filler metal rod coated with chemicals that provide <u>flux</u> and <u>shielding</u>
- Currents typically used in SMAW range between 30 and 300 A at voltages from 15 to 45 V.
- Usually performed manually
- Most common welding, 50 % of industrial welding uses SMAW

SMAW: Electrode-coating functions

- Produces gases to shield weld from air
- Adds alloying elements
- De-oxidation
- Produces slag to protect & support weld
- Controls cooling rates
- Stabilizes arc

Electrode coating in SMAW-constituents

- Shielding gas is generated by either the decomposition or dissociation of the coating,
  Cellulosic $\rightarrow$generates H_2, CO, H_2O and CO_2
  Limestone ($CaCO_3$)$\rightarrow$ generates CO_2 and CaO slag
  Rutile (TiO_2) up to 40% $\rightarrow$ easy to ignite, gives slag detachability, fine bead appearance, generates O_2 & H_2 by hydrolysis
- Slag formers (flux): SiO, MnO_2, $FeO.Al_2O_3$
- Arc stabilizers: Na_2O, CaO, MgO, TiO_2
- Deoxidizer: Graphite, Al, Wood flour
- Binder: sodium silicate, K silicate
- Alloying elements: V, Co, Mo, Zr, Ni, Mn, W etc.

SMAW-Adv & Applications

- It is preferred over oxyfuel welding for thicker sections—above 5 mm —because of its higher power density.
- The equipment is portable and low cost, making SMAW highly versatile and most widely used AW processes.
- Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys

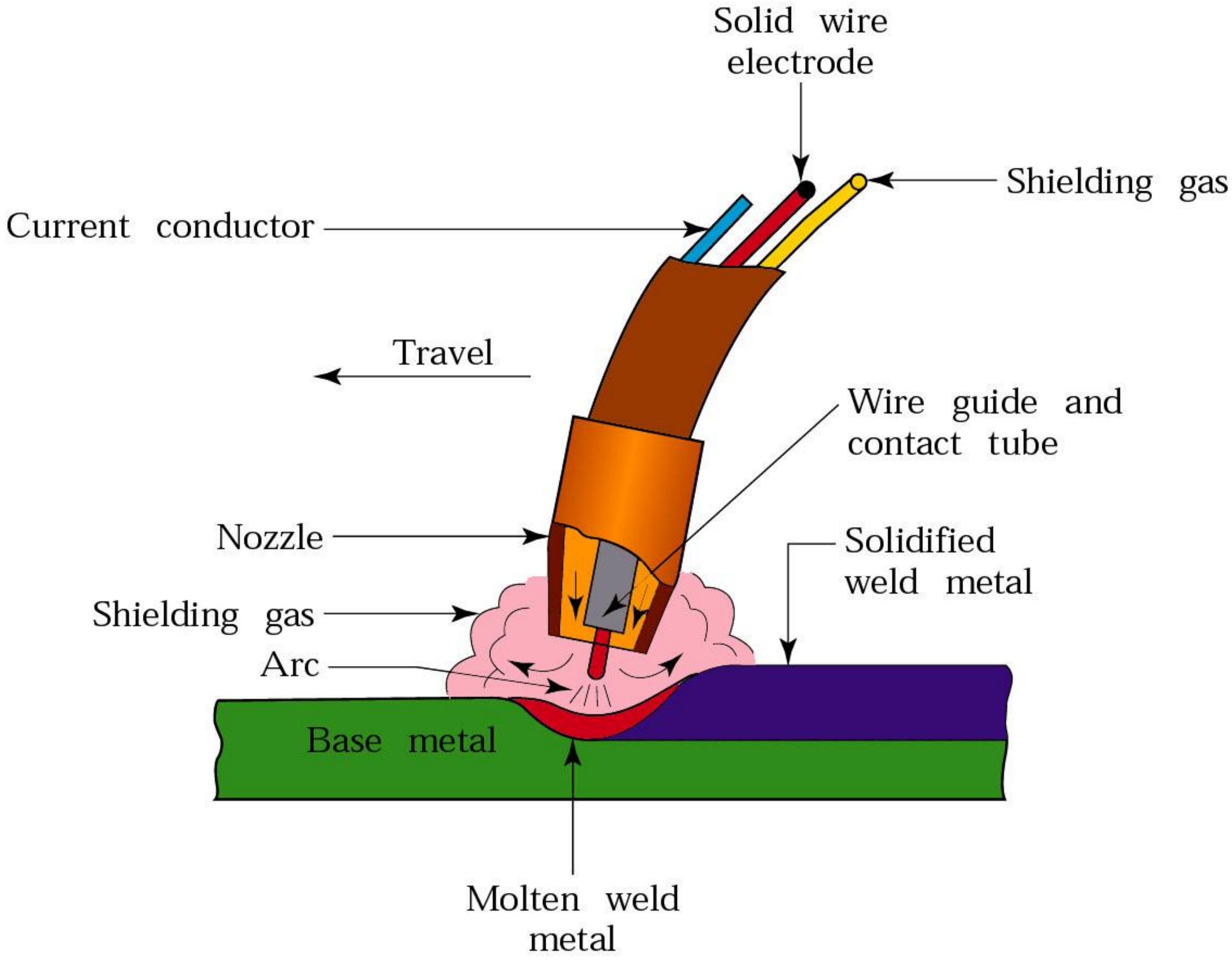
SMAW-Disadvantages

- Electrode length varies during the operation
- Length affects the resistance heating of the electrode,
- Current levels $\rightarrow$ To be maintained within a safe range or the coating will overheat and melt prematurely when starting a new welding stick

SMAW-Disadvantages

- Use of the consumable electrode $\rightarrow$ must periodically be changed $\rightarrow$ reduces the arc time
- Offers limited shielding protection compared to inert gas shielded processes
- Some of the other AW processes overcome the limitations of welding stick length in SMAW by using a continuously fed wire electrode

AW-Type 2: Gas metal arc welding (GMAW) -MIG

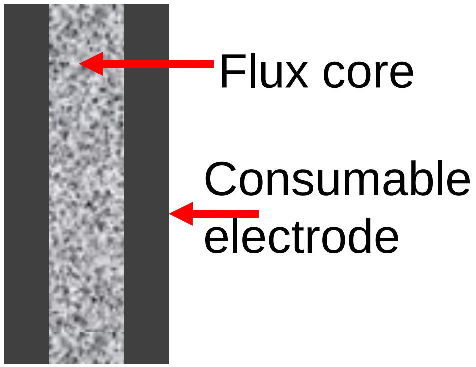


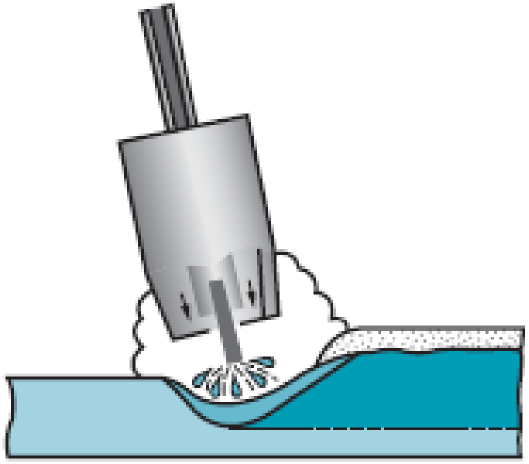
Gas metal arc welding-Features

- Consumable wire electrode is fed continuously and automatically from a spool through the welding gun
- Inert shielding gas : protects the arc and the molten or hot, cooling weld metal from air. Also, provides desired arc characteristics through its effect on ionization
- No electrode coating
- No flux or additional filler
- DCRP used (electrode +ve, work –ve)

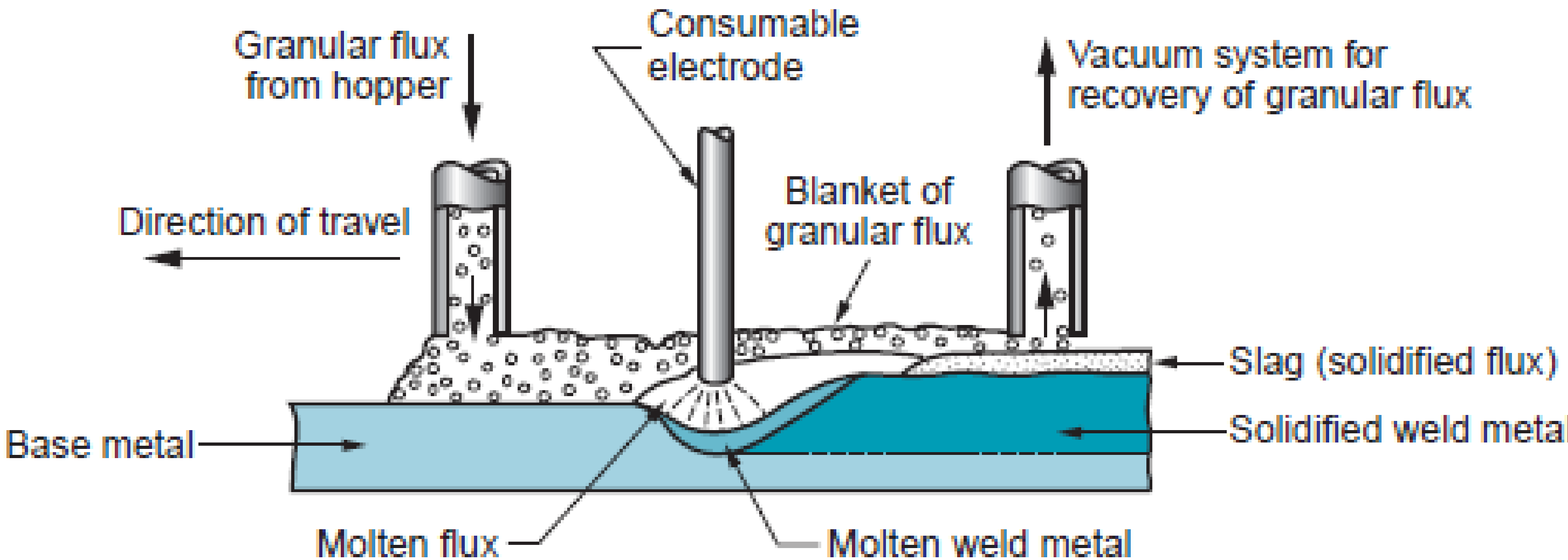
AW-Type 3: Flux-Cored Arc Welding (FCAW)

- Flux cored electrode
- Consumable wire electrode
- With/ Without shielding gas
- Core contents-
  – alloying elements,
  – shielding gas generators
  – flux, etc.





AW-Type 4 Submerged Arc welding (SAW)

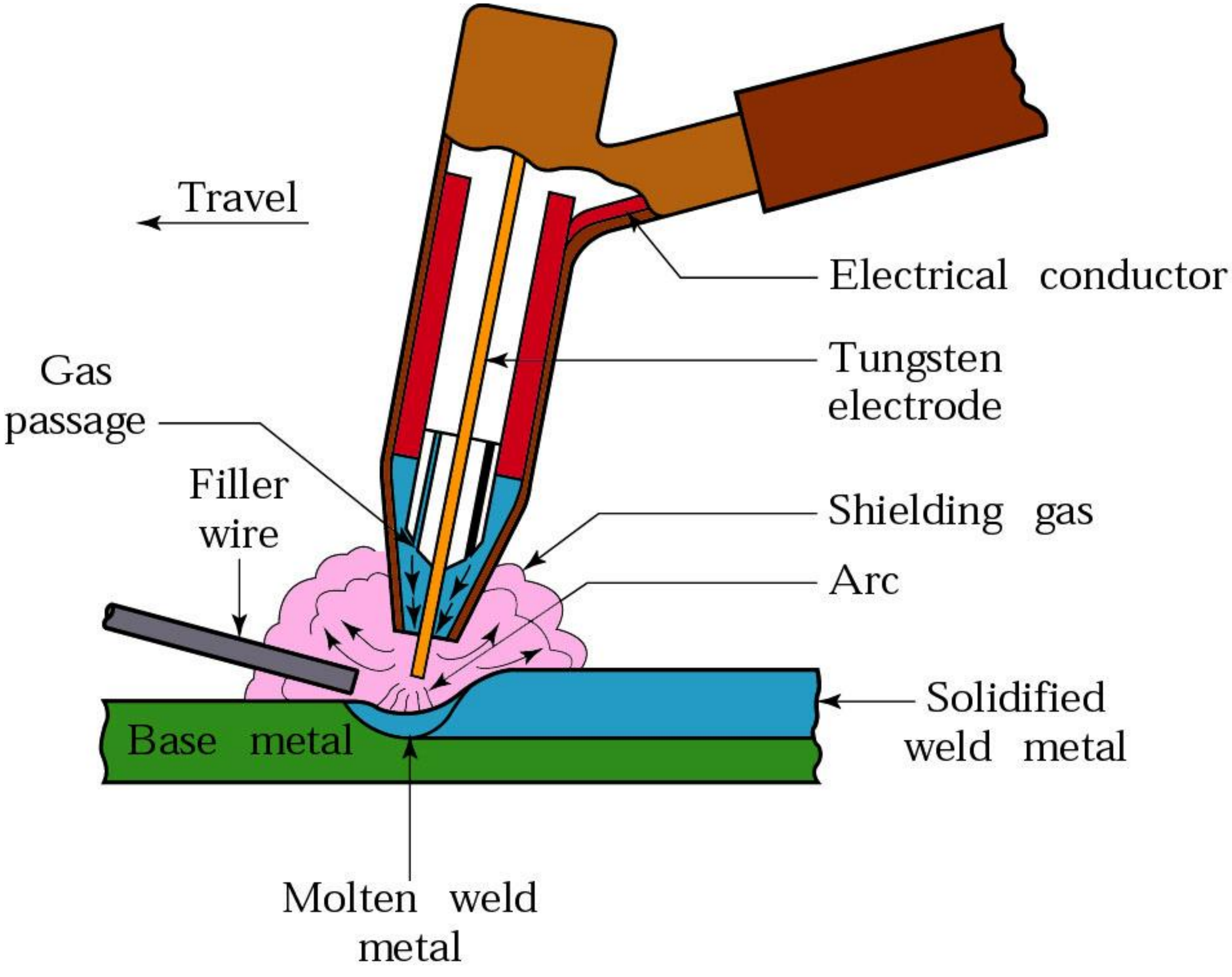


The blanket of granular flux submerges the welding operation, prevents sparks, spatter, and radiation

Submerged Arc welding

- Continuous, <u>consumable bare wire </u>electrode
- <u>Arc shielding </u>provided by a cover of <u>granular flux</u>
- Granular flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper
- <u>Unfused flux </u>remaining after welding can be recovered and <u>reused</u>
- <u>efficiency of Energy transfer </u>from the electrode to workpiece is very high- Low losses
- Welding is restricted to <u>flat and horizontal positions</u>

AW-Type 5: Gas Tungsten Arc Welding (GTAW or TIG)



GTAW- Features

- Non-consumable tungsten electrode
- Inert gas for arc shielding
- With or without filler rod
- Aluminium and stainless steel
- high-quality welds, no weld spatter because no filler metal
- Little or no post weld cleaning because no flux is used

Arc welding Types-Summary

Name	Electrode type	Electrode coating	Filler rod	Shielding gas	Flux	Remarks
Shielded metal arc welding (SMAW)	Consumable rod	YES	NIL	Provided by electrode coating	Provided by electrode coating	Manual welding
Gas metal arc welding (GMAW)-MIG	Consumable wire	NIL	NIL	YES	NIL	Automated welding
Flux-Cored Arc Welding (FCAW)	Consumable wire electrode	NIL	NIL	With/without	Provided by electrode core	Manual/automated
Submerged Arc welding (SAW)	Consumable wire electrode	NIL	NIL	NIL	Granular flux	Manual/automated
Gas Tungsten Arc Welding (GTAW-TIG)	Non consumable	NIL	With/without	YES	NIL	Automated welding