Ministry of Higher Education
Higher Institute For Engineering
And Modern Technology Marg

# MED 151: Casting operations and materials Joining:

## First Simester

Assicate Prof.Dr. Sayed Elnggar
Dr.Gomaa A.Abdelrazek

2026

# CONTENTS


| Title | Page |
|---|---|
| CHAPTRR.1:<br>Introduction<br>**1-Casting technology**:<br>1.1 - types of foundries, steps in making casting; cast metals; types,<br>1.2 -materials and allowances of patterns;<br>1.3 moulding processes and materials; melting furnaces,<br>1.4 furnace charge and its calculations,<br>1.5-gating and risering system design, solidification of metals and alloys, | <br><br><br>5<br>6<br>10<br>14<br><br>23<br>27 |
| CHAPTRR.2<br>2.1- riveting.<br>2.2- welding , sources of thermal energy in welding<br>2.3- operations of fusion welding, specifications of welding, materials , electric resistance welding, soldering and brazing<br>2.4-heat transfer in welding process, metallurgical changes,<br>2.5- welding defects, inspection and testing,<br>2.6- planning of welding processes; practical training | <br>55<br>70<br>73<br><br>79<br><br>121<br>122 |

**MED 151 Casting operations and materials Joining:**

**3 Cr. hrs. =[ 2Lect + 2Tut + 1Lab]** **Prerequisite: MED 121**

**1-Casting technology**:

1.1 - types of foundries, steps in making casting; cast metals; types,
1.2 -materials and allowances of patterns;
1.3 moulding processes and materials; melting furnaces,
1.4 furnace charge and its calculations,
1.5-gating and risering system design, solidification of metals and alloys,
1.6casting defects inspection and testing of castings, production management in foundries, practical training.

**2-Metal joining processes**:

-riveting,
-welding , sources of thermal energy in welding,
-operations of fusion welding, specifications of welding, materials , electric resistance
welding, soldering and brazing,
-heat transfer in welding process, metallurgical changes,
- welding defects, inspection and testing,
- planning of welding processes; practical training

**مكص ٢٢١ عمليات السباكة ووصل المعادن**

**تكنولوجيا السباكة:** عمليات وطرق السباكة، مواد القوالب وخواصها، افران الصهر، مواد الشحنة وحساباتها، تصميم نظم الصب والتغذية، تجمد المعادن والسبائك عيوب المسبوكات والاختبارات وطرق التفتيش والفحص، إدارة الإنتاج فى المسابك، تدريب عملى.

**أساليب وصل المعادن:** وصل المعادن بالبرشام، لحام المعادن ، مصادر الطاقة الحرارية المستخدمة فى اللحام ، لحام الصهر وعملياته ، توصيف مواد اللحام المقاومة الكهربية ، لحام المونة الطرية والصادة ،
الإنتقال الحرارى أثناء عمليات اللحام ، التغيرات الميتالورجية ، عيوب اللحامات ، طرق الكشف على الملحومات ،التخطيط لعمليات اللحام المختلفة ، تدريب عملى.

**Laboratory:**

1 Practice on Standard casting processes of different types of materials with Measurement of allowances with inspection of defects

2 Practice of designing special patterns, moulds, gating, risering system,… etc

3 Practice on standard welding operations(Butt welding, Arc welding, seam welding,… etc) with

inspection of defects

4 Practice on standard Soldering operations with inspection of defects.

5 Practice on standard Brazing operations with inspection of defects .

6 Practice on standard riveting operations with inspection of defects .

**References:**


 P.N.Raw, Manufacturing Technology. Foundary, Forming and welding, Tata McGraw -Hill New Delhy, 2nd Ed., 2004

 G.k.Lal:S.k choudhury, fundamentals of Manufacturing processes, Alpha international, Ltd, 2005


Assessment:

Final Exam : 50% , Quizzes: 20% , Year work: 20% , Experimental/Oral: 10%

# CHAPTER.1
# Casting Technology

# 1-Types of foundries, steps in making a casting; cast metals; types

## FOUNDRY PROCESSES

## INTRODUCTION

To understand the foundry process, it is necessary to know how a mold is made and what factors are important to produce a good casting.

A foundry is a collection of the necessary material and equipment to produce a casting.

A **foundry** is an industrial plant for producing certain kinds of product.

**Overview of Casting Technology**

**Casting Definition:**

*"A casting is a shape obtained by pouring liquid material into a mould or cavity and allowing it to freeze and thus to take the form of the mould."*

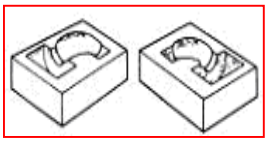
| | |
|---|---|
| Advantages | Complex shapes<br>Net-shape ability<br>Very large parts<br>Variety of metals<br>Mass production |
| Disadvantages | Poor accuracy<br>Poor surface<br>Internal defects<br>Mechanical properties<br>Environmental impact |

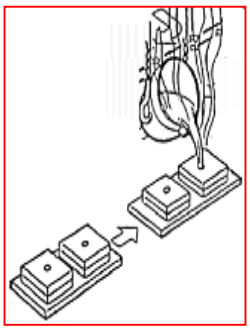
## 1.1.Types of foundries

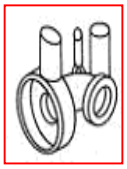
### Different Casting Processes

| Process | Advantages | Disadvantages | Examples |
|---|---|---|---|
| Sand | many metals, sizes, shapes, cheap | poor finish & tolerance | engine blocks, cylinder heads |
| Shell mold | better accuracy, finish, higher production rate | limited part size | connecting rods, gear housings |
| Expendable pattern | Wide range of metals, sizes, shapes | patterns have low strength | cylinder heads, brake components |
| Plaster mold | complex shapes, good surface finish | non-ferrous metals, low production rate | prototypes of mechanical parts |
| Ceramic mold | complex shapes, high accuracy, good finish | small sizes | impellers, injection mold tooling |
| Investment | complex shapes, excellent finish | small parts, expensive | jewellery |
| Permanent mold | good finish, low porosity, high production rate | Costly mold, simpler shapes only | gears, gear housings |
| Die | Excellent dimensional accuracy, high production rate | costly dies, small parts, non-ferrous metals | gears, camera bodies, car wheels |
| Centrifugal | Large cylindrical parts, good quality | Expensive, few shapes | pipes, boilers, flywheels |

## Steps in making casting:









Refractory mold → pour liquid metal → solidify, remove → finish

1. Pour the molten metal into a mold
2. Allow time for metal to solidify
3. Break or remove the mold to get casting
4. Clean and inspect casting-Separate gating and riser system
5. Heat treatment of casting is sometimes required to improve metallurgical properties

The elements necessary for the production of sand casting will be considered

- Mold
- Pattern
- Core
- Molding Procedure
- Sand
- Properties of Cast liquid
- Behavior of Cast Material

## cast metals; types

## General Characteristics of Casting Processes

| Process | Typical materials cast | Weight (kg) | | Typical surface finish ($\mu$m, $R_a$) | Porosity* | Shape complexity* | Dimensional accuracy* | Section thickness (mm) | |
|---|---|---|---|---|---|---|---|---|---|
| | | Minimum | Maximum | | | | | Minimum | Maximum |
| Sand | All | 0.05 | No limit | 5-25 | 4 | 1-2 | 3 | 3 | No limit |
| Shell | All | 0.05 | 100+ | 1-3 | 4 | 2-3 | 2 | 2 | -- |
| Expendable mold pattern | All | 0.05 | No limit | 5-20 | 4 | 1 | 2 | 2 | No limit |
| Plaster mold | Nonferrous (Al, Mg, Zn, Cu) | 0.05 | 50+ | 1-2 | 3 | 1-2 | 2 | 1 | -- |
| Investment | All (High melting pt.) | 0.005 | 100+ | 1-3 | 3 | 1 | 1 | 1 | 75 |
| Permanent mold | All | 0.5 | 300 | 2-3 | 2-3 | 3-4 | 1 | 2 | 50 |
| Die | Nonferrous (Al, Mg, Zn, Cu) | <0.05 | 50 | 1-2 | 1-2 | 3-4 | 1 | 0.5 | 12 |
| Centrifugal | All | -- | 5000+ | 2-10 | 1-2 | 3-4 | 3 | 2 | 100 |

*Relative rating: 1 best, 5 worst.

*Note*: These ratings are only general; significant variations can occur, depending on the methods used.

## 1.2.-materials and allowances of patterns

**PATTERNS**

Definition:

-A pattern (model) is a form used to prepare and produce a mold cavity. **or**

It is a full-sized model of the part, slightly enlarged to account for shrinkage and machining allowances in the casting

Types of patterns:

1-The pattern may be permanent, so that it may be reused repeatedly. Or

2-The pattern may be expendable (disposable), made up of a material that is melted out before or burnt up during casting.

Pattern materials

Wood :

- common material because it is easy to work, but it warps (Disadvantage of wood is humidity absorption.)

Metal :

- more expensive to make, but lasts much longer like aluminium alloys (low in density).

Plastic:

- compromise between wood and metal .

## Types of patterns in sand casting :

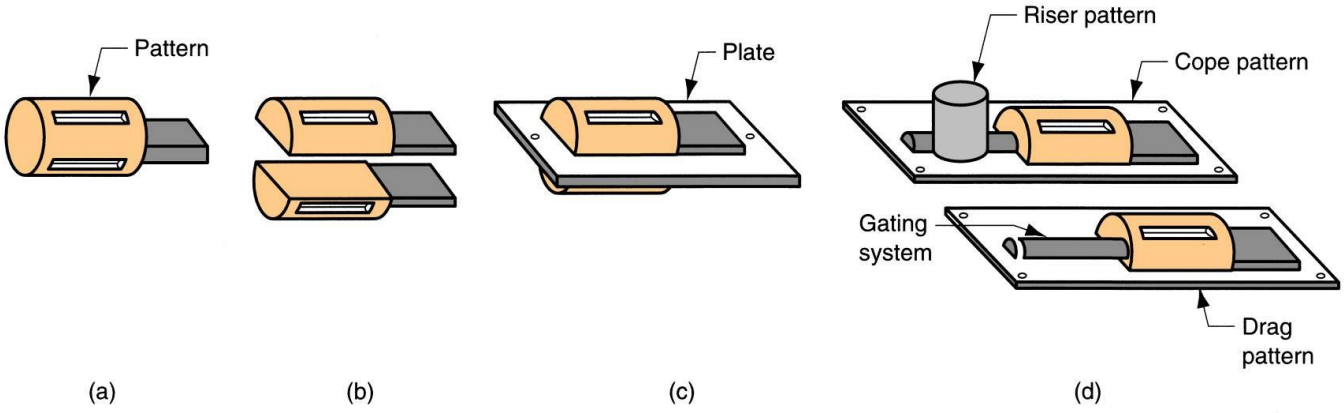
The Figure : Types of patterns used in sand casting:

(a) solid pattern

(b) split pattern

(c) match-plate pattern

(d) cope and drag pattern



## Pattern Allowances

### 1. Shrinkage Allowance:

Shrinkage takes place in a volumetric way. Each dimension is measured with a shrinkage rule, which automatically gives shrinkage allowance.

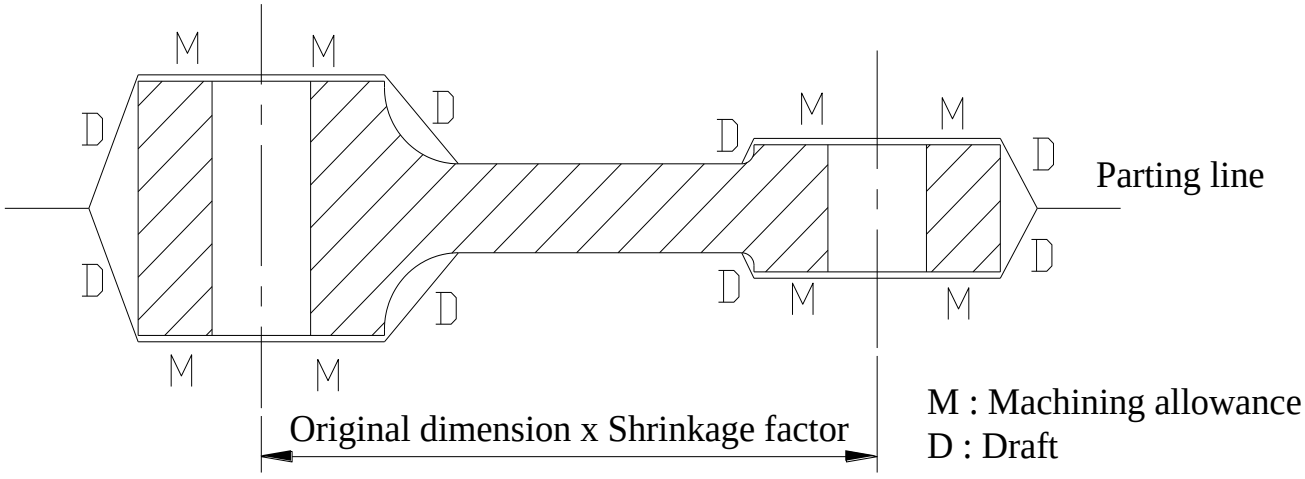



*Fig. 1. Pattern Allowances for a Cast Connecting Rod.*

Typical shrinkage allowances:

| | Cast Iron | Steel | Al | Brass | Bronze |
|---|---|---|---|---|---|
| In/ft | 1/8 | 1/4 | 5/32 | 3/36 | 1/8-1/4 |
| % | 1.04 | 2.08 | 1.30 | 2.0 | 1.04-2.08 |

**Rate of Contraction of Various Metals**

| Material | Dimension | Shrinkage allowance (inch/ft) |
|---|---|---|
| Grey Cast Iron | Up to 2 feet<br>2 feet to 4 feet<br>over 4 feet | 0.125<br>0.105<br>0.083 |
| Cast Steel | Up to 2 feet<br>2 feet to 6 feet<br>over 6 feet | 0.251<br>0.191<br>0.155 |
| Aluminum | Up to 4 feet<br>4 feet to 6 feet<br>over 6 feet | 0.155<br>0.143<br>0.125 |
| Magnesium | Up to 4 feet<br>Over 4 feet | 0.173<br>0.155 |

**2. Draft:** It is the taper placed on the sides of the pattern on the parting line. This allows the pattern to be removed from the mold without damaging the sand surface. Draft is added to the dimensions on the parting line

Exterior dimensions: 1/8 - 1/4 (in/ft), 1.04 %- 2.08 %

Interior dimensions: As large as 3/4 (in/ft), 6.25 %

**3. Machining Allowance:** It is given on the working areas of the part where further machining will be performed. In value, it is equal to shrinkage allowance.

**4. Shake:** Negative allowance is given by making the pattern slightly smaller to compensate for the rapping of the mold.

## 1.3..Molding processes and materials; melting furnaces,

### MOLDS

Definition:

A mold is the container that has the cavity of the shape to be cast.

**Molds materials:**

It may be made of sand ,metal, plaster, ceramics, or other refractory substances. Good castings can not be produced without good molds

There are two types of molds:

1. Permanent mold: A mold used **more than once**. They are generally produced from metallic materials such as; heat resisting (Ni-Cr) steels.

2. Expendable mold: A mold **used only once** and then destroyed to separate the component. They are generally produced from sand. (for casting of ferrous materials we have to use this type of mold, because melting points of ferrous materials are very high).

There are plenty types of expendable molds, but we will deal with sand molds only;

a) Green Sand Molds: The most common type consisting of forming the mold from damp molding sand (silica, clay and moisture)

b) Skin-dried Molds: It is done in two ways;

(1) The sand around the pattern to a depth of about 1/2 in(10 mm). is mixed with a binder so that when it is dried it will leave a hard surface on the mold. (2) Entire mold is made from green sand, but a spray or wash, which hardens when heat is applied, is used.

c) Dry Sand Molds: These molds are made entirely from fairly coarse molding sand mixed with binders (linseed oil gelatinised). They baked before being used. A dry sand mold holds its shape when poured and is free from gas troubles due to moisture.

# Mold characteristics:

i) The mold must be strong enough to hold the weight of the metal,

ii) The mold must resist the erosive action of the rapidly flowing metal during pouring,

iii) The mold must generate minimum amount of gas when filled with molten metal.

iv) The mold must be constructed in such a way that any gasses formed can pass through the body of the mold itself (permeability).

v) The mold must be refractory enough to withstand the high temperature of the metal.

vi) The mold must collapse easily after the casting solidifies.

## SAND

Silica sand ($SiO_2$) is well suited for molding purposes because it can withstand a high temperature without decomposition. This sand is low in cost, has longer life, and is available in a wide range of grain sizes and shapes.

Pure silica sand is not suitable in itself for molding, since it lacks binding qualities. The binding qualities can be obtained by adding 8-15 % clay .

| | | | | |
|---|---|---|---|---|
| Silica ($SiO_2$) | + | Binders | $\Rightarrow$ | **Green Sand Mold** |
| | | Moisture 5-10% | | (used in castings of Cast Iron |
| | | Clay 8-15% | | and Non-ferrous Alloys) |

| | | | | |
|---|---|---|---|---|
| Silica ($SiO_2$) | + | Binders | $\Rightarrow$ | **Dry Sand Mold** |
| | | Linseed Oil | | (used in castings of Steels) |
| (40 part) | | (1 part) | | |

Dry it first and then bake at 180-220$^0$C for 2 hours

# Melting furnaces

## Melting Practices

Melting is an equally important parameter for obtaining a quality castings. A number of furnaces can be used for melting the metal, to be used, to make a metal casting. The choice of furnace depends on the type of metal to be melted. Some of the furnaces used in metal casting are as following:.

- Crucible furnaces
- Cupola
- Induction furnace
- Reverberatory furnace

## Crucible Furnace.

Crucible furnaces are small capacity typically used for small melting applications. Crucible furnace is suitable for the batch type foundries where the metal requirement is intermittent. The metal is placed in a crucible which is made of clay and graphite. The energy is applied indirectly to the metal by heating the crucible by coke, oil or gas.The heating of crucible is done by coke, oil or gas. .

**Coke-Fired Furnace (**Figure 13**) .**

- Primarily used for non-ferrous metals
- Furnace is of a cylindrical shape
- Also known as pit furnace
- Preparation involves: first to make a deep bed of coke in the furnace
- Burn the coke till it attains the state of maximum combustion
- Insert the crucible in the coke bed
- Remove the crucible when the melt reaches to desired temperature

# Classification of Melting Furnaces

A furnace is a refractory lined chamber in which temperatures as high as 1800°C can be attained with a view to melt a charge. Equipment for lower temperatures is called oven. Furnaces are used in industry for melting purposes. They vary in sizes (capacity), types of fuel used and types of charge to be melted. Given below is the general classification of furnaces used in foundry based on the type of fuel used:

A) Furnaces using Chemical energy of fuel (Fuel fired furnaces)

B) Furnaces using Electrical energy (Electric furnaces)

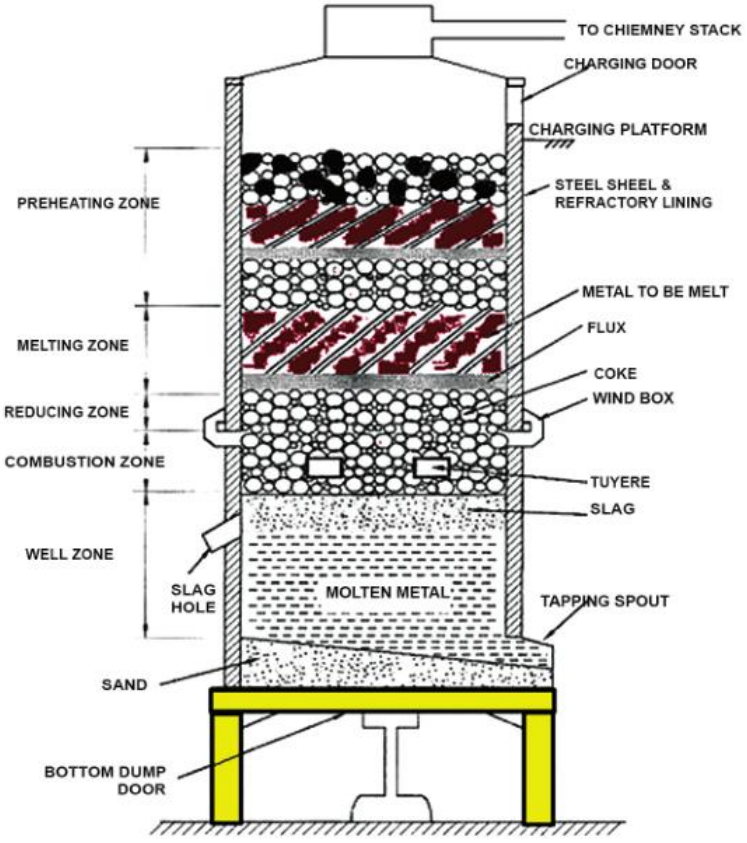
## A. Fuel-fired furnaces:

### A.1. Stationery furnaces:

| | | | |
|---|---|---|---|
| A. | 1.1 | Coke fired: | Cupola, Pot furnaces, Crucible furnace |
| | 1.2 | Oil/ gas fired: | Stationery type – Reverberatory, Movable furnace - Rotary furnace |

### A.2. Electric furnaces:

| | | | |
|---|---|---|---|
| A. | 2.1 | Resistance type: | Laboratory muffle furnace, Wire-winding type furnace |
| | 2.2 | Arc Furnaces: | i) Direct arc ii) Indirect arc |
| | 2.3 | Induction furnaces: | i) Coreless type ii) Core-type Channel furnace |

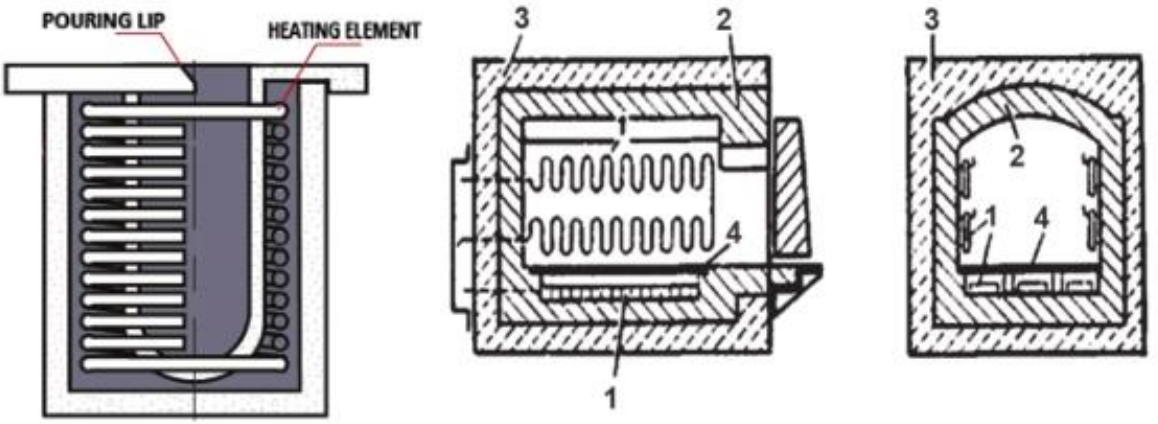



***Schematic diagram of a Cupola***

**Melting zone:**The lower layer of metal charge is termed as melting zone of Cupola.

# Electric Furnaces

## Resistance Furnace



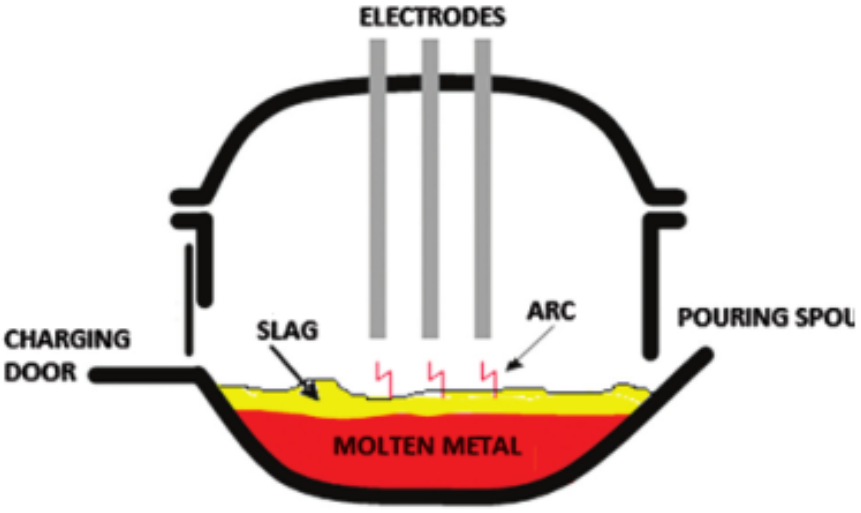

***Schematic diagram of Indirect heat resistance furnace***

(1 - heating element, 2 - refractory lining, 3 - heat insulation, 4 - refractory hearth plate)

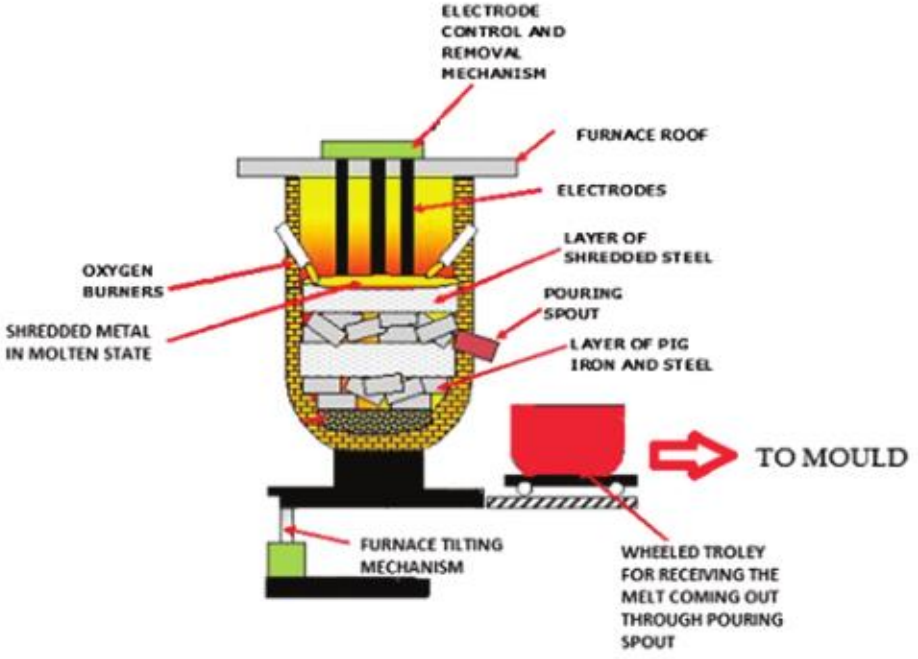
Resistance furnace is an electric furnace in which heat is developed by the passage of current through distributed resistors (heating units) mounted apart from the charge.

Electric furnaces generally being used in modern foundries are either arc furnaces or induction furnaces. A third type, the resistance furnace, is still used in the production of silicon carbide and electrolytic aluminum. In this type, the furnace charge (i.e., the

Electric arc furnaces are used for melting metals and alloys which have high-melting-point. The furnace consists of a saucer-shaped hearth made of refractory material for collecting the molten metal, refractory material lining also extends to the sides and top of the furnace. Two or three carbon electrodes are dipped into the furnace from the roof or the sides. Doors in the side of the furnace allow removal of molten alloys (the products), removal of slag etc. The scrap metal charge is placed on the hearth and melted by the heat from an electric arc formed between the electrodes.




***Schematic diagram of Electric Arc Furnace***



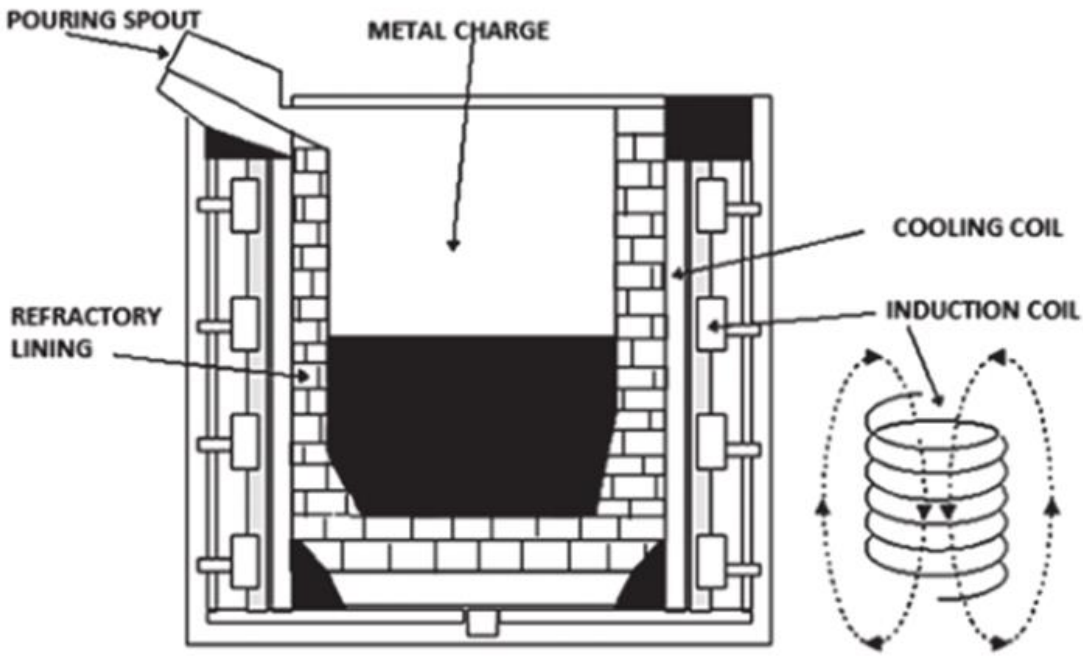

***Basic layout of an Electric Arc Furnace***

Electric Arc Furnace Operating Cycle:Scraps melt in this type of furnace are divided into two grades: (i) shred (this consists of scraps which have light thicknesses)

(ii) heavy melt (this consists of large slabs and beams)

# Coreless type Induction Furnace

Coreless type induction furnace (as shown in Fig . ) consists of a cylindrical crucible with refractory lining. It has copper coils that are protected by a shield and kept cool by water circulating through a cooling coil. A layer of refractory material is placed above the coils.




*Schematic diagram of Coreless Induction Furnace*

# 14 Charge Calculations in Induction Furnaces

## Background

Induction melting furnaces are widely used in ferrous and nonferrous foundries for producing alloys with specific composition. Induction melting is a batch melting operation. At the beginning of the heat, the furnace is charged with melting stock usually composed of commercially pure primary metal and scrap from one or more sources. Upon melting the metal charge, the alloy composition is adjusted by

adding master alloys. Because of oxidation of the metal and the alloying elements, flux (limestone, dolomite with other secondary fluxes such as sodium carbonate and borax-silica mixtures) is added to produce fluid slag. Unlike other melting techniques, oxidation of charged metal is very small and usually ignored in charge calculations.

### Principles of Mass Balances

Mass Balance calculations are based on the Mass Conservation law, which simply states that

matter can neither be created nor destroyed. This law applies to the total mass as well as to species that constitute the matter. This Based on this law, for any material that enters or leaves any batch nonreactive process system, one may write the following mass balance statements:

Total Mass Balance Mass of input materials into the system = Mass of output materials at the end of the process. Species Mass Balance Mass of species (i) entering the system = Mass of species (i) leaving the system

## Principles of Mass Balances

Mass Balance calculations are based on the Mass Conservation law,. This law applies to the total mass as well as to species that constitute the matter. This Based on this law, **for any material that enters or leaves any batch non-reactive process system ‘**

## Total Mass Balance

Mass of input materials into the system = Mass of output materials at the end of the process

## Species Mass Balance

**Mass of species (i) entering the system = Mass of species (i) leaving the system where :**

**ass of species (i) = Total mass * (i) wt * %100**

## ALLOYING: CHARGE CALCULATION

$$\text{AMOUNT TO BE ADDED} = \frac{(REQUIRED\ AMOUNT - OBTAINED\ AMOUNT) * TOTAL\ WEIGHT}{PURITY\ OF\ ALLOYING\ ELEMENT}$$

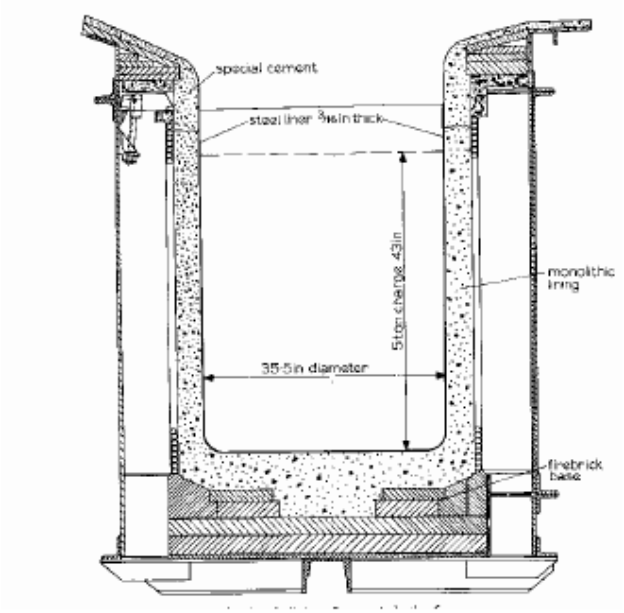
**Example**: Carbon content desired = 2.6%, Carbon content obtained= 2.1%,

Purity of carbon = 98%, total weight of cast iron = 2000kg

***Solution:***

$$\text{AMOUNT of Carbon} = \frac{(2.6-2.1)*2000}{98}$$

$$= 10.2\ kg$$

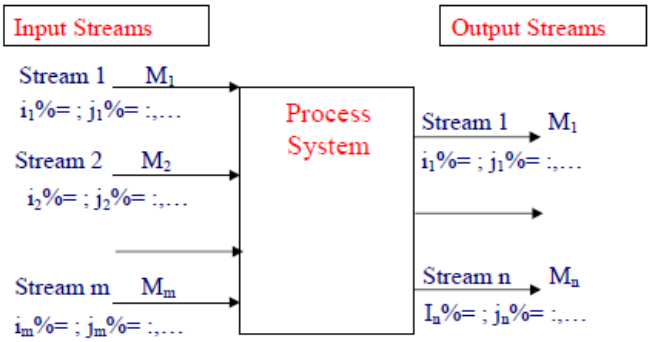



Sketch of a 5 tons induction furnace

Where:

Mass of species (i) = Total mass * (i) wt% * 100

The mass balance equations for a system with m input and n output streams shown below is




Total Mass Balance

$$\sum_{l=1}^{Inputstreams\ m} M_l - \sum_{k=1}^{ouputstreams\ n} M_k = 0$$

Species (i) Mass Balance

$$\sum_{l=1}^{Inputstreams\ m} i_l\ wt\%\ M_l - \sum_{k=1}^{ouputstreams\ n} i_k\ wt\%\ M_k = 0$$

Solution Methodology

1. Draw a box reactor showing the input and output streams of charge materials and products
2. For each input and output stream, write the amount and composition of charge or product materials
3. If the amount of material is not known, give it a name.
4. From this sketch, determine number of unknowns (say n)
5. Develops n balance equations
6. Solve the resultant set of linear equations

Problem Statement

High-strength “Shape Memory” alloys such as Incoloy 903 are made of iron alloyed with nickel,
cobalt, titanium and niobium to achieve the desired expansion effects of deformed materials upon releasing the load. These alloys are being produced by melting steel scrap and rejects of these shape memory alloys together with master alloys of alloying elements in induction furnaces. Write a computer program to calculate the amount of charging materials for the production of these alloys in a 3 MW induction furnace in a plant from the available materials given in the table below. The program should allow the operator of the furnace to enter the amount and composition of the alloy to be produced and print out the amount of the charging materials in kilograms.

| Material | Ni | Co | Ti | Nb | C | Si |
|---|---|---|---|---|---|---|
| Steel Scrap | | | | | 0.1 % | 0.05 % |
| Incoloy Scrap | 53 % | 10 % | 1 % | 4 % | 0.02 % | 0.15 % |
| Ferrosilicon | | | | | | 45.0 % |
| Cobalt steel | | 17 % | | | .03 % | .01 % |
| Nickel Master Alloy | 38 % | 3 % | | 4.7 % | | |
| Pure Niobium | | | | 100 % | | |
| Titanium Master alloy | 0.6 % | | 88.2 % | 11 % | .02 % | |

Test the code using the following data:

Weight of prodeced alloy = 2000 Kgs
Alloy composition:

| Ni | Co | Ti | Nb | C | Si |
|---|---|---|---|---|---|
| 38 % | 8 % | 1.5 % | 4.8 % | 0.03 % | 0.2 % |

Your report should include the following:

- A problem statement
- Equations to be solved
- Program flowchart
- Source code
- Results of test case

## 1.5-Gating and risering system design, solidification of metals and alloys.

### CORES

Definition:

A core is a body of material, usually sand, used to produce a cavity in or on a casting. A core must have sufficient strength to support itself and should not fracture when liquid metal is approaching to it.

### PROPERTIES OF CAST LIQUID

The properties of the castings depend on foundry skin as well as other material properties. Under similar foundry conditions, the properties will be affected by:

### Factors affecting properties of cast liquid

a) **Viscosity of the liquid metal**: It is a function of superheat that is the degree of overheating above the melting temperature and the pouring process is essentially a problem of fluid flow.

b) **Surface Tension**: It affects the wetting of inclusions and also limits the minimum radius that can be filled without pressure (typically to 0.1 mm in cavity casting).

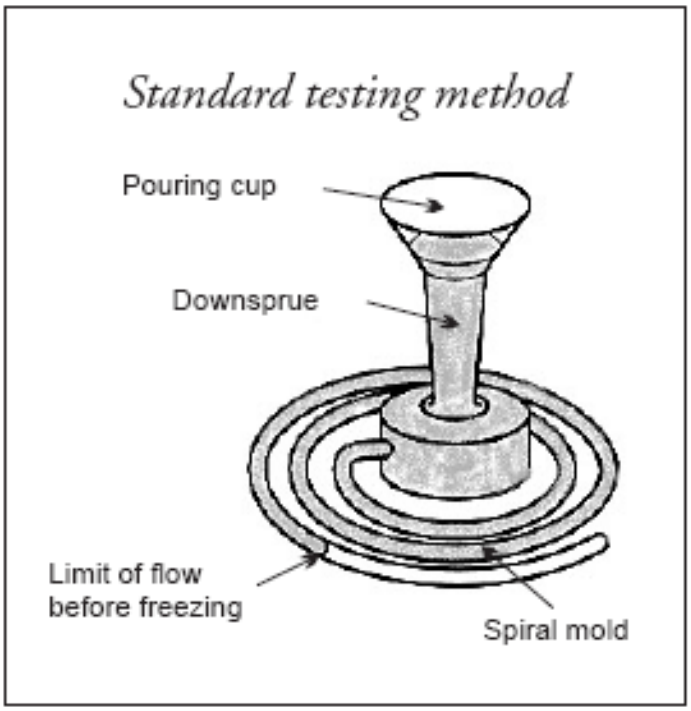
c) **Oxide Films:** Surface of the liquid metal quickly oxidizes and metals act as if it is flowing in an envelope. Aluminum produces many problems due to quick formation of strong oxides.

d) **Fluidity:** It is material plus mold property. It is the ability to fill the cavity in the mold.

Fluidity is a measure of the capability of a metal to flow into and to fill the mold before freezing.

Factors affecting fluidity:

1. Pouring temperature
2. Metal composition
3. Heat transfer to the surroundings
4. Viscosity of the liquid metal




In the foundry practice, test for fluidity is carried out for each ladle just before pouring the molten metal into the mold

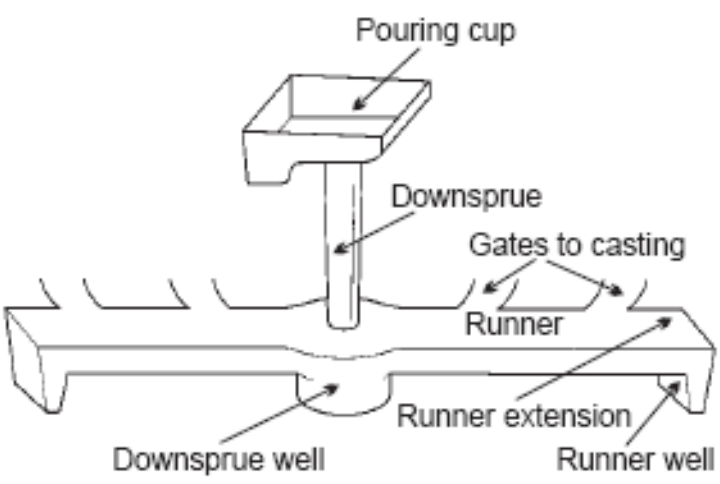
# Gating System

## Definition:

Channel through which molten metal flows into cavity from outside of mold

At top of downsprue, a *pouring cup* is often used to minimize splash and turbulence as the metal flows into downsprue

The pouring cup, downsprue, runners, etc., are known as the *mold gating system*, which serves to deliver the molten metal to all sections of the mold cavity.




Gating system in sand casting

# Riser

## Definition:

Reservoir in the mold which is a source of liquid metal to compensate for shrinkage during solidification

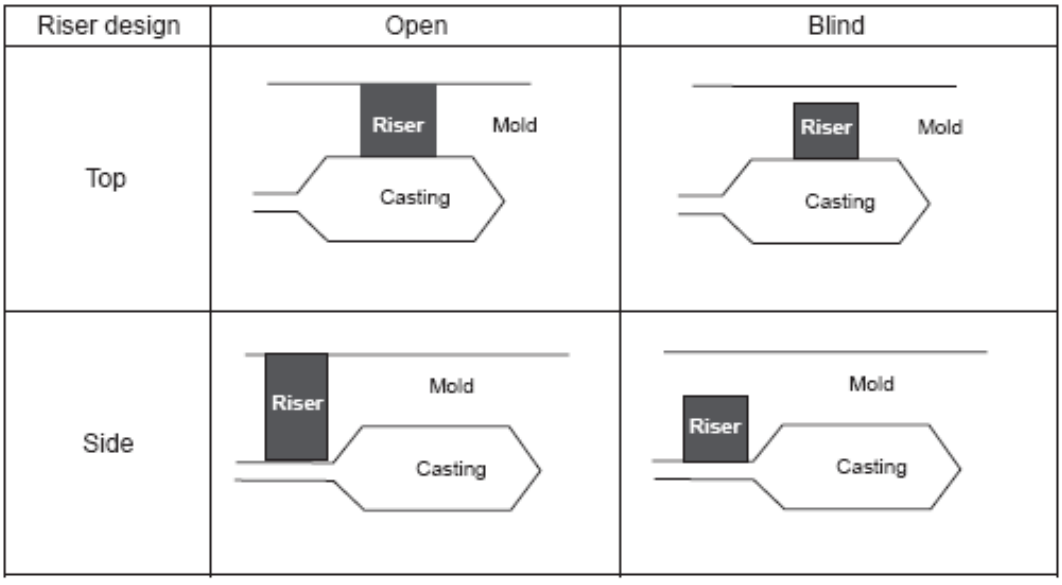
The riser must be designed to freeze after the main casting in order to satisfy its function

## RISER (FEEDER) DESIGN

Several riser designs are used in practice as shown in the figure. The riser must remain molten until after the casting solidifies.

The *Chvorinov's Rule* is used to calculate the riser's dimensions.

Possible types and positions for risers in sand casting



# Riser Design

- Risers should take longer to cool than the casting: (t)=temp.

$$t_{riser} = 1.25 t_{casting}$$

$$(V/A)^2_{riser} = 1.25\,(V/A)^2_{casting}$$

$$V = \pi D^2 H/4$$

$$A = \pi DH + 2(\pi D^2/4)$$

For a cylindrical riser: $\pi D^2 + 2\pi DH - 2A = 0$

$$D = -H \pm \sqrt{(\pi^2 H^2 - 2A\pi)}/\pi$$

## HEATING ENERGY

Heat energy required = Heat to rise $T_m$ + Heat to fusion (solid→liquid) + Heat to rise $T_{pouring}$

$$H = \rho V\left\{C_s(T_m - T_o) + H_f + C_e(T_p - T_m)\right\}$$

where

$H$ : Total heat required, Btu (J)

$\rho$ : Density, lbm/in$^2$ (g/cm$^3$)

$C_s$ : Weight specific heat for solid, Btu/lb-°F (J/g- °C)

$V$ : Volume of metal, in$^3$ (cm$^3$)

$T_m$ : Melting temperature, °F (°C)

$T_o$ : Room temperature, °F (°C)

$H_f$ : Heat of fusion, Btu/lb-°F (J/g- °C)

$C_e$ : Weight specific heat for liquid, Btu/lb-°F (J/g- °C)

$T_p$ : Pouring temperature, °F (°C)

**Heating the Metal**

1. Heat to melting point: $\rho V C_s (T_m - T_o)$
2. Heat of fusion to convert from solid to liquid: $\rho V H_f$
3. Heat molten metal to pouring temp.: $\rho V C_l (T_p - T_m)$

$\rho$ = density, V = volume, $C_s$ = specific heat,
$H_f$ = latent heat of fusion, T = temperature

- Properties vary with temperature and phase
- Melting may occur over a temperature range
- Heat loss to the ambient


# Heating the Metal

1. Heat to melting point: $\rho V C_s (T_m - T_o)$
2. Heat of fusion to convert from solid to liquid: $\rho V H_f$
3. Heat molten metal to pouring temp.: $\rho V C_l (T_p - T_m)$

$\rho$ = density, V = volume, $C_s$ = specific heat,
$H_f$ = latent heat of fusion, T = temperature

- Properties vary with temperature and phase
- Melting may occur over a temperature range
- Heat loss to the ambient

# Heating the Metal

- Heating furnaces are used to heat the metal to molten temperature sufficient for casting
- The heat required is the sum of:
  1. Heat to raise temperature to melting point
  2. Heat of fusion to convert from solid to liquid
  3. Heat to raise molten metal to desired temperature for pouring

## HEATING ENERGY

Heat energy required = Heat to rise $T_m$ + Heat to fusion (solid→liquid) + Heat to rise $T_{pouring}$

$$H = \rho V\left\{C_s(T_m - T_o) + H_f + C_e(T_p - T_m)\right\}$$

where

$H$ : Total heat required, Btu (J)
$\rho$ : Density, lbm/in$^2$ (g/cm$^3$)
$C_s$ : Weight specific heat for solid, Btu/lb-°F (J/g- °C)
$V$ : Volume of metal, in$^3$ (cm$^3$)
$T_m$ : Melting temperature, °F (°C)
$T_o$ : Room temperature, °F (°C)
$H_f$ : Heat of fusion, Btu/lb-°F (J/g- °C)
$C_e$ : Weight specific heat for liquid, Btu/lb-°F (J/g- °C)
$T_p$ : Pouring temperature, °F (°C)

# Pouring the Molten Metal

For this step to be successful, metal must flow into all regions of the mold, most importantly the main cavity, before solidifying

Factors that determine success:

- Pouring temperature
- Pouring rate
- Turbulence

**POURING ANALYSIS**

Sum of the energies from Bernoulli eqn.

$$h_1 + \frac{P_1}{\rho} + \frac{V_1^2}{2g} + F_1 = h_2 + \frac{P_2}{\rho} + \frac{V_2^2}{2g} + F_2$$

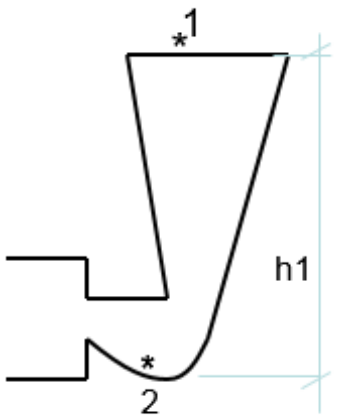
Head + Press.+ Kinetic E. + Fric.

$P_1 = P_2 = 0$ Atmospheric pressure

$F_1 = F_2 = 0$ Neglected

$h_2 = 0$ Base (Datum) point

$V_1 = 0$ Speed at the beginning of pouring




$$\Rightarrow h_1 = \frac{V_2^2}{2g} \Rightarrow V_2 = \sqrt{2gh}$$

For continuity law Volume rate of flow remains constant

$Q = V_1 A_1 = V_2 A_2$ (Volumetric flow rate)

$$MFT = \frac{V}{Q}$$

*MFT* = Mold filling time (sec)

*V* = Volume ($cm^3$)

*Q* = Volumetric flow rate ($cm^3/sec$)

**Chvorinov's rule:**

$$TST = C_m (V/A)^n$$

*TST*: Total Solidification Time (min)

$C_m$ : Mold Constant ($min/cm^2$)

*V* : Volume ($cm^3$)

*A* : Surface area ($cm^2$)

*n* : Exponent (*n* =2)

# Solidification and Cooling

## Solidification Processes

- Starting work material is either a liquid or is in a highly plastic condition, and a part is created through solidification of the material
- Solidification processes can be classified according to engineering material processed:
  - Metals
  - Ceramics, specifically glasses
  - Polymers and polymer matrix composites (PMCs)

# Solidification of Metals

## Definition:

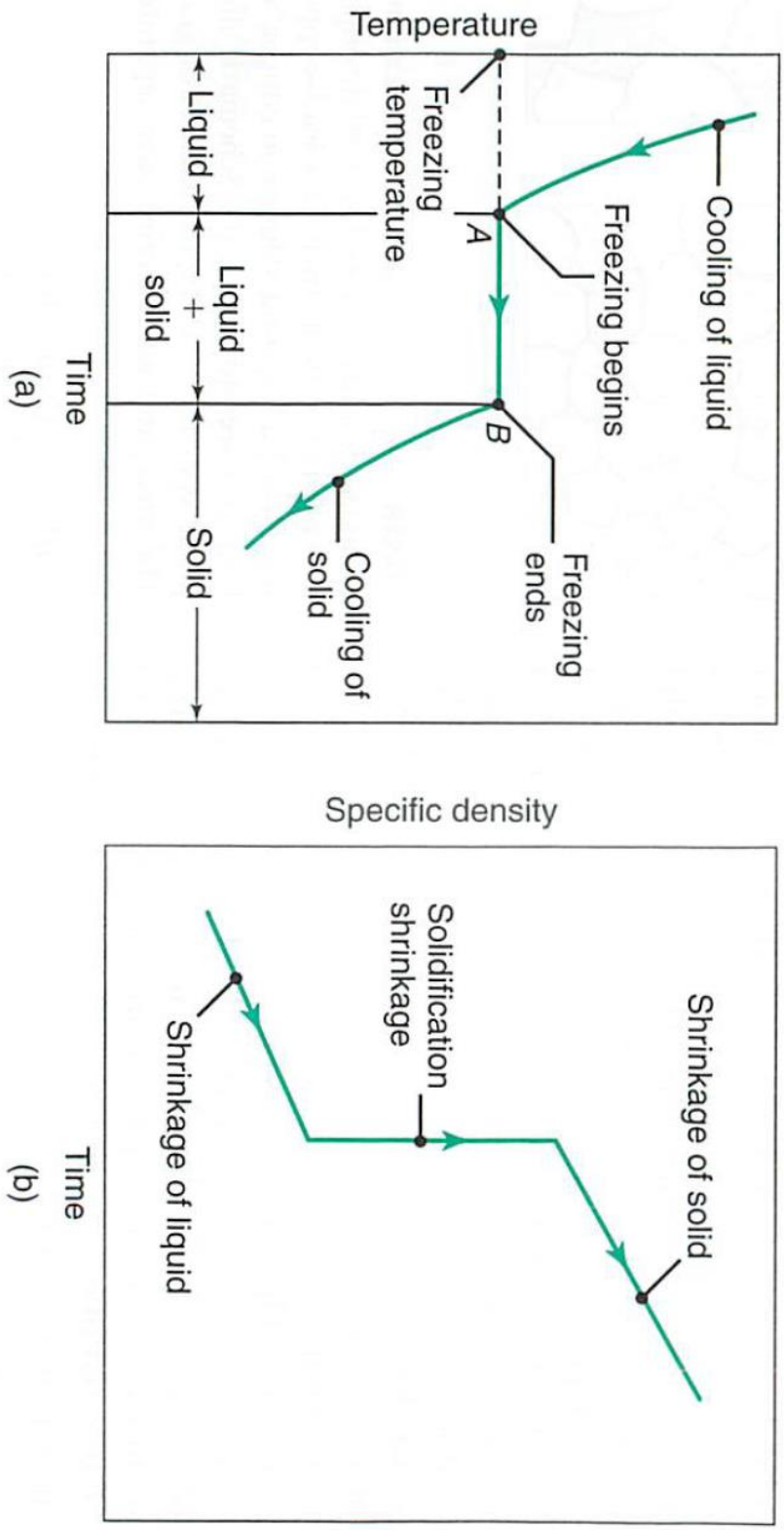
Transformation of molten metal back into solid state

Solidification differs depending on whether the metal is

- A pure element or

-An alloy

# Cooling Curves



# Solidification Time

Chvorinov's rule - The solidification time of a casting is directly proportional to the square of the volume-to-surface area ratio of the casting.

$$TST = C_m \left( \frac{V}{A} \right)^n$$

- Solidification takes time
- Total solidification time $T_{TS}$ = time required for casting to solidify after pouring
- $T_{TS}$ depends on size and shape of casting by relationship known as *Chvorinov's Rule*

  where $TST$ = total solidification time; $V$ = volume of the casting; $A$ = surface area of casting; $n$ = exponent with typical value = 2; and $C_m$ is *mold constant.*

# Cast Structure

- Nature of Cast Structure
- Chill zone - A region of small, randomly oriented grains that forms at the surface of a casting as a result of heterogeneous nucleation.
- Columnar zone - A region of elongated grains having a preferred orientation that forms as a result of competitive growth during the solidification of a casting.
- Equiaxed zone - A region of randomly oriented grains in the center of a casting produced as a result of widespread nucleation.

## Development of the ingot structure of a casting during solidification:

**(a) Nucleation begins,**

**(b) the chill zone forms,**

**(c) preferred growth produces the columnar zone3, and**

**(d) additional nucleation creates the equiaxed zone**

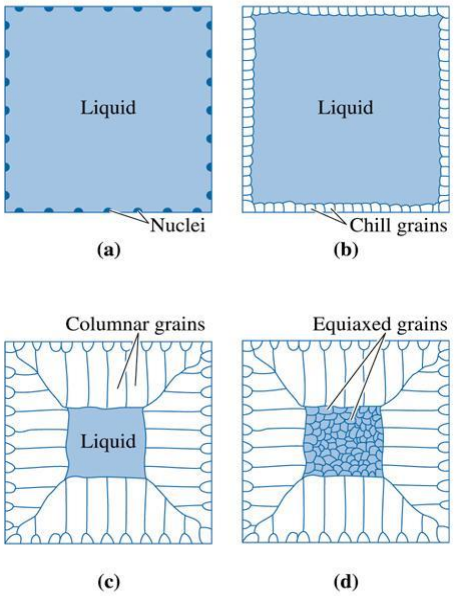


**TABLE 8-2 ■ *Shrinkage during solidification for selected materials***

| Material | Shrinkage (%) |
|---|---|
| Al | 7.0 |
| Cu | 5.1 |
| Mg | 4.0 |
| Zn | 3.7 |
| Fe | 3.4 |
| Pb | 2.7 |
| Ga | +3.2 (expansion) |
| $H_2O$ | +8.3 (expansion) |
| Low-carbon steel | 2.5–3.0 |
| High-carbon steel | 4.0 |
| White Cast Iron | 4.0–5.5 |
| Gray Cast Iron | +1.9 (expansion) |

*Note: Some data from Ref. [9]*

# Pouring Calculations 1

Minimum mold filling time, MFT

$$MFT = V/Q$$

Q: volumetric flow rate, $cm^3/s$

V: mold cavity volume, $cm^3$

Volumetric flow rate remains constant

$$Q = v_1A_1 = v_2A_2$$

(CONTINUITY EQUATION)

Q: volume rate of flow $cm^3/s$

*v*: velocity of the liquid metal

A: cross-sectional area, $cm^2$

Flow of liquid metal through gating system & mold

$$v = (2gh)^{1/2}$$

*v*: velocity of the liquid metal at base of sprue

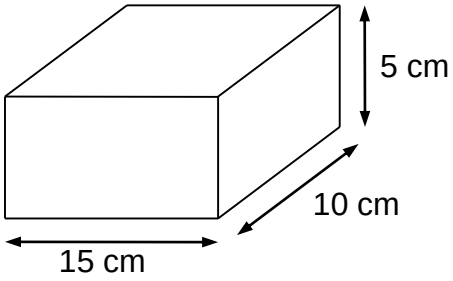
g = gravitational acceleration, 981 $cm/s^2$

h = height of sprue, cm

**EXAMPLE.1.**

A cylindrical riser with dimensions of D=h must be designed. Previous observations show TST=1.6 min. for casting. Determine dimension of riser.

*$TST_{riser}$=2 min. suggested as.*




**Solution:**

$$TST = C_m (V/A)^n$$

$$V_c = 15 \times 10 \times 5 = 750 cm^3$$

$$A_c = 2(15 \times 10 + 15 \times 5 + 10 \times 5) = 550 cm^2$$

$$1.6 = C_m (750/550)^2$$

$$\rightarrow \; C_m = 0.86 \min/cm^2$$

$$V_r = \frac{\pi}{4} D^2 h = \frac{\pi}{4} D^3$$

$$A_r = \pi D h + \frac{2\pi}{4} D^2 = \frac{6\pi}{4} D^2$$

$$\frac{V_r}{A_r} = \frac{\pi/4\, D^3}{6\pi/4\, D^2} = \frac{D}{6}$$

$$2 = 0.86(D/6)^2$$

$$D = 9.15 cm \qquad h = 9.15 cm$$

## Example 2.

- The downsprue leading into the runner of a certain mold has a length = 175 mm.
- The cross-sectional area at the base of the sprue is 400 mm2.
- The mold cavity has a volume = 0.001 m3.
- Determine: (a) the velocity of the molten metal flowing through the base of the downsprue, (b) the volumetric flow rate, and (c) the time required to fill the mold cavity.

- Solution:
- (a) Velocity $v = (2gh)^{0.5}$

$= (2 \times 9810 \times 175)^{0.5}$

$= \mathbf{1853\ mm/s}$

- (b) Volume flow rate $Q = vA$

$= 1853 \times 400$

$= \mathbf{741{,}200\ mm^3/s}$

- (c) Time to fill cavity $MFT = V/Q$

**1.6casting defects inspection and testing of castings, production management in foundries,**

**CASTING QUALITY**

There are numerous opportunities in the casting operation for different defects to appear in the cast product. Some of them are common to all casting processes:

## Casting defects

***Misruns***: Casting solidifies before completely fill the mold. Reasons are low pouring temperature, slow pouring or thin cross section of casting.

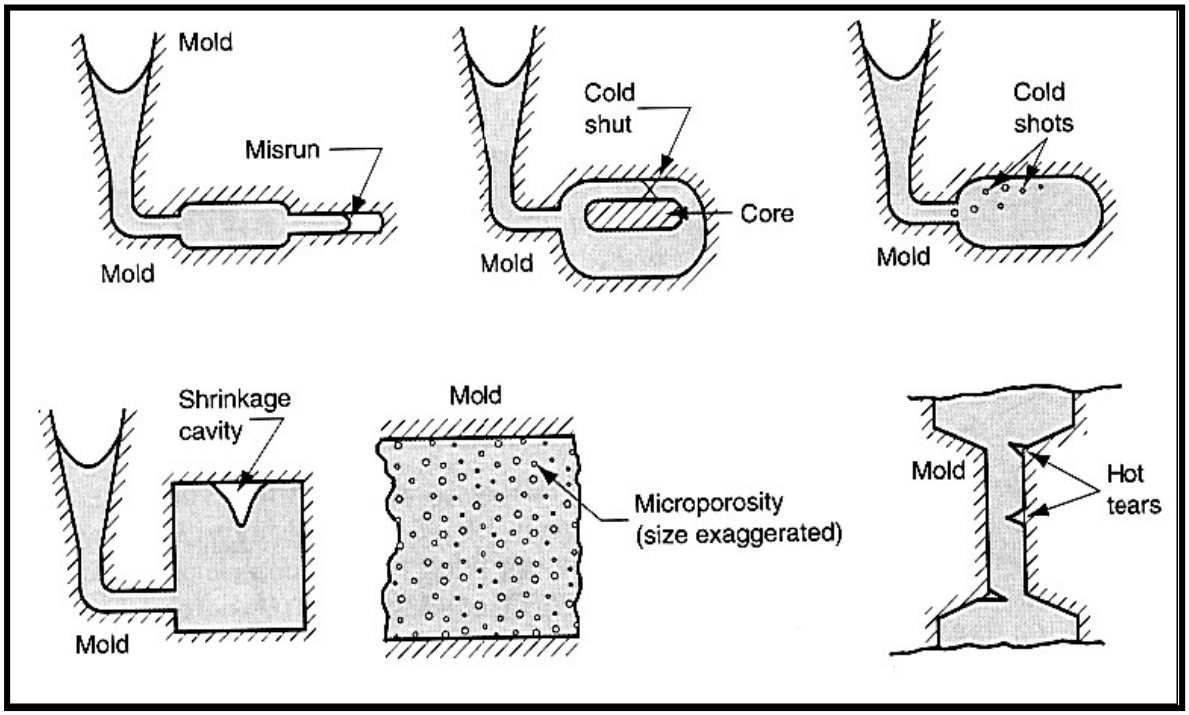
***Cold shut****:* Two portions flow together but without fusion between them. Causes are similar to those of a misrun.

***Cold shots****:* When splattering occurs during pouring, solid globules of metal are entrapped in the casting. Proper gating system designs could avoid this defect.

***Shrinkage cavity****:* Voids resulting from shrinkage. The problem can often be solved by proper riser design but may require some changes in the part design as well.

***Microporosity:*** Network of small voids distributed throughout the casting. The defect occurs more often in alloys, because of the manner they solidify.

***Hot tearing****:* Cracks caused by low mold collapsibility. They occur when the material is restrained from contraction during solidification. A proper mold design can solve the problem.




Some defects are typical only for some particular casting processes, for instance, many defects occur in sand casting as a result of interaction between the sand mold and the molten metal. Defect found primarily in sand casting are gas cavities, rough surface areas, shift of the two halves of the mold, or shift of the core, etc.

# Inspection and testing of Castings

## Types of Inspections:

1-process inspections

In process inspections are carried out before a lot of castings have been completed to detect any flaws that may have occurred in the process so that corrective measures can be taken to remove .

2-finished product inspections.

Finished product inspections are carried out after the castings have all been completed .

## The inspection methods :

1-Destructive

Destructive methods generally relate to sawing or breaking off of parts of the castings at places where voids or internal defects are suspected.

Castings may also be damaged during strength tests

2- Non-destructive categories depending upon the magnitude of damage done to the casting during inspection.

# Destructive methods

## 1-Impact Test:

In this test the casting is subjected to a blow from a hammer of known weight striking or falling on the casting. Defective castings fail under the impact of the blow but the method is very crude and unreliable.

### Impact Test:

**It can test both:**

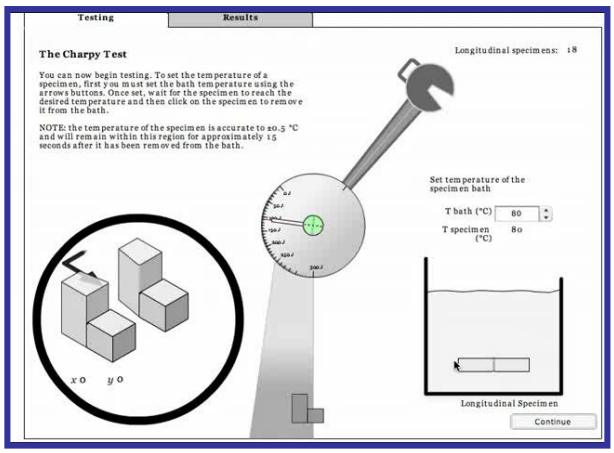
**A-Brittleness**

The brittleness of a material is the property of breaking without much permanent distortion. There are many materials, which break or fail before much deformation take place. Such materials are brittle e.g., glass, cast iron It only shows the lack of plasticity.

On stress-strain diagram, these materials don't have yield point and value of E is small.

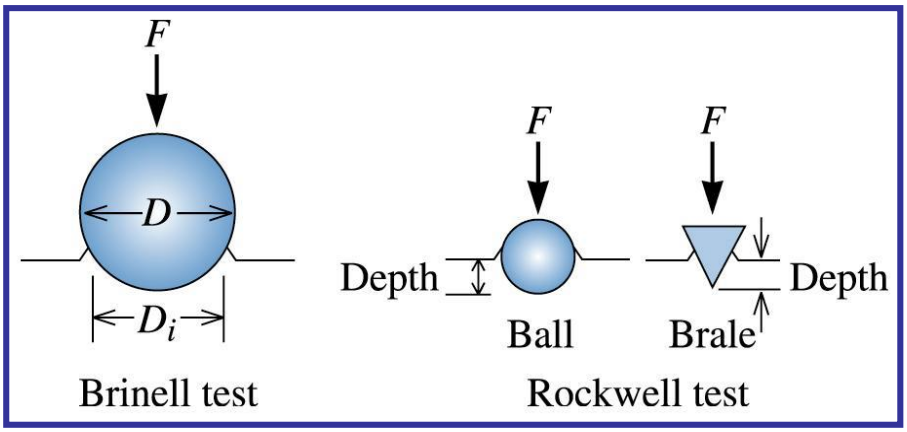
**B-Toughness**

The toughness of a material is its ability to withstand both plastic and elastic deformations. It is a highly desirable quality for structural and machine parts to withstand shock and vibration.



## Hardness testing

- Hardness may be defined as the resistance to permanent indentation.
- Three common hardness measuring tests are
  - Rockwell test
  - Brinell




**Indentors for the Brinell and Rockwell hardness tests**

## non destructive methods

### 1-Visual Inspection:

It consists of inspecting the surface of the casting with naked eye or sometimes with a magnifying glass or microscope. It can only indicate surface defects such as blow holes, fusion, swells, external cracks, and mismatch.

### 2-Dimensional Inspection:

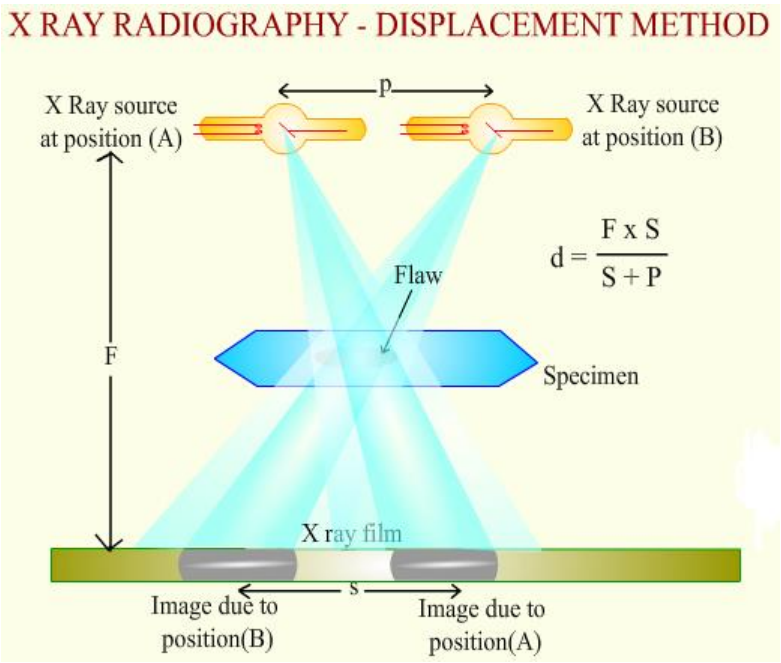
Dimensional inspection is carried out to make sure that the castings produced have the required overall dimensions including allowances for machining



## 4- X-RAY RADIOGRAPHY – Displacement Method

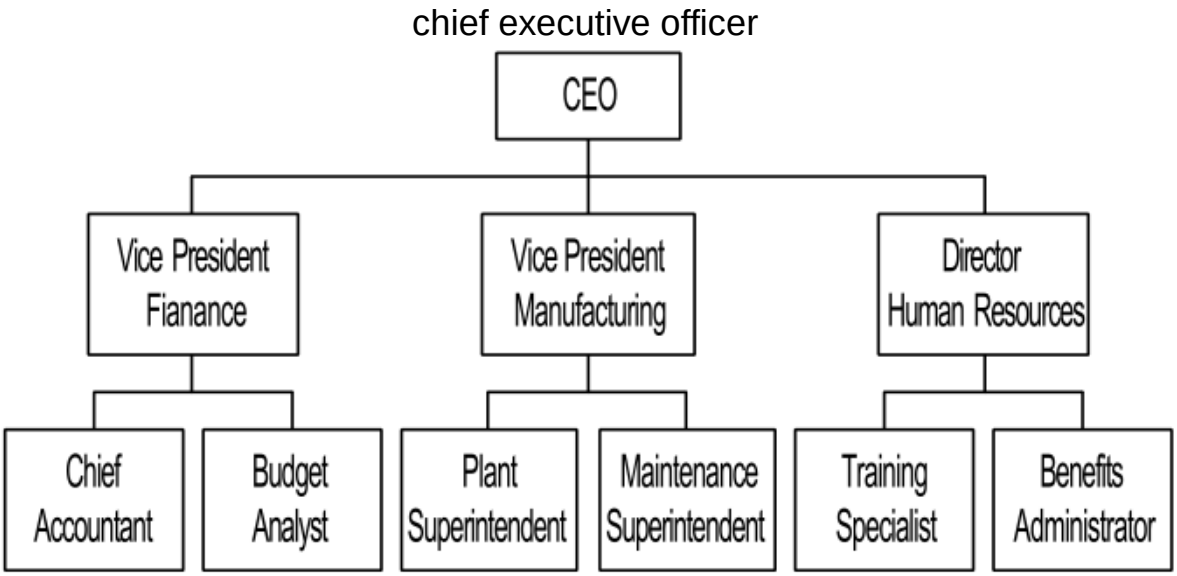
### Principle

X-rays are exposed over the specimen by keeping the x-ray source at position ‘A’ and then at ‘B’ by displacing the source through a certain distance. The images are recorded at positions ‘A’ and ‘B’. From the displacements of the x-ray tube and the images, the exact position of the defect can be determined.



# Production management in foundry

## A Sample Organization Chart



# CHAPTER.2.
# Metal Joining Processes

**MED 151 Casting operations and materials Joining:**

**2-Metal joining processes**:

2.1-riveting,

2.2.-welding , sources of thermal energy in welding,

2.3.-operations of fusion welding, specifications of welding, materials , electric resistance

welding, soldering and brazing,

2.4-heat transfer in welding process, metallurgical changes,

2,5,- welding defects, inspection and testing,

2.6.- planning of welding processes; practical training

**مكص ٢٢١ عمليات السباكة ووصل المعادن**

**أساليب وصل المعادن:** وصل المعادن بالبرشام، لحام المعادن ، مصادر الطاقة الحرارية المستخدمة فى اللحام ، لحام الصهر وعملياته ، توصيف مواد اللحام المقاومة الكهربية ، لحام المونة الطرية والصادة ،

الإنتقال الحرارى أثناء عمليات اللحام ، التغيرات الميتالورجية ، عيوب اللحامات ، طرق الكشف على الملحومات ،التخطيط لعمليات اللحام المختلفة ، تدريب عملى.

# Types of metal joining

## Fusion welding

**Gas welding**

***Oxyacetylene welding***

**Arc welding**

***Shielded metal arc welding (SMAW) Gas-tungsten arc welding (GTAW) Gas-metal arc welding (GMAW) Flux-core arc welding (FCAW) Plasma arc welding (PAW) Submerged arc welding (SAW) Electroslag welding (ESW(***

**High energy beam welding**

***Electron beam welding (EBW)***

***Laser beam welding (LBW(***

**Friction (stir) welding**

## Other joining techniques

**Riveting**

**Bolting**

**Brazing**

**Soldering**

**Adhesive joining**

## 21 Rivets

Before modern welding techniques came into common use, riveting was one of the most common methods for joiing sheet metal. Since the advent of the new welding techniques and modern machines that form seams on sheet metal, riveted seams are not so common in modern sheet metal work. However, the sheet metal worker will often use rivets on sheet metal too heavy for machine forming and where welding is not practical.

Rivets may be made from steel, copper, brass, aluminium or other materials. Standards for rivets sizes and shapes have been put forward by several agencies.

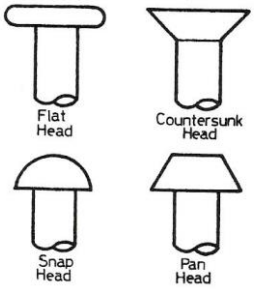
Riveting may be done by hand or by machine. When the job is performed by hand, as is usually the case in sheet metal work, it is done with a hammer and rivet set.

## Types of Rivets

Many types of rivets are used in the sheet metal shop. The most common types are the tinman's rivets, flathead, snap head (also called roundhead) and pop rivets.

The countersunk is used where a flush surface is desired, and the snaphead when exceptional strength is required.

**Types of Rivets**



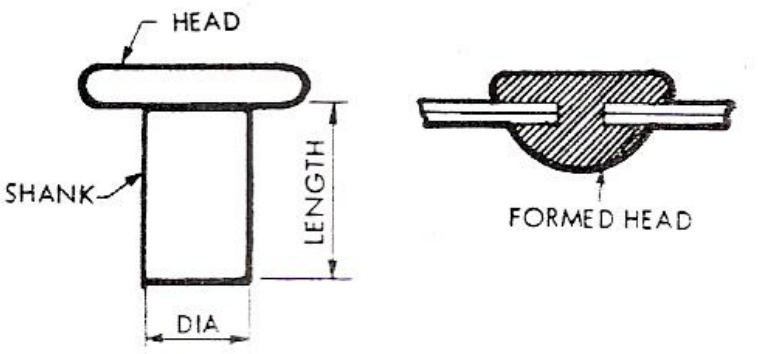
## Rivet Sizes

The size of the tinman's rivets are determined by the weight of 1,000 rivets i.e. 1 lb. rivets weigh 1 lb. per thousand, 2 lb. rivets weigh 2 lb. per thousand.

Flathead rivets vary in diameter from 3/32" to 7/16" in steps of 1/32". Other rivets vary in size with 1/8" and 3/16" snaphead rivets being the most popular in the sheet metal shop.

F1athead, snaphead and countersunk rivets may be purchased in various lengths depending upon the thickness of the metal being joined.

There are no definite rules to follow in selecting the size of a rivet. In general the length should be sufficient to protrude through the pieces being joined, from l½ times the diameter of the rivet. This allows ample material for forming the head.

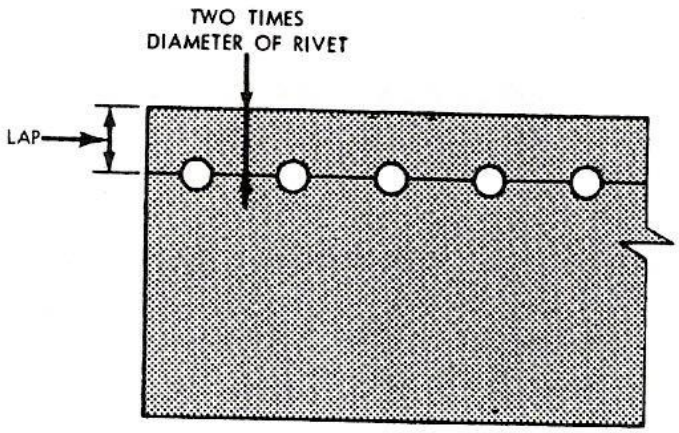



**Rivet Sizes**

## Spacing Rivet Holes

Rivet holes should be spaced according to the job specification. The space from the edge

of the metal to the centre of the rivet line should be at least twice the diameter of the rivet, thus preventing the rivet from tearing out. The minimum distance between the rivets should be three times rivet dia. approx. The maximum distance between rivets should never be such that the material is allowed to buckle between them.




**Spacing Rivet Holes**

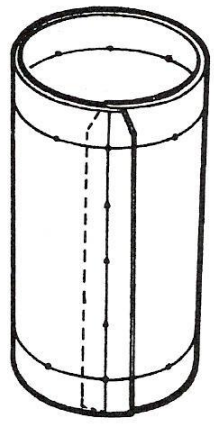
The method of spacing rivet holes for longitudinal seams in pipes is different from the manner in which the rivet holes are spaced for cross seams.

Although there are various methods of laying out holes for longitudinal seams, the metal strip procedure is generally preferred when the same job is laid out repeatedly.

This method consists of using a narrow strip of metal in which the required number of holes have being evenly spaced and pricked punched. The strip is then laid on the edge of the metal and the location of the holes marked by prick punching through the strip into the metal. One draw back to this method is, as the strip is continually used the holes become enlarged and accurate marking becomes difficult.

Care should be taken to see that the strip is not reversed when switching to the opposite side of the work, since the distances from the end holes are not alike.

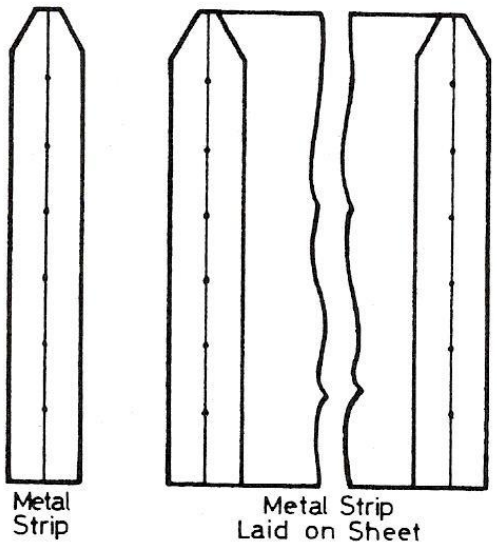
Longitudinal Seams



## Riveting Seams

When making round pipe with riveted seams, the section of the pipe should be formed with the burred edge of the hole on the outside of the pipe. After selecting the correct size rivets and rivet set and hammer, place a rivet in one end hole and place the job on a stake.

Rivet as described previously, proceed to rivet other end and centre of cylinder and then rivet alternately right and left of centre




Riveting Seams

## Single-Strap Butt Joint

To make a riveted butt joint it is necessary to use a separate piece of metal called a 'strap' to join the two component edges.

## Double-Strap Butt Joint

When two cover plates are riveted on either side of a butt joint, the joint is known as a 'double-strap butt joint'.

When single or double straps are used for riveted butt joints the rivets may be arranged as follows:

Single riveted: One row of rivets on each side of the butt;

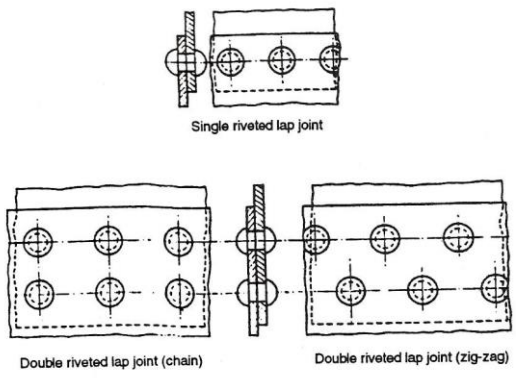
Double, triple or quadruple riveted: In which case the chain or zig-zag formation may be employed.

## Riveted Joints

Riveting is a method of making permanent joints. The process consists of drilling or punching the plates to be riveled, inserting the rivet, and then closing it by an applied compression force so that it completely fills the hole and forms a rigid joint.

A variety of riveted joints is used in construction and fabrication work:

1. single riveted lap joint;
2. double riveted lap joint;
3. single-strap butt joint;
4. double-strap butt joint




**Types of Riveted Joints**

## Single Riveted Lap Joint

This is the simplest of all riveted joints and is widely used for joining both thick and thin plates. The plates to be joined are overlapped by a short distance. Then a single row of rivets, conveniently spaced along the middle of the lap, completes the joint.

## Double Riveted Lap Joint

A lap joint with two rows of rivets is known as a double riveted lap joint. Sufficient overlap must be provided to take a double row of rivets. This type of joint may have the two rows of rivets arranged in a square formation. This is known as chain riveting. If the rivets are arranged diagonally to form triangles, this is called zig-zag riveting

Types of Rivet and Rivet-Head

The standard types of rivet heads are shown in Figure 11 and Figure 12. Also shown is the way in which thin material is joined to thick material with countersunk rivets.

Tinners and flat-head rivets are used in most general sheet metal fabrications, where the metal is very thin and little strength is required. The countersunk head is used when a flush surface is required, and the roundhead or snaphead is most widely used where the joint must be as strong as possible. Mushroom head or 'knobbled' rivets, as they are called in the steel construction industry, are used where it is important that the rivet head does not stick up above the surface too much. They are used on outer fuselage skins of aircraft

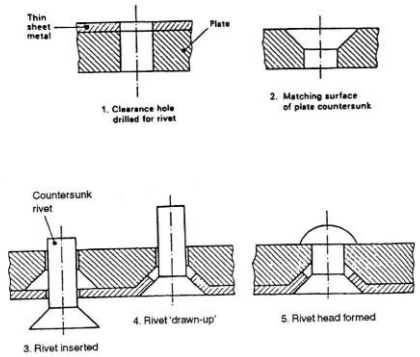
in order to decrease 'drag'. In the case of steel chutes and bunkers they are used to reduce obstruction on the inside surfaces.

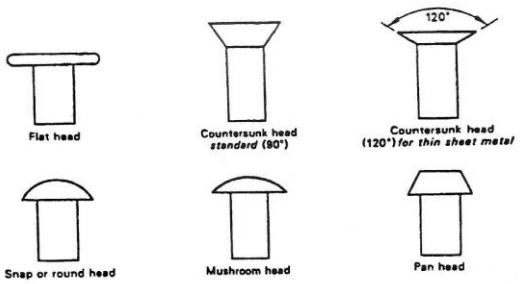
Pan head rivets are very strong and are widely used for girders and heavy constructional engineering.

'Tinners' are similar to flat-head rivets. They are made of soft iron and are usually coated with tin to prevent corrosion and to make them easier to soft solder.

Always use the correct rivet for a particular metal to be riveted. When riveting aluminium, for example, use aluminium rivets; and when riveting copper use copper rivet

**- Standard Types of Rivet Heads**



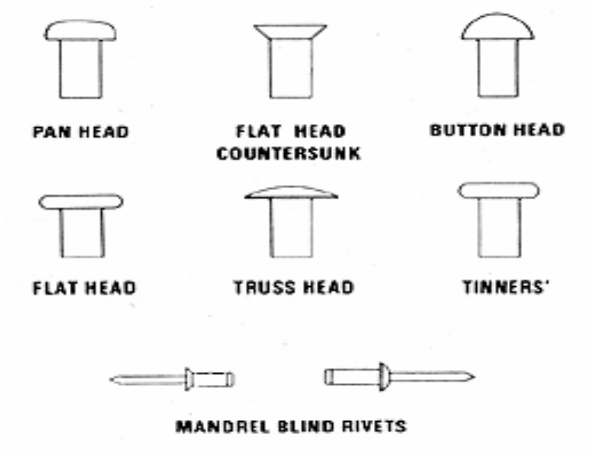



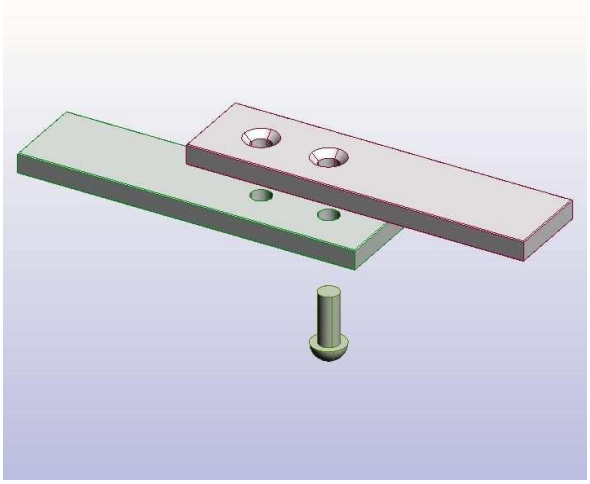

**Countersunk Riveting of Thin Material to Thick Material**

2.1.-riveting,

## Riveting Principles:

- Two or more pieces are jointed by inserting a headed shank through a hole and closed by forming a head on the projecting part of the shank.
-The holes are generally 1/16 in(0.025 mm) greater than the nominal diameter of undriven rivet.



## BASIS FOR DESIGN RECOMMENDATIONS

### Behavior of individual fasteners

The behavior and strength of a single rivet subjected to either tension, shear, or combined tension and shear.

### 1 .Rivets Subjected to Tension

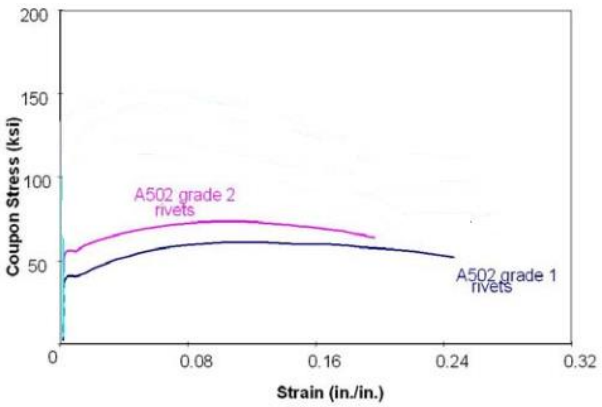
-The tensile strength of a driven rivet depends on the mechanical properties of the rivet material before driving and other factors related to the installation process

-Most tension tests of driven rivets showed a tendency to decrease in strength as the grip length was increased.

The tensile capacity $B_u$ of a rivet is equal to the product of the rivet cross-sectional area $A_b$ and its tensile strength $\sigma_u$. The cross section is generally taken as the undriven cross section area of the rivet.[2.11] Hence,

$$B_u = A_b \sigma_u$$

Depending on the type of rivet material, driving method, grip length, and such, $\sigma_u$ may exceed the undriven rivet strength by 10 to 20%.

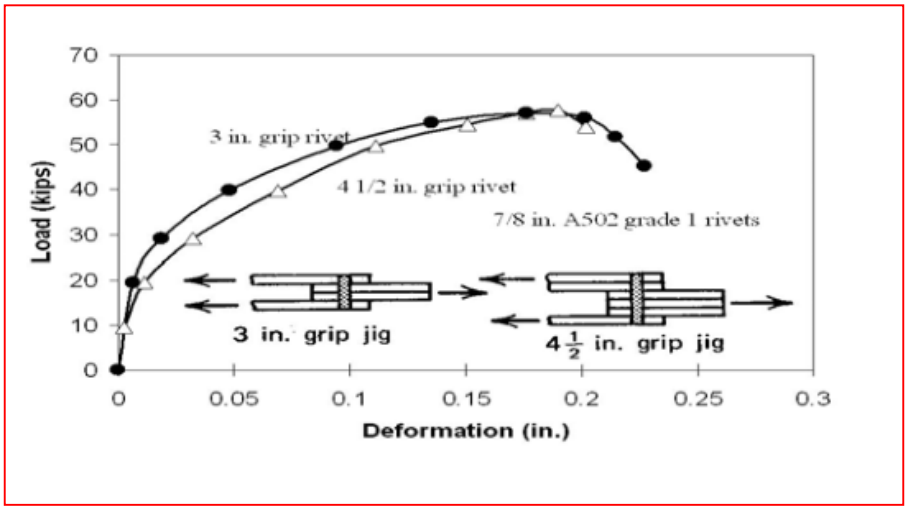



Coupon stress versus strain relationships for different fastener materials.

## 2 Rivets Subjected to Shear

-An average shear strength to tensile strength ratio of about 0.67 to 0.83

-A slight decrease in strength for rivets in single shear as compared with the double shear loading condition




Shear versus deformation curves

The ratio of the shear strength $\tau_u$ to the tensile strength $\sigma_u$ of a rivet was found to be

$$\tau_u = 0.75\sigma_u$$

The shear resistance of a rivet is directly proportional to the available shear area and the number of critical shear planes. If a total of $m$ critical shear planes pass through the rivet, the maximum shear resistance $S_u$ of the rivet is equal to

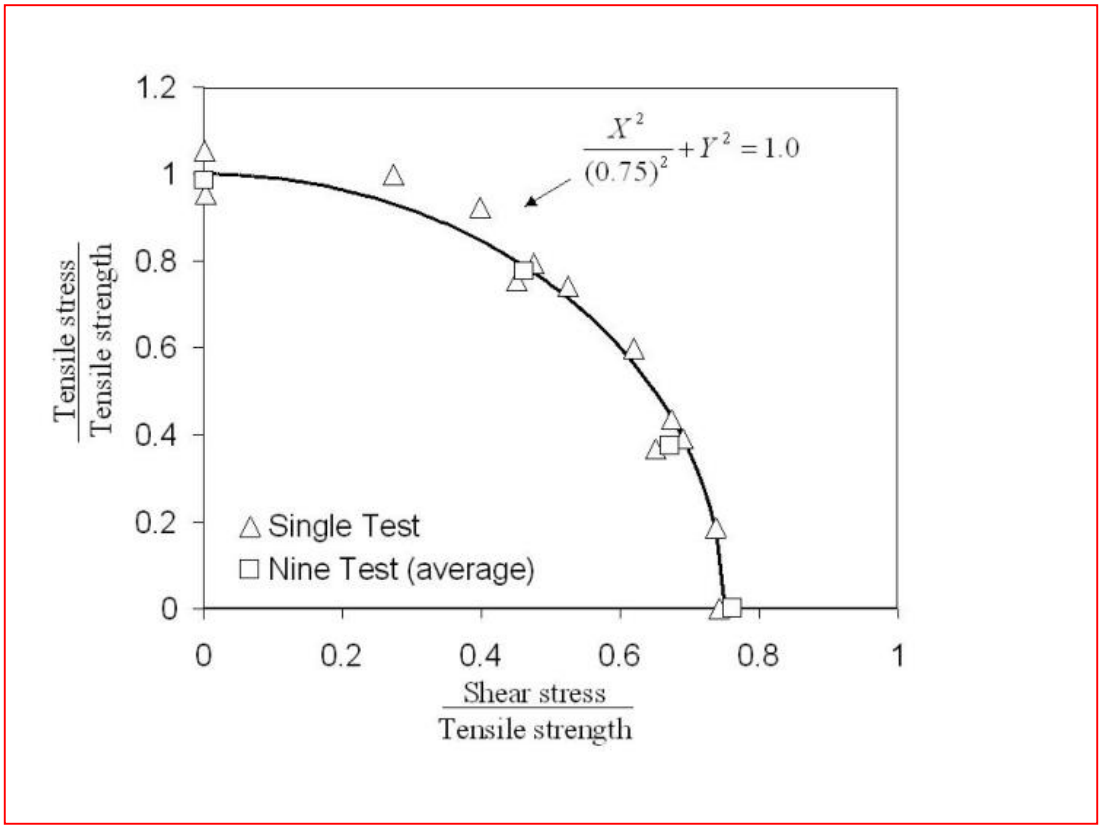
$$S_u = 0.75mA_b\sigma_u$$

where $A_b$ is the cross-section area of undriven rivet.

### 3 Rivets Subjected to Combined Tension and Shear

The elliptical interaction curve given adequately defines the strength of rivets under combined tension and shear relates the shear stress component to the critical tensile stress component.

This defined the strength of rivets subjected to a combined tension and shear loading as where x is the ratio of the shear stress on the shear plane to the tensile strength of the rivet ( $\tau / \sigma_u$ ) and y represents the ratio of the tensile stress to the tensile strength ($\sigma / \sigma_u$ ).



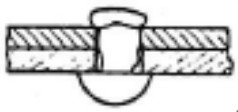
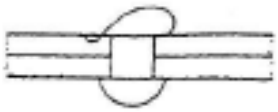
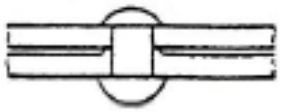
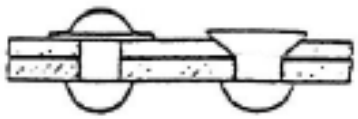
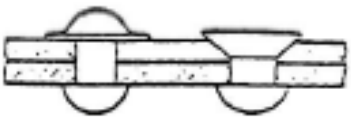

Interaction curve for rivets under combined tension and shear.

## Defects in Riveted Joint

When making joints with rivets, the following points should be followed to prevent many common defects:

1. use the correct allowance for edge clearance and pitch when marking out;
2. all drilled or punched holes should be made to the correct clearance size to suit the rivet diameter, or as specified on the drawing;
3. remove any 'burrs' from around the edges of all holes before finally assembling the parts to be joined;
4. ensure that holes are correctly aligned and matched before inserting the rivet;
5. use the proper type of rivet as specified on the drawing;
6. use rivets of the correct length;
7. when inserting rivets, do not attempt to force or drive them into the hole;
8. always use the correct tools for the job.

Some of the common forms of defects associated with riveted connections are shown in Table.

| Cause of Riveting Defect | Resultant Effect |
|---|---|
| Sheets not closed together – rivet not drawn up sufficiently. | Weak joint. Rivet shank swells between the plates.<br>Not enough shank protruding to form correctly shaped head.  |
| Rivet holes not matched. | Weak misshapen head.<br>Rivet deformed and does not completely fill the hole.  |
| Insufficient hole clearance. | Rivet not completely 'drawn through'. Not enough shank protruding to form head. <br>Original head of rivet 'stands proud', the formed head is weak and misshapen. |
| Hole too large for rivet. | Hole not filled.<br>Rivet tends to bend and deform. Head weak and poorly shaped.  |
| Rivet set or dolly not struck square. | Badly shaped head off-centre.<br>Sheet damaged by riveting tool.  |
| Drilling burrs not removed. | Not enough shank protruding to form the correct size head.<br>Plates or sheets not closed together. Unequal heads.  |
| Rivet too short. | Not enough shank protruding to produce correct shaped head. <br>Plate surface damaged. Countersinking not completely filled. |
| Rivet too long. | Too much shank protruding to form required head. <br>'Flash' formed around head (Jockey cap). Countersinking over-filled. |

**Common Defects in Riveting**

## The Strength of Riveted Joints

A riveted joint is only as strong as its weakest part, and it must be borne in mind that it may fail in one of four ways:

i. shearing of the rivet;

ii. crushing of the metal;

iii. splitting of the metal;

iv. rupture or tearing of the plate.

These four undesirable effects are shown in Figure 13 to Figure 16.

Note: For design purposes the rivet should only be loaded in shear and its tensile strength

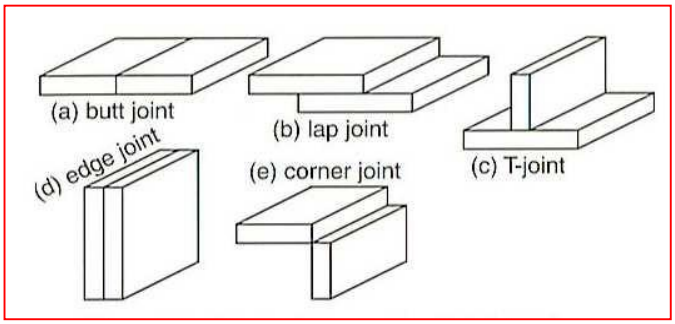
in assuming to be zero.

Selecting the Correct Size of Rivet

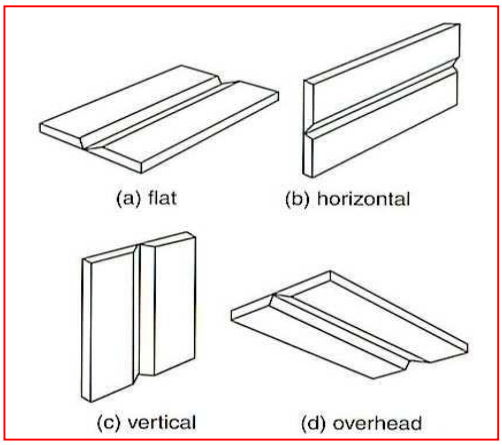
To obtain the full strength of a riveted joint, a rivet of the correct diameter and length must be used. For example, if a rivet of a larger diameter were inserted in a thin sheet, the pressure required to drive the rivet would cause bulging of the thin metal around the rivet head. The diameters of rivets for metal plate work may be determined by use of the following formula:

$$D=1.25\sqrt{T}$$ (Urwin's formula);

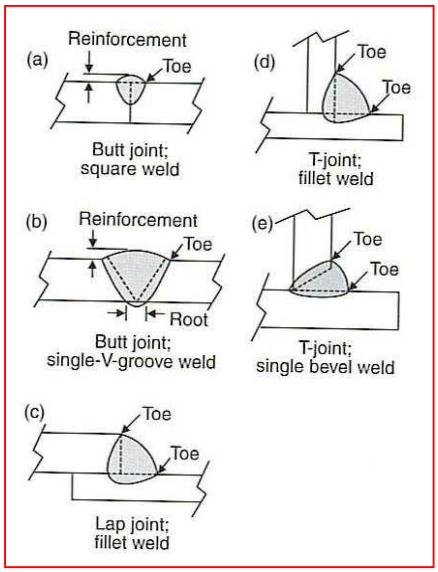
# 2.2.-welding , sources of thermal energy in welding,
# Fusion welding
# Types of joints and welding positions




***Five basic types of weld joint designs.***




**Four welding positions**

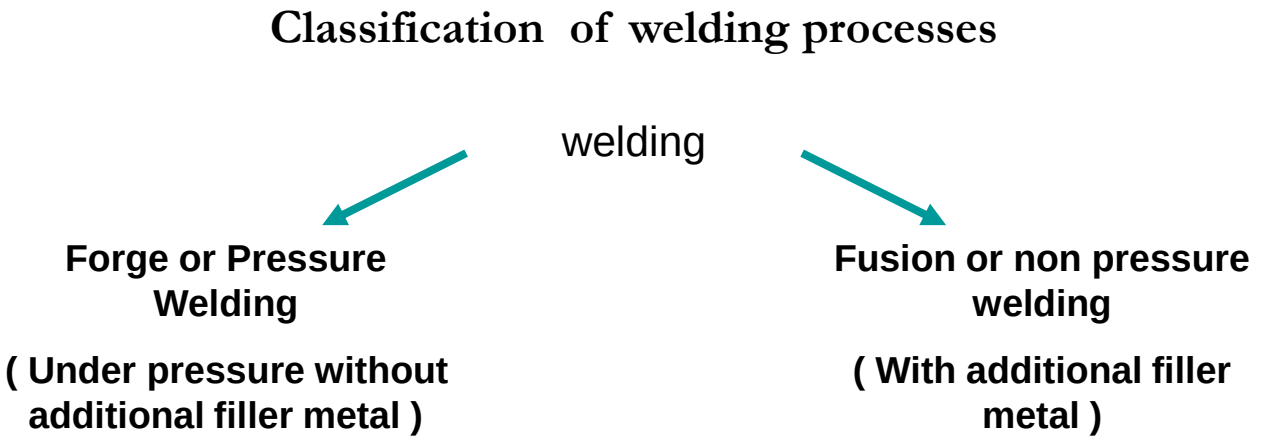



***Typical weld joint variations.***

- The surface of the weld is called *the face*.
- The two junctions between the face and the workpiece surface are called *the toes*.
- The portion of the weld beyond the workpiece surface is called *the reinforcement*.

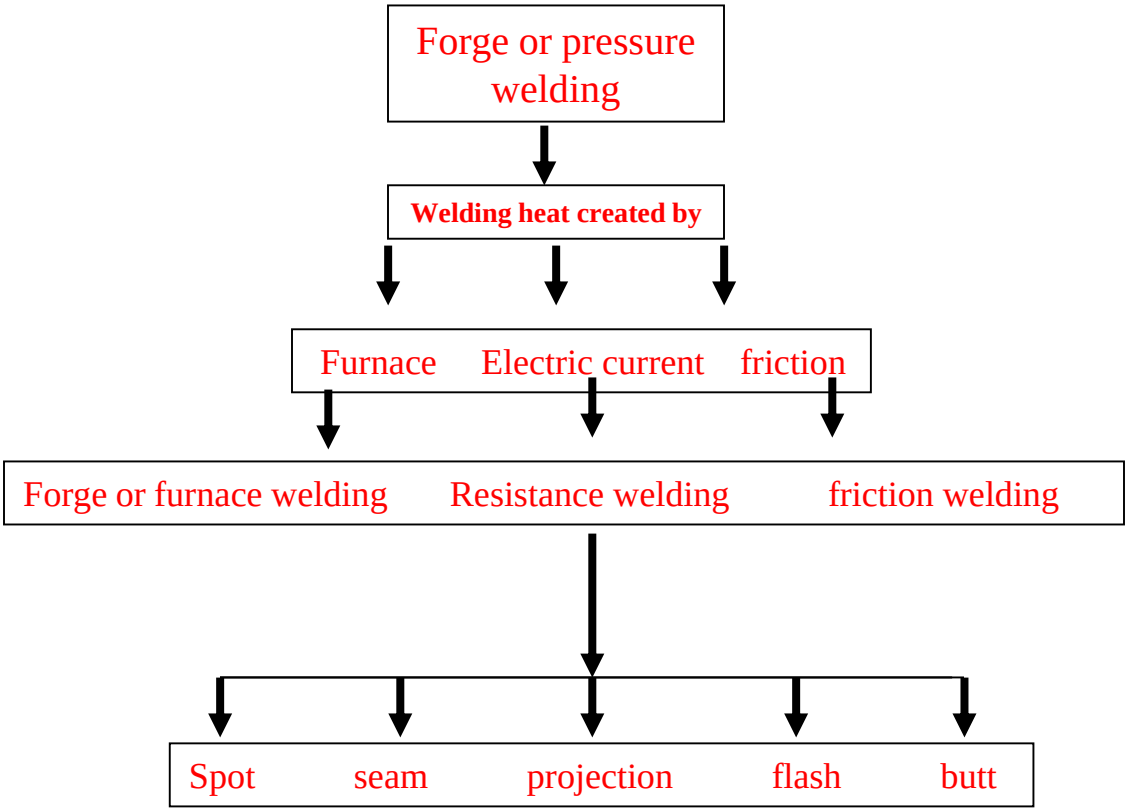
# WELDING DEFINITION:

Welding is a process of metal joining by heat and sometimes pressure

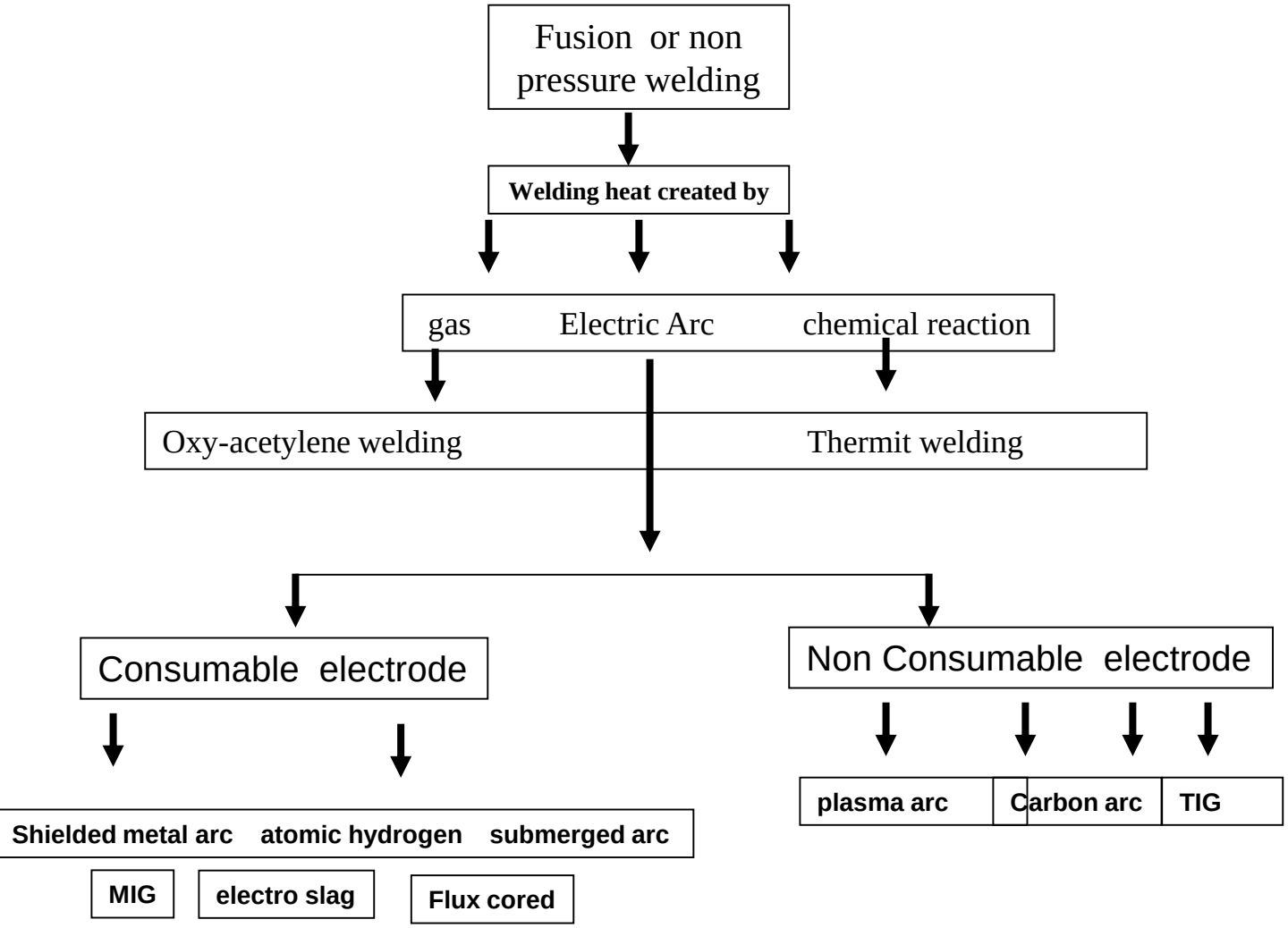



**Forge or Pressure welding :-** The work piece are heated to plastic state & then work pieces are joined together by applying pressure on them. In this case no filler material is used.

**Fusion or non- pressure welding :-** Here edge of work piece to be joined & filler material both are heated to a temp. above the melting point of the metal & then allow to solidify


Forge or pressure welding
Welding heat created by
Furnace
Electric current
friction
Forge or furnace welding
Resistance welding
friction welding
Spot
seam
projection
flash
butt

# 2.3. operations of fusion welding



## Other processes of welding are :

**Solid State welding :** The solid state welding depends upon the theory

that if two perfectly clean metallic surfaces are placed in an intimate contact ,

the cohesive force between atoms of the two surfaces is sufficient to hold them together.

The various solid state welding process are:

- Friction Welding
- Ultrasonic Welding
- Diffusion Welding
- Explosive Welding

**Modern Welding Processes:**

- Electron Beam Welding
- Laser Beam Welding

Terms used in welding :

Weld Pool :- Nature of deposition of the filler material in fusion zone is know as weld pool ( Puddle )

Slag :- molten or fused flux is called as slag

Flux :- mixture of Borax and sodium carbonate is coated to electrode for shielding purpose.

Electric arc ：An electric arc is a discharge of electric current across a gap in a circuit . To initiate the arc in Arc Welding electrode is brought into contact with work and then quickly separated from it by a short distance

Electric arc between the electrode and work piece closes the electric circuit. The arc temperature may reach ١٠٠٠٠°F (٥٥٠٠°C), which is sufficient for fusion the work piece edges and joining them.

Arc Welding

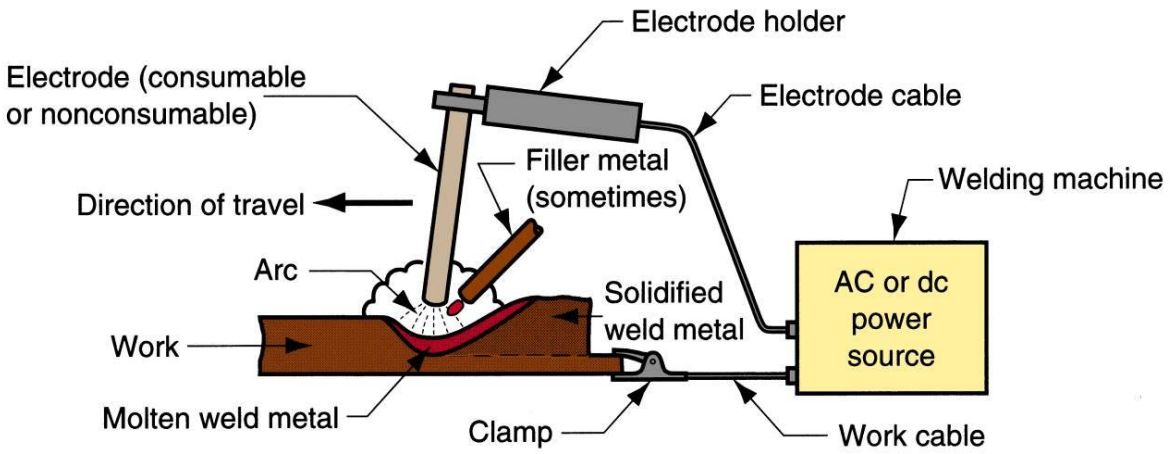



Figure : Basic configuration of an arc welding process.

A pool of molten metal is formed near electrode tip, and as electrode is moved along joint, molten weld pool solidifies in its wake

# Two Basic Types of AW Electrodes

- **Consumable – consumed during welding process**
  - **Source of filler metal in arc welding**
- **Nonconsumable – not consumed during welding process**
  - **Filler metal must be added separately**

Consumable Electrodes :

Forms of consumable electrodes :

**Welding rods are 9 to 18 inches and 3/8 inch or less in diameter and**
**must be changed frequently**

**Weld wire can be continuously fed from spools with long lengths of wire, avoiding frequent interruptions**

**In both rod and wire forms, electrode is consumed by arc and added to weld joint as filler metal**

Non consumable Electrodes :

Made of tungsten which resists melting
Gradually depleted during welding (vaporization is principal mechanism)
Any filler metal must be supplied by a separate wire fed into weld pool

# Terms used in welding :

Shielding is one of the unique requirements of arc welding.

Welds will have better chemical and physical properties if the air can be kept away from the weld puddle. Such gases as oxygen, hydrogen, and nitrogen, along with water vapor (moisture) all tend to reduce the quality of the weld. Dirt, dust, and metal oxides (contaminants) also reduce the weld quality.

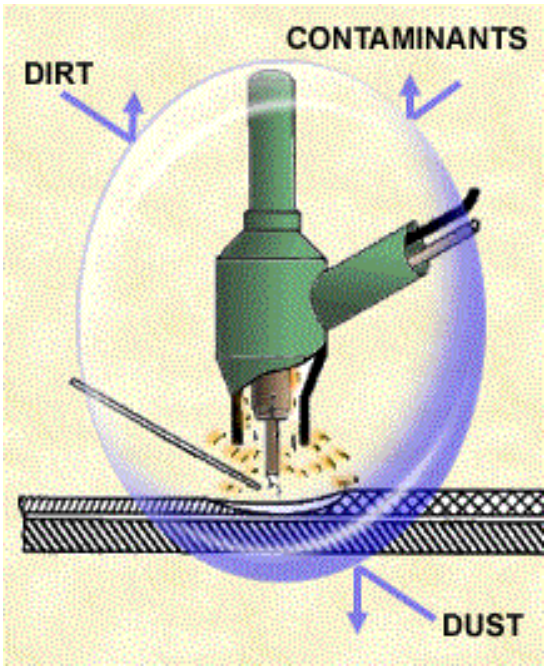
Shielding of the arc preserves the integrity of the

weld joint.

Shielding is provided either by :

•Decomposition of the electrode covering, known as flux – Flux coated electrode

•A gas (or gas mixture) which may be inert.




Shielding

- e.g., argon, helium, CO2

Terms used in welding :

## Functions of flux

Protects the weld from oxidizing with atmosphere by producing a shield of gas around the arc and weld pool

Provide the slag which floats at the top of molten metal so as to protect the weld from rapid cooling and to protect weld from atmosphere. The slag is then brushed off after weld gets cooled.

## Various Flux Application Methods

Pouring granular flux onto welding operation

Stick electrode coated with flux material that melts during welding to cover operation ( flux coated electrodes )

Tubular electrodes in which flux is contained in the core and released as electrode is consumed

## 2.4-heat transfer in welding process, metallurgical changes,

### Power Source in Arc Welding

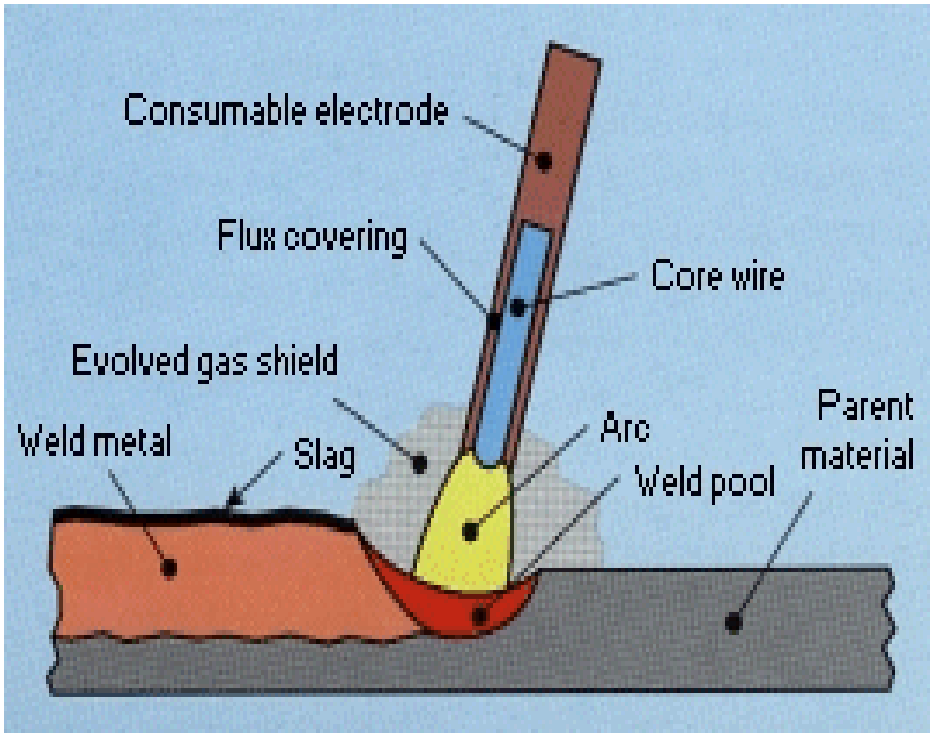
Direct current (DC) vs. Alternating current (AC)

- AC machines less expensive to purchase and operate, but generally restricted to ferrous metals
- DC equipment can be used on all metals and is generally noted for better arc control

### Polarity in Arc Welding

- Polarity is defined as the type of potential given to the workpiece or electrode.
  - In case of a A.C. power source , positive and negative terminal are not fixed . i.e. the terminal which is positive during one half cycle , becomes negative in another half.
  - In case of a D.C. power source , positive and negative terminals are fixed. So polarity principle mainly applicable in case of D.C. power source.
  - Polarity is of two types :
  - 1. Straight Polarity : Electrode is having negative terminal while workpiece is connected to the positive terminal of D.C. power supply
  - 2. Reverse Polarity : Electrode is connected to positive terminal , whereas work piece is connected to the negative terminal of the D.C. power source.
  - About 2/3 of the total heat produced during welding is generated at positive terminal , while the rest of the total heat is generated at negative terminal.
  - So if our job is thick , means we want more heat on work piece, so we connect work piece to the positive terminal , hence we adopt straight polarity. Similarly , if the job is thin, means , we want less heat on job , so we connect work piece to the negative terminal , hence we adopt reverse polarity
  - If our electrode is non-consumable, means we want less heat on electrode so we connect electrode to the negative terminal .i.e. use of straight polarity.

# Shielded Metal Arc Welding




- Consumable electrode coated with chemicals that provide flux and shielding
- The filler metal (here the consumable electrode) is usually very close in composition to the metal being welded.

# Shielded Metal Arc Welding

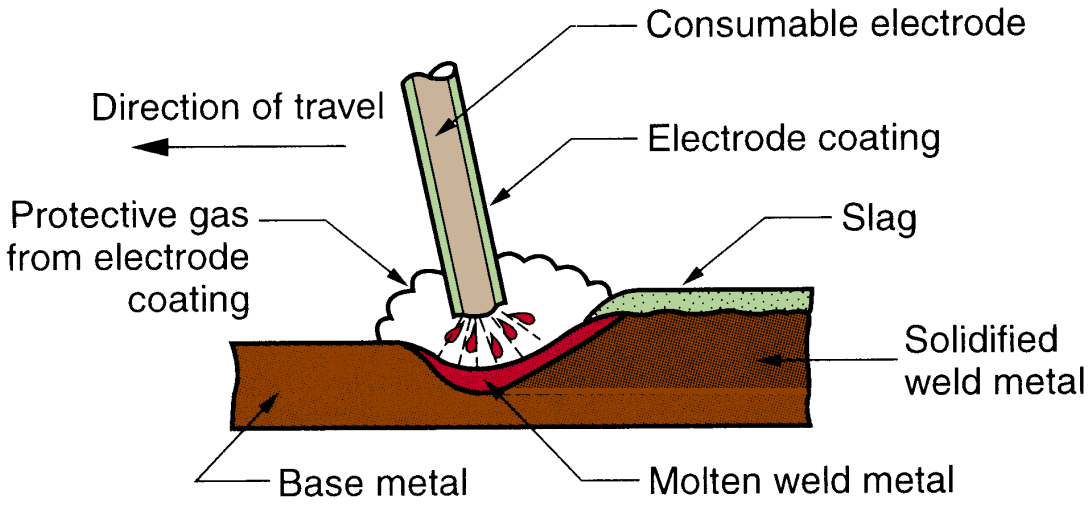



Figure : Shielded metal arc welding (SMAW).

- Used for steels, stainless steels, cast irons, and certain nonferrous alloys
- Not used or rarely used for aluminum and its alloys, copper alloys, and titanium

# INERT GAS WELDING

In conventional arc welding ( metal arc welding ), the fluxes are used to shield atmosphere around the molten metal and arc.

In inert gas ( Arc ) welding, separate inert gas such as argon, helium, carbon dioxide are used for surrounding the electric arc and molten metal from the metal .

Thus inert gas serves as a shielding gas which displaces the oxygen and nitrogen from the air surrounding the arc and molten metal. Thus it provides protective shield around arc and molten metal. Thus it eliminates formation of metal oxides and nitrides which lower weld metal ductility and toughness.

Inert gas welding is of following types

1. Gas tungsten arc welding (GTAW) or Tungsten inert gas ( TIG )
2. Gas metal arc welding ( GMAW ) or Metal inert gas ( MIG )

## Similarities between TIG and MIG

1. No fluxes are used to shield the atmosphere around molten metal
2. Instead of that , both are using separate inert gas ( Argon, helium, Carbon dioxide ) for shielding purpose

## Differences between TIG and MIG

### TIG

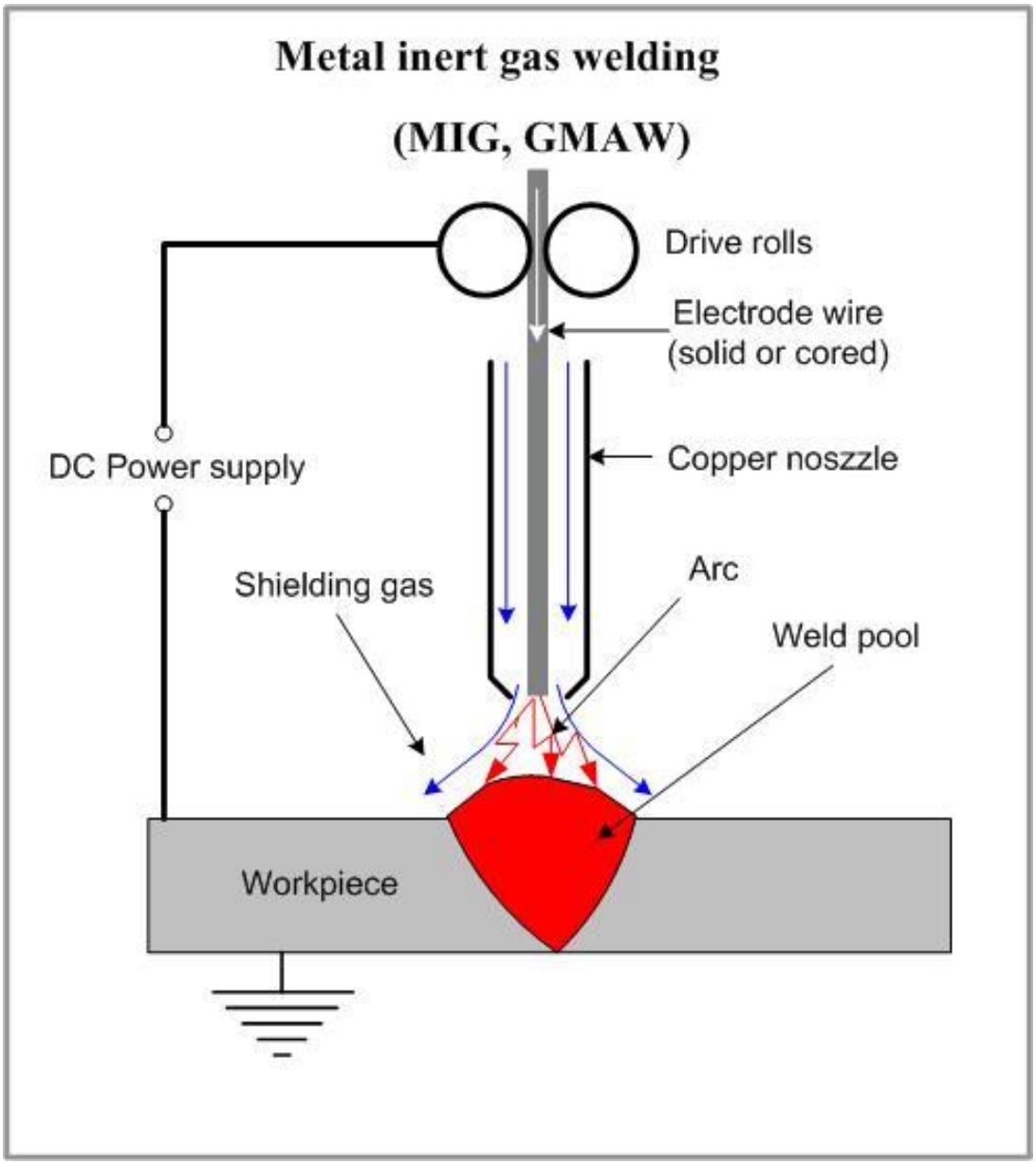
1. Arc is stuck between a non consumable tungsten electrode and work piece to be welded.

2. Filler material is added from a hand held filler rod or wire of the same composition as the work piece

### MIG

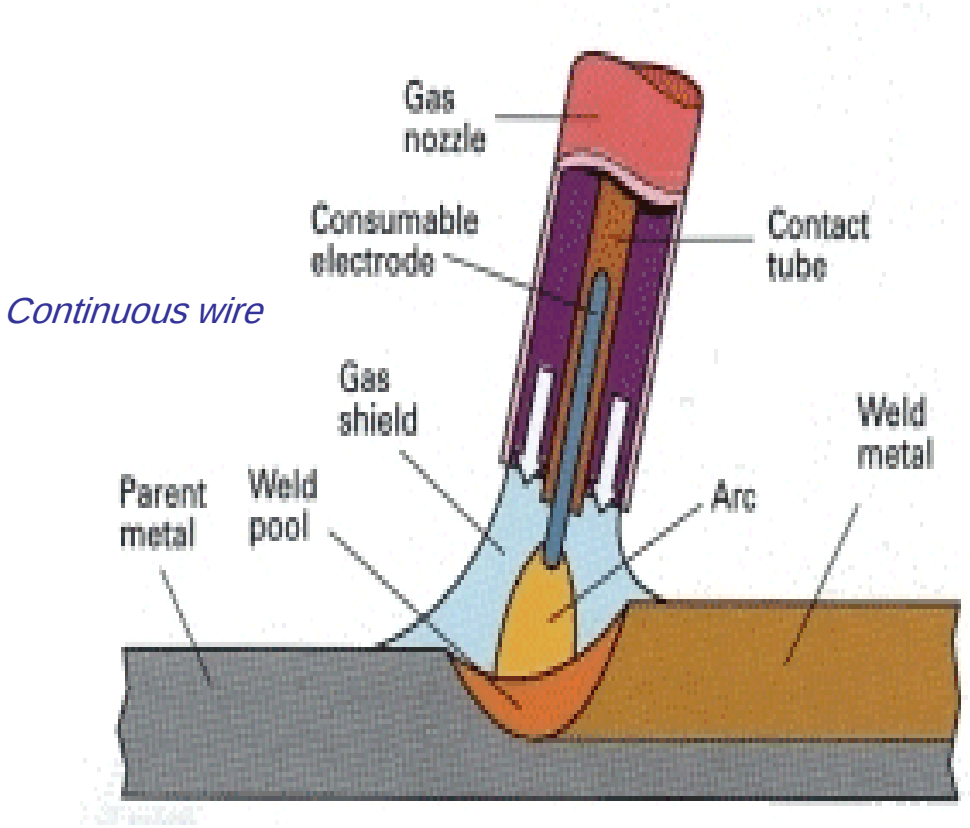
1. Arc is struck between consumable electrode( which serves as a filler material ) and work piece to be welded.

2. The electrode / filler is a wire fed from a reel continuously to the welding zone. Consumable electrode is having the same composition as work piece material




Uses a consumable electrode (filler wire made of the base metal)
Inert gas is typically Argon

# Gas Metal Arc Welding (MIG)




Uses a consumable electrode (filler wire made of the base metal)
Inert gas is typically Argon

# Gas Metal Arc Welding ( TIG )

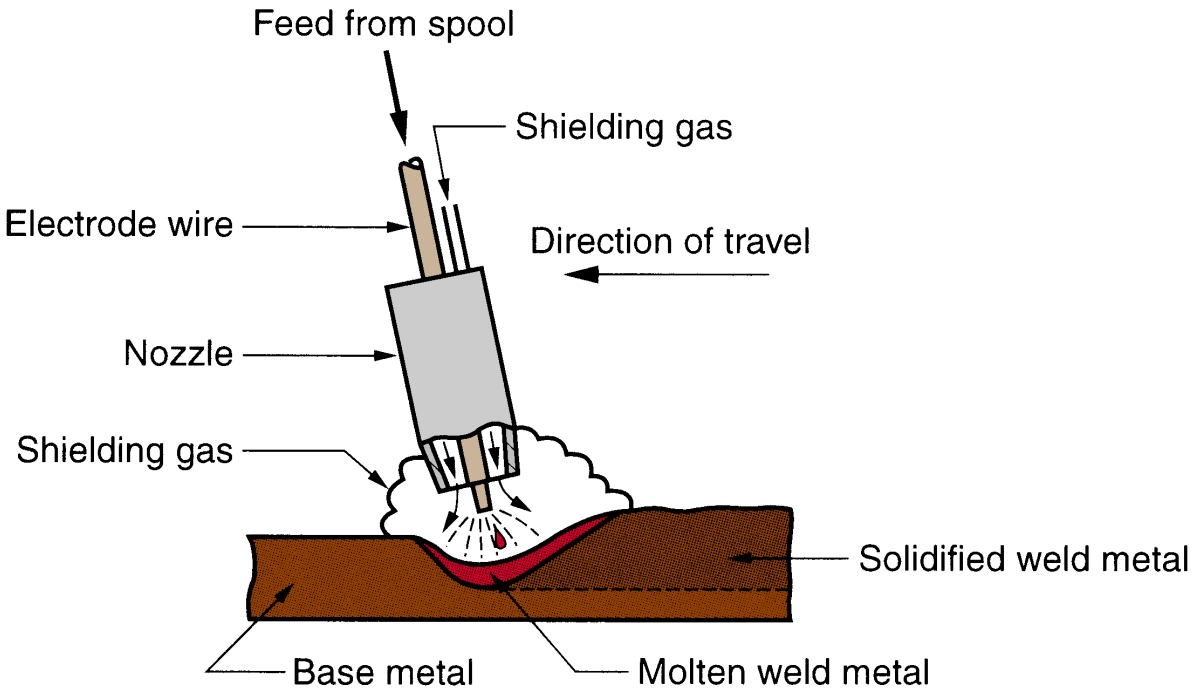
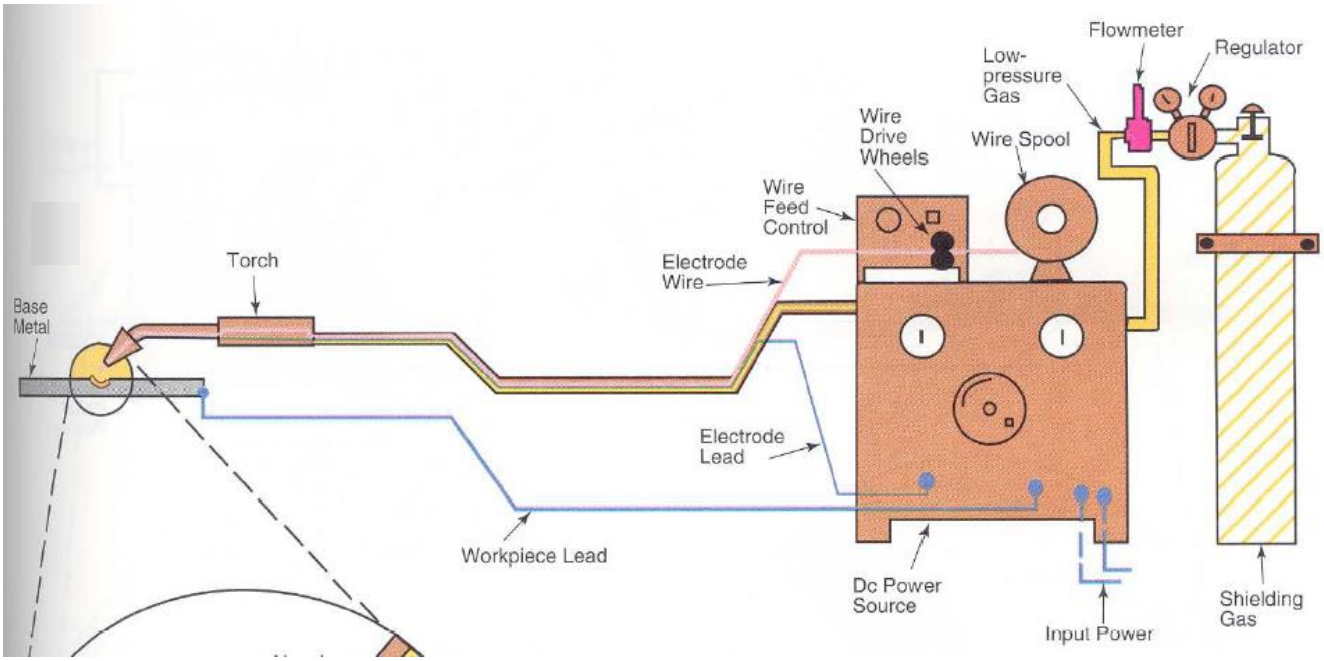



Figure : Gas metal arc welding (GMAW).

# GMAW ( MIG ) :- Main equipment

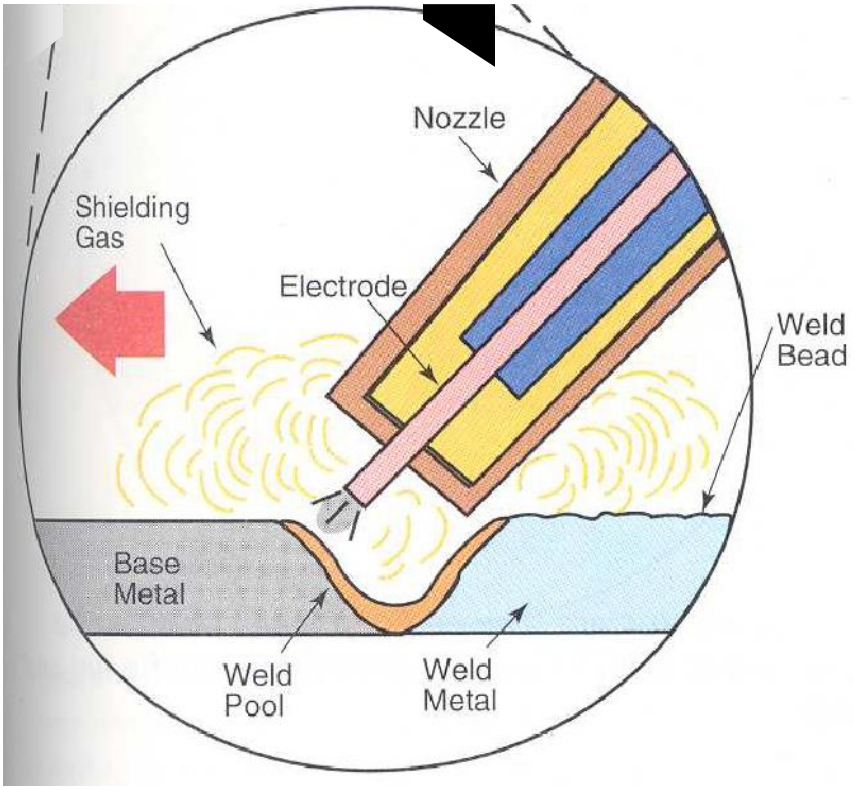
- torch
- electric power source
- shielding gas source
- wire spool with wire drive control

## Equipment required for the GMAW



# The GMAW ( MIG ) process

The heat is produced by an electric arc between the continuously fed metal electrode and the base metal. Both the base metal and the filler are melt. The weld area is protected by inert shield gases.




**Characteristics of the weld joint by GMAW**

Weldable metals:

-steel carbon

- steel low-allow

- steel stainless

- aluminum

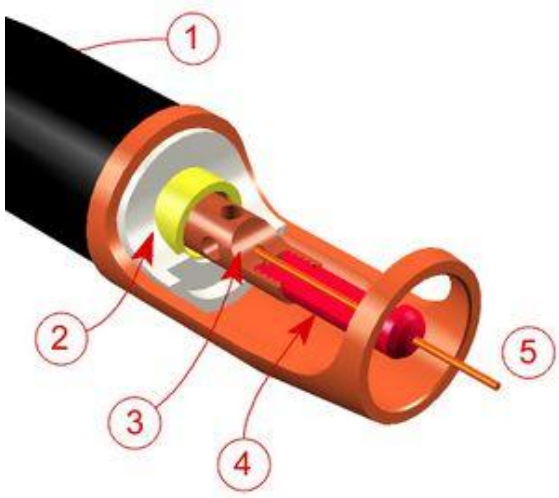
- copper and its allows

- nickel and its allows

- magnesium

- reactive metal (titanium, zirconium, tantalum)

GMAW ( MIG ) process




GMAW torch nozzle cutaway image : dedloM **(٢)** ،eldnah hcroT **(١)** tresni tun latem dedaerht dna (etihw ni nwohs) cirtceleid cilonehp tuptuo elzzoN **(٥)** ،ebut tcatnoC **(٤)** ،elzzon sag gnidleihS **(٣)** ،(wolley) ecaf

## Metal Inert Gas Welding (MIG, GMAW(

**Metal Inert Gas Welding (Gas Metal Arc Welding)** gnidlew cra eht si ،muileh ،nogra) sag lanretxe na yb dedleihs si dlew eht hcihw ni ،ssecorp .(serutxim sag rehto ro enegyxo + nogra ،٢OC

Consumable electrode wire, having chemical composition similar to that of the parent material, is continuously fed from a spool to the arc zone. The arc heats and melts both the work pieces edges and the electrode wire. The fused electrode material is supplied to the surfaces of the work pieces, fills the weld pool and forms joint.

Due to automatic feeding of the filling wire (electrode) the process is referred to as a semi-automatic. The operator controls only the torch positioning and speed .

**Advantages of Metal Inert Gas Welding (MIG, GMAW :(**

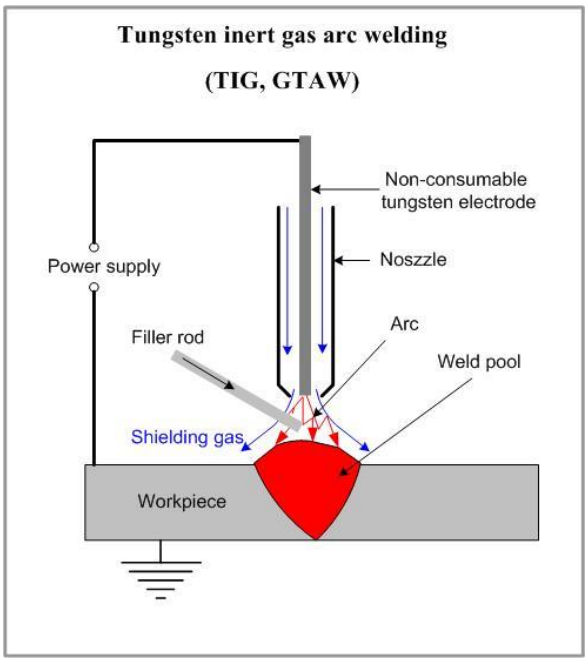
- •Continuous weld may be produced (no interruptions؛(
- •High level of operators skill is not required؛
- •Slag removal is not required (no slag؛(
- • High welding speed and can be easily automated

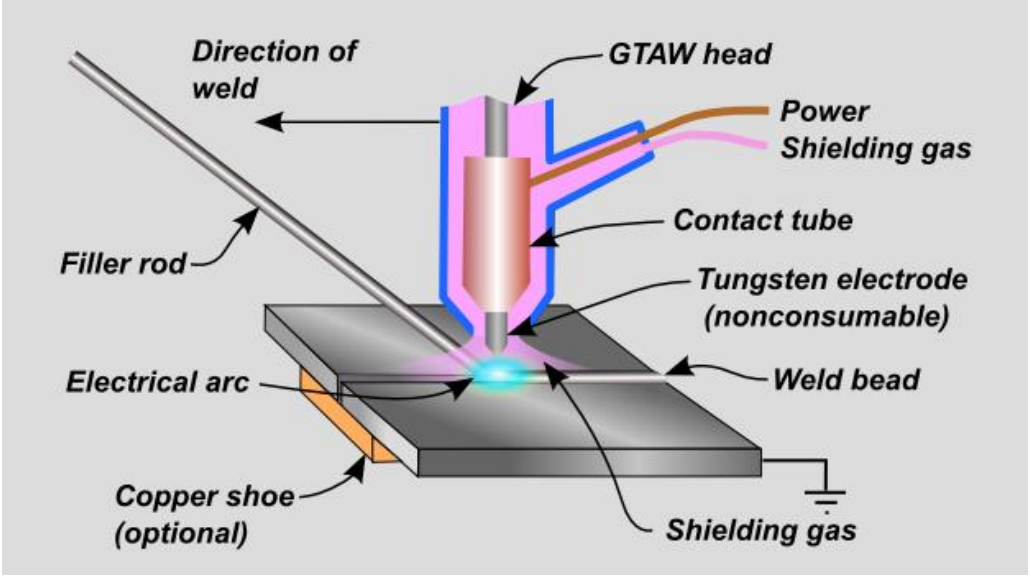
**Disadvantages of Metal Inert Gas Welding (MIG, GMAW :(**

- •Expensive and non-portable equipment is required؛
- •Outdoor application are limited because of effect of wind, dispersing the shielding gas.

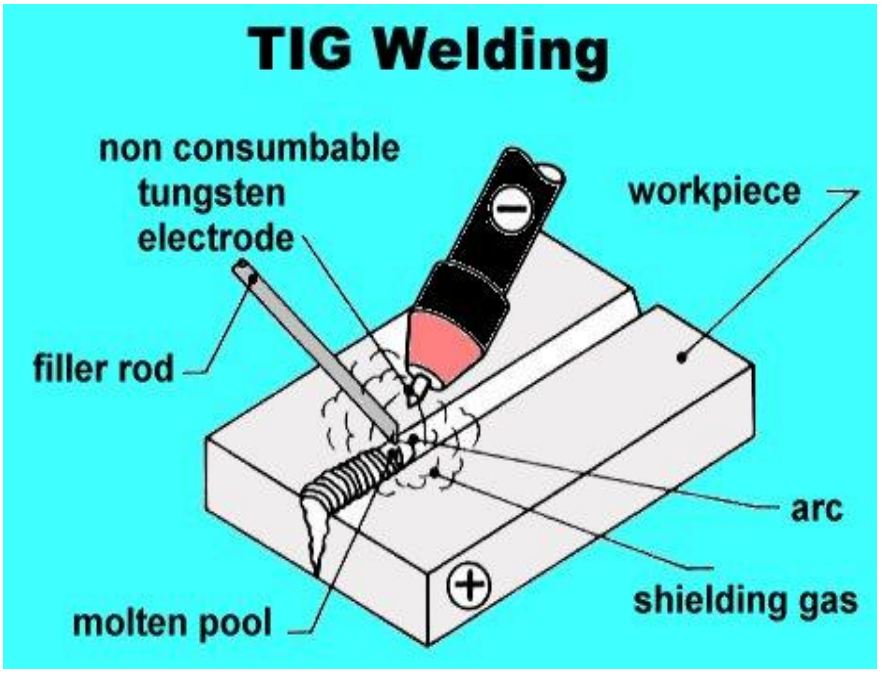
GMAW Advantages over SMAW

- Better arc time because of continuous wire electrode
  - Sticks must be periodically changed in SMAW
- Better use of electrode filler metal than SMAW
  - End of stick cannot be used in SMAW
- Higher deposition rates
- Eliminates problem of slag removal
- Can be readily automated






## Gas Tungsten Arc Welding ( TIG )




## Gas Tungsten Arc Welding ( TIG )

## Gas Tungsten-Arc Welding

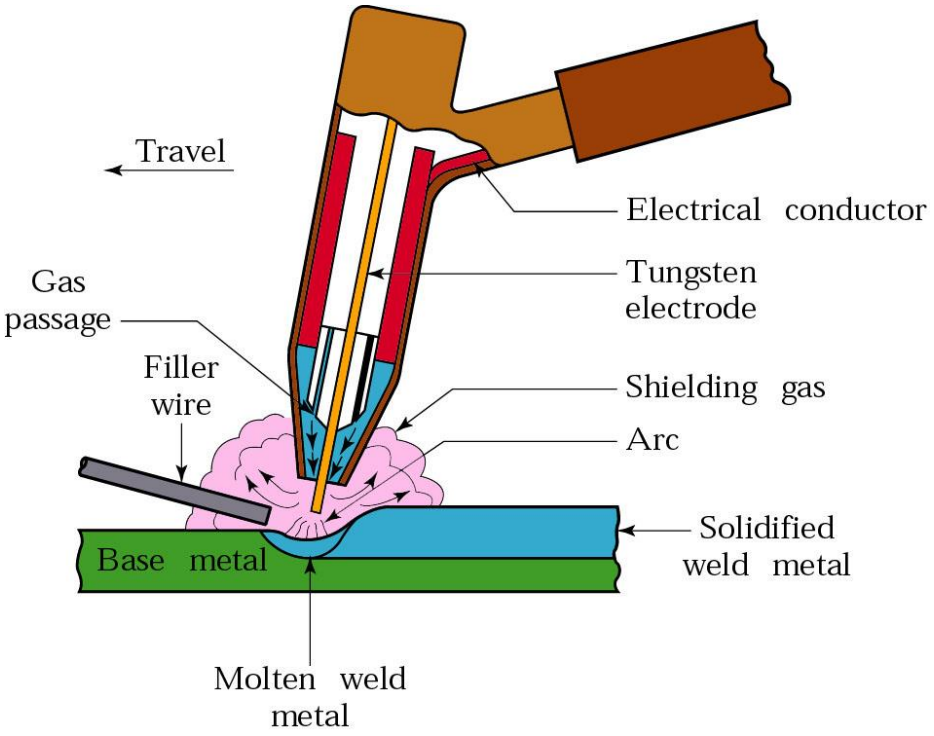



**Figure : The gas tungsten-arc welding process, formerly known as TIG (for tungsten inert gas) welding.**

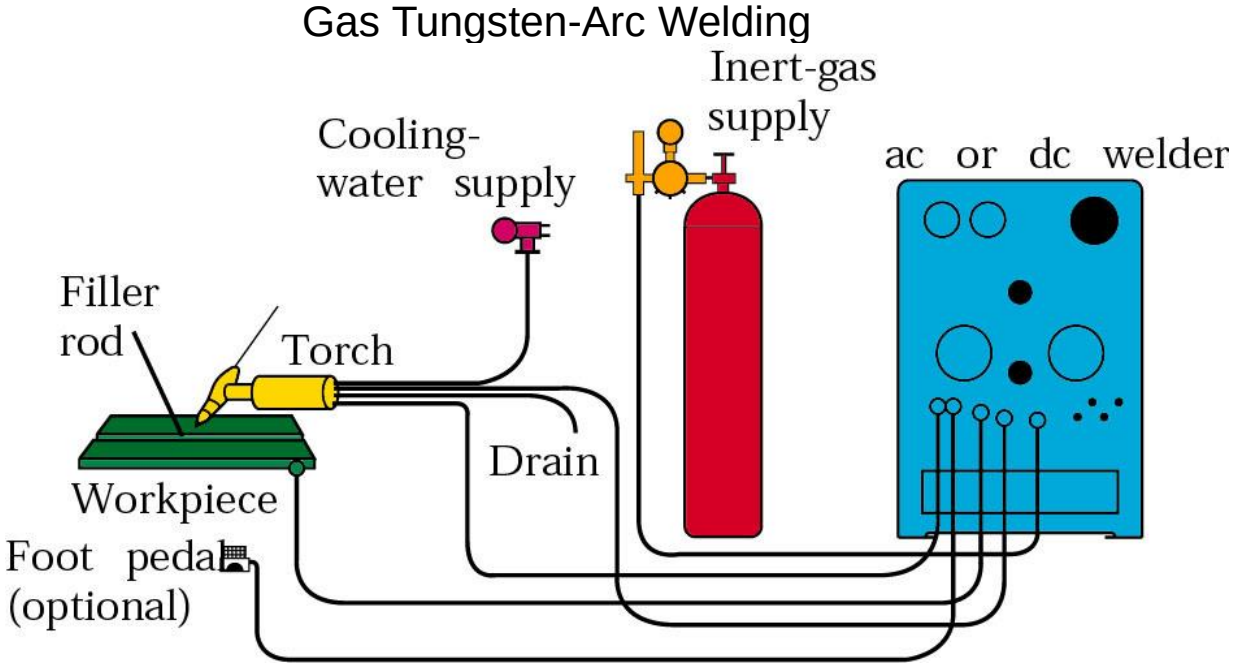



Figure : Equipment for gas tungsten-arc welding ( TIG )operations.

## *Tungsten Inert Gas Arc Welding (TIG, GTAW(*

**Tungsten Inert Gas Arc Welding (Gas Tungsten Arc Welding)** eht si kcurts cra cirtcele na yb detareneg si taeh hcihw ni ssecorp gnidlew .eceip krow eht dna edortcele elbamusnoc-non netsgnut a neewteb

The weld pool is shielded by an inert gas (argon, helium, nitrogen) protecting the molten metal from atmospheric contamination.

The heat produced by the arc melts the work pieces edges and joins them. Filler rod may be used, if required.

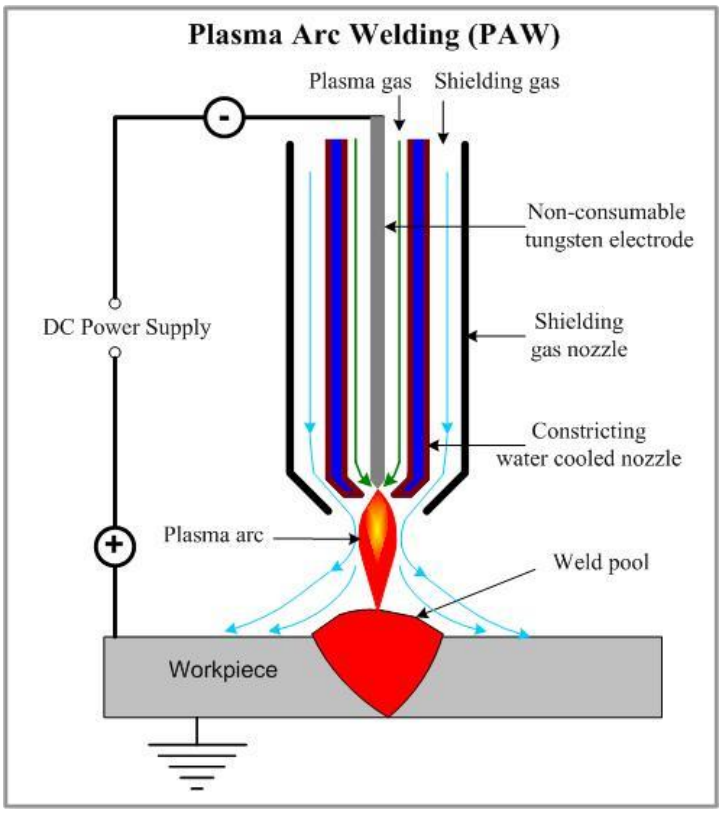
Tungsten Inert Gas Arc Welding produces a high quality weld of most of metals. Flux is not used in the process.

### *:(Advantages of Tungsten Inert Gas Arc Welding (TIG, GTAW*

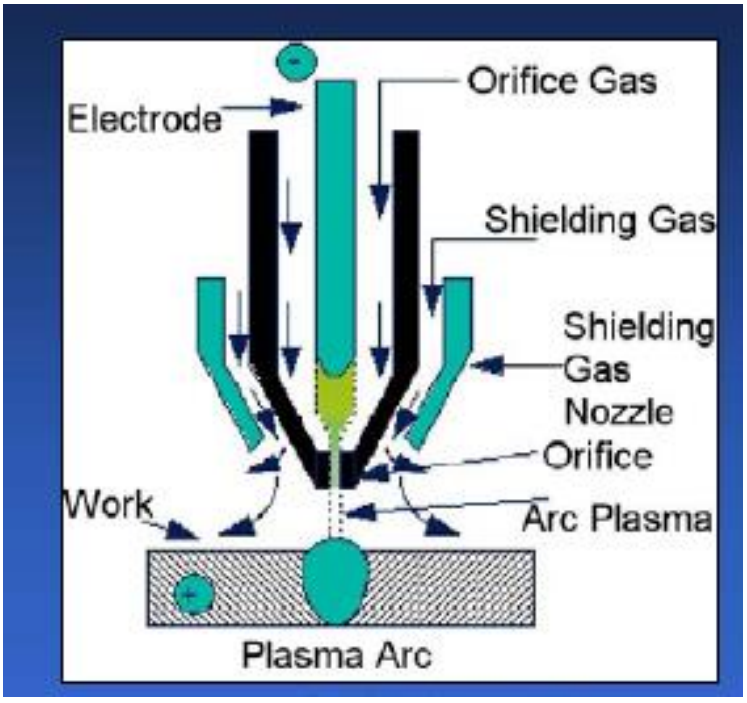
- ؛Weld composition is close to that of the parent metal•
- High quality weld structure•
- ؛(Slag removal is not required (no slag•
- Thermal distortions of work pieces are minimal due to concentration • .of heat in small zone
- Flux is not used; therefore, finished welds do not require cleaning of • corrosive residue.

### *:(Disadvantages of Tungsten Inert Gas Arc Welding (TIG, GTAW*

- ؛Low welding rate•
- Relatively expensive•
- Requres high level of operators skill•




# Plasma Arc Welding



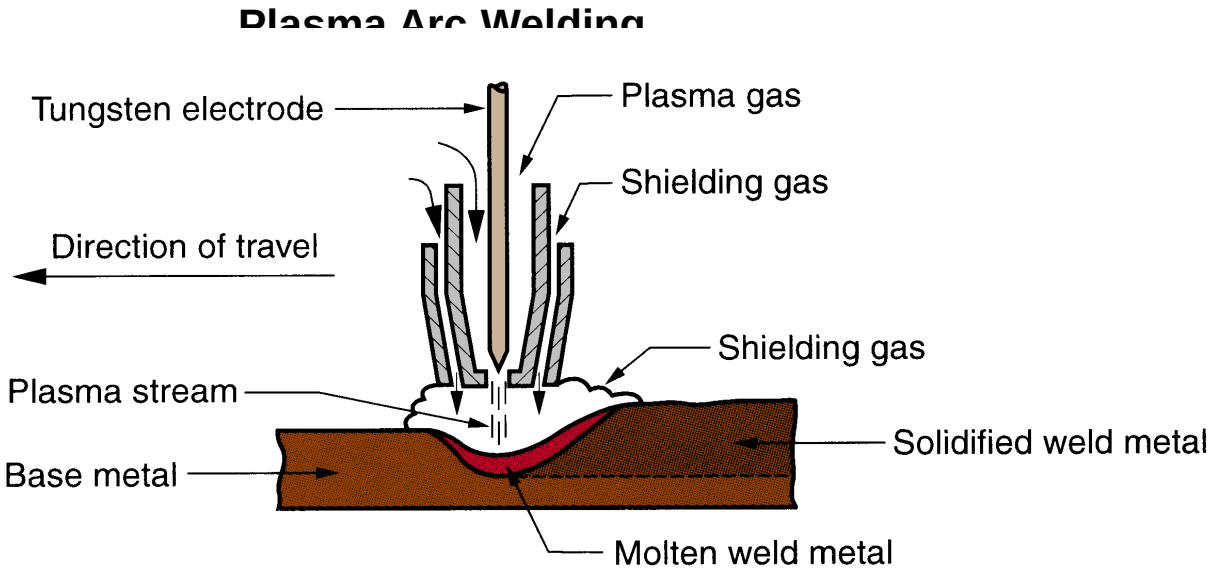



**Figure : Plasma arc welding (PAW)**

- **Temperatures in PAW reach 28,000°C (50,000°F), due to constriction of arc, producing a plasma jet of small diameter and very high energy density**

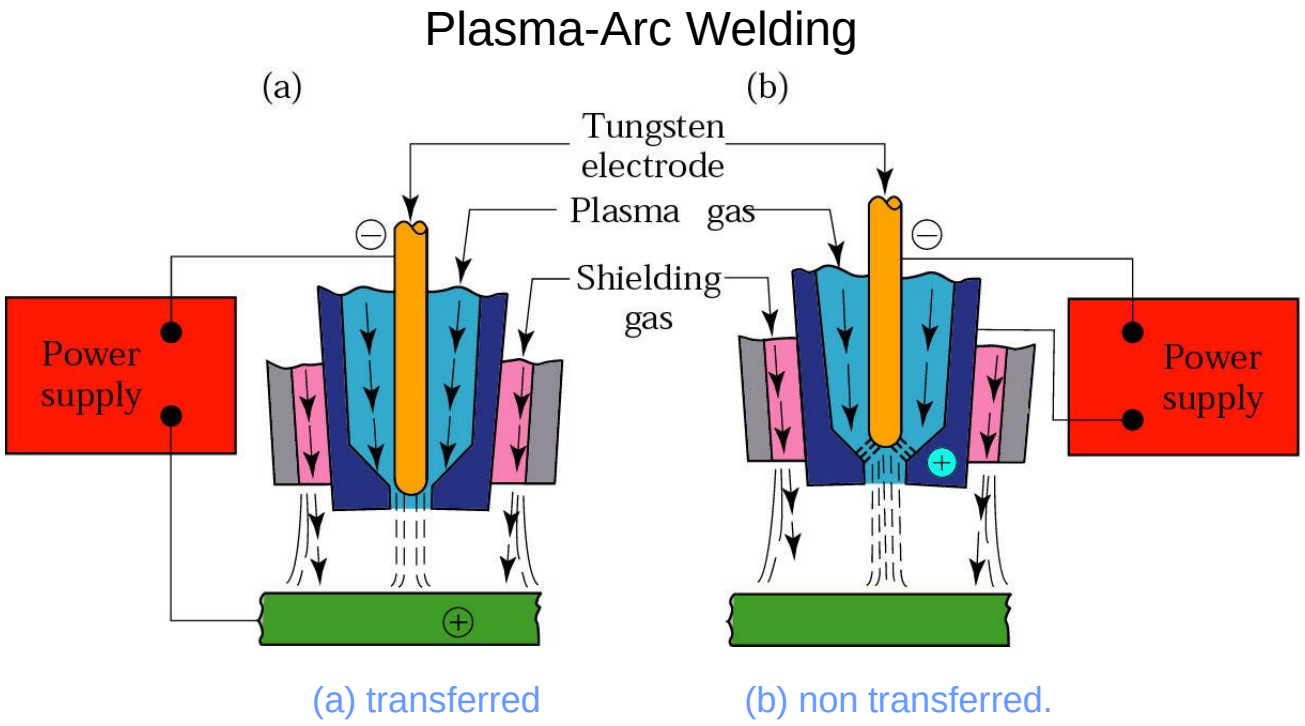



Figure : Two types of plasma-arc welding processes: (a) transferred, (b) non transferred. Deep and narrow welds can be made by this process at high welding speeds.

# Plasma Arc Welding (PAW)

## PAW is the next step in GTAW.

a yb detareneg taeh gnizilitu ssecorp gnidlew a si **Plasma Arc Welding** elbamusnoc-non netsgnut a neewteb kcurts ( tej amsalp) cra detcirtsnoc retaw ro (**transferred arc process**) eceip krow eht rehtie dna edortcele .(**non-transferred arc process**) elzzon gnitcirtsnoc delooc

**Plasma** is a high temperature ionised gas which is a mixture of positive .ions, electrons and neutral gas molecules

The gas is forced past an electric arc thtough a constricted openining( .orifice ) at the end of water cooled nozzle

Due to this gas gets heated and becomes ionised which is a plasma. As the arc is constricted, proportion of ionised gas increases and plasma jet is .created This results in a more concentrated heat source at a higher temperature that greatly increases the heat transfer efficiency, allowing for faster travel speeds.

This plasma jet will take a narrow, columnar shape that make it ideal for welding

This process uses two inert gases , one forms the plasma and second .shield the arc weld metal. Filler rod may or may not be supplied

# Plasma Arc Welding (PAW)

*Transferred arc process* ytisned ygrene hgih fo tej amsalp secudorp ‹scimareC fo gnittuc dna gnidlew deeps hgih rof desu eb yam dna .syolla lekciN ‹syolla muinatiT ‹syolla reppoC ‹syolla munimulA ‹sleets

Arc is struck between tungsten non-consumable electrode and work piece

*Non-transferred arc process* ygrene wol ylevitaler fo amsalp secudorp gniyarps amsalp rof dna slatem suoirav fo gnidlew rof desu si tI .ytisned )gnitaoc)

Arc is struck between non consumable electrode and water cooled constricted nozzle. Since the work piece in non-transferred plasma arc welding is not a part of elctric circuit, the plasma arc torch may move from one work piece to other

*Advantages of Plasma Arc Welding (PAW()*

Ensures greater arc stability

- Requires less operator skill due to good tolerance of arc to misalignments؛
- High welding rate؛
- High penetrating capability (keyhole effect؛(

*Disadvantages of Plasma Arc Welding (PAW )*

- Expensive equipment ؛

High distortions and wide welds as a result of high heat input .

# Flux-Cored Arc Welding (FCAW)

Adaptation of shielded metal arc welding, to overcome limitations of stick electrodes

- Electrode is a continuous consumable tubing (in coils) containing flux and other ingredients (e.g., alloying elements) in its core
- Two versions:
  - Self-shielded FCAW - core includes compounds that produce shielding gases
  - Gas-shielded FCAW - uses externally applied shielding gases

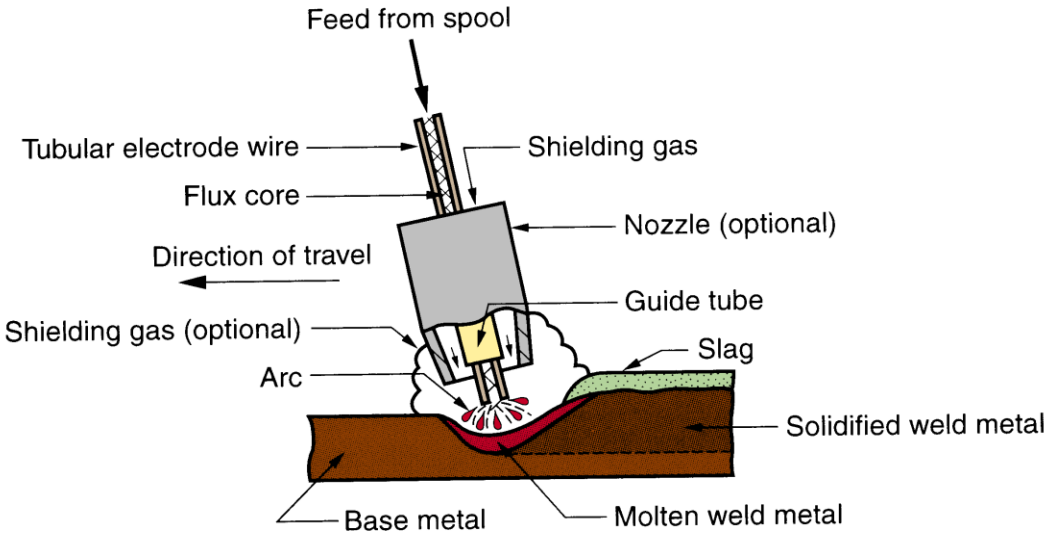



Figure : Flux-cored arc welding. Presence or absence of externally supplied shielding gas distinguishes the two types: (1) self-shielded, in which core provides ingredients for shielding, and (2) gas-shielded, which uses external shielding gases.

## Flux-Cored Arc-Welding

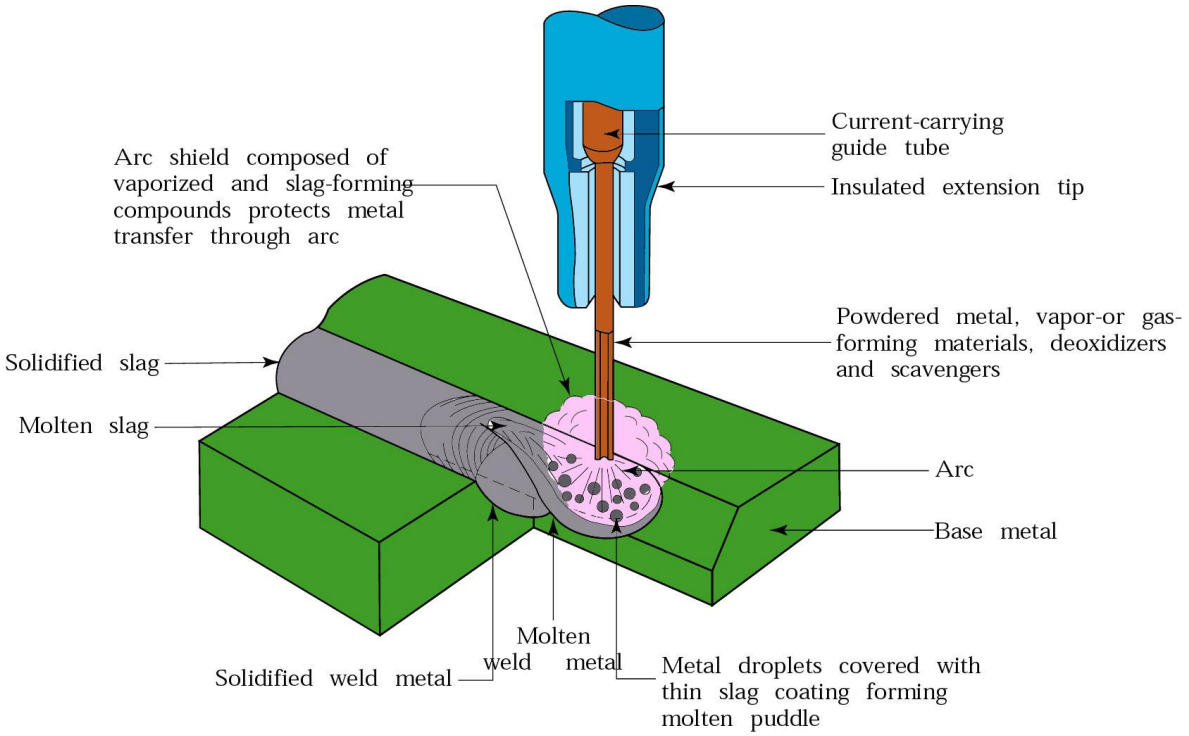



Figure : Schematic illustration of the flux-cored arc-welding process. This operation is similar to gas metal-arc welding

## Electrogas Welding (EGW)

Uses a continuous consumable electrode, either flux-cored wire or bare wire with externally supplied shielding gases, and molding shoes to contain molten metal

- When flux-cored electrode wire is used and no external gases are supplied, then special case of self-shielded FCAW
- When a bare electrode wire used with shielding gases from external source, then special case of GMAW

# Electro gas Welding

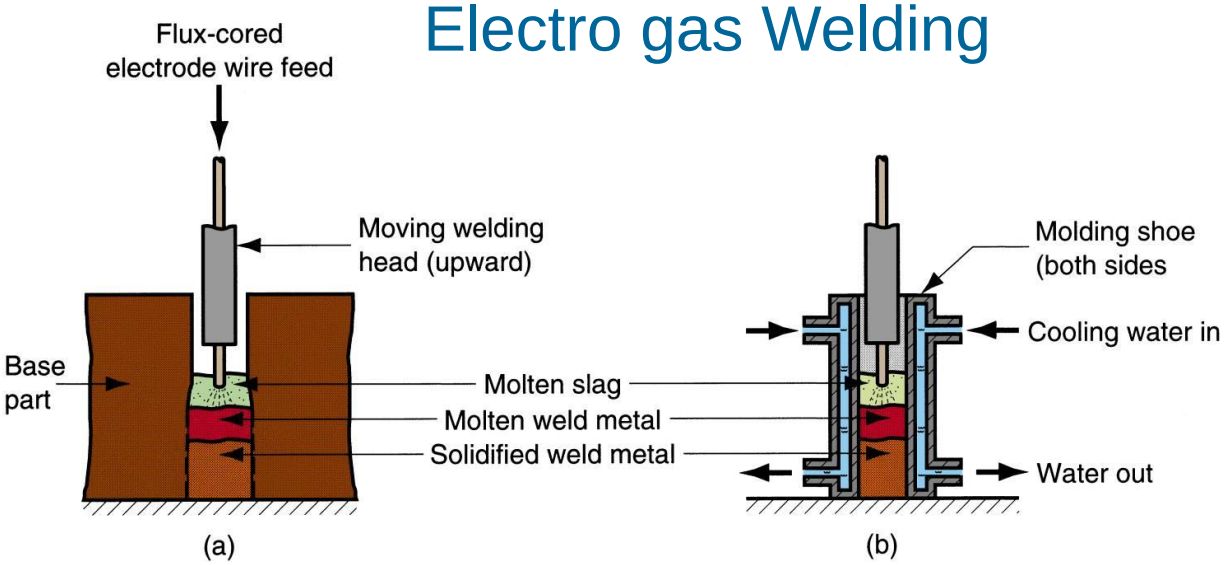
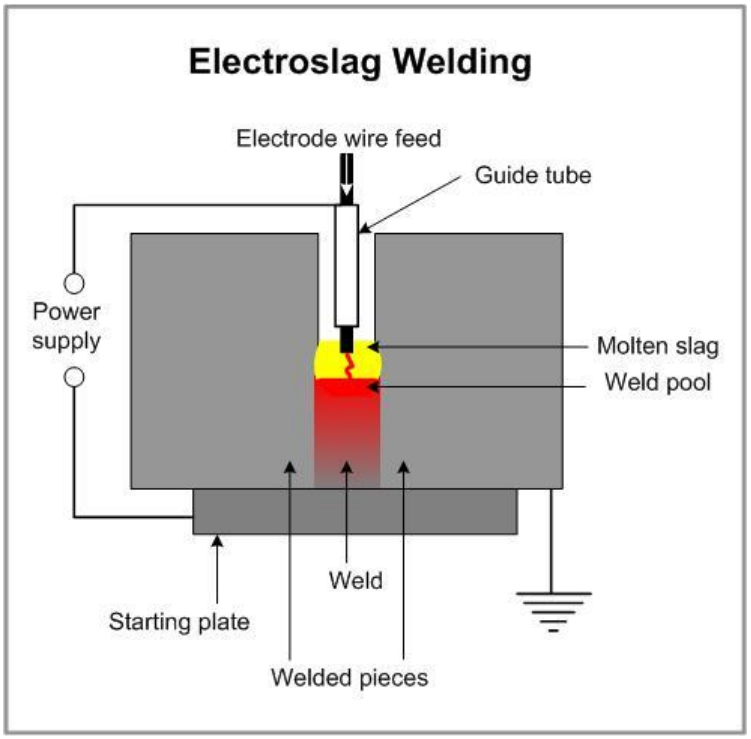
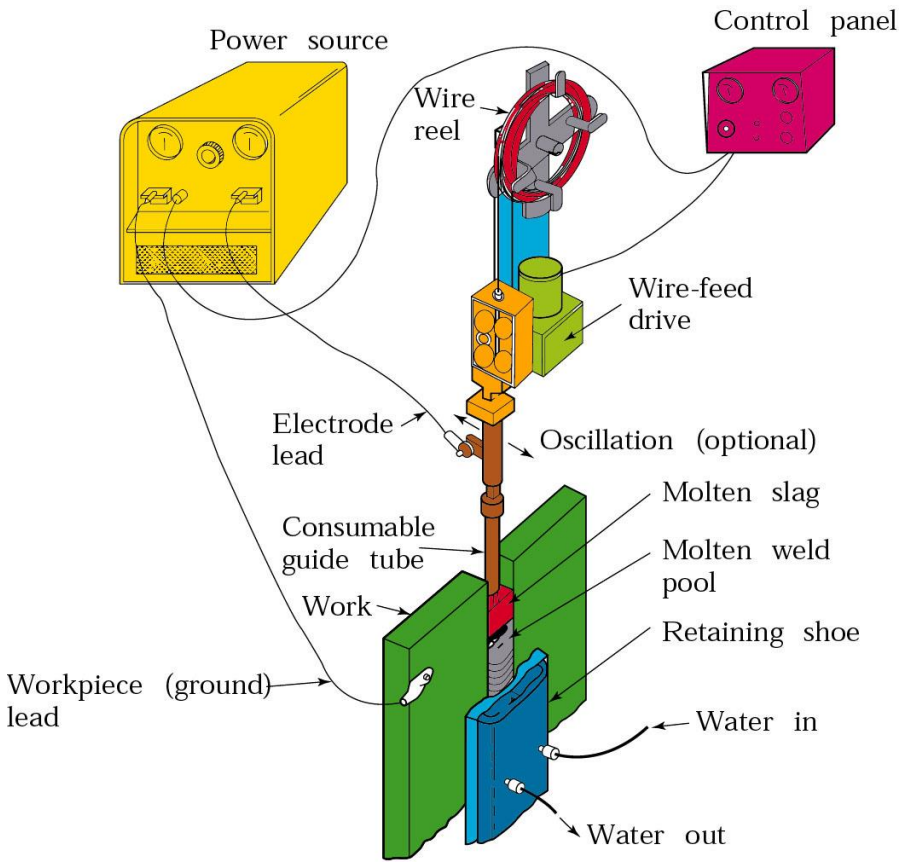



Figure : Electro gas welding using flux-cored electrode wire: (a) front view with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides.



# Equipment for Electro slag Welding




**1.** Electro slag Welding is the welding process in which the heat is generated by an electric current passing between the consumable electrode (filler metal ) and the work piece through a molten slag, which covers the weld surface.

2. In this process, plates to be welded are put in vertical position with certain gap. The consumable wire electrode is kept in this gap.
Prior to welding, the gap between the two work pieces is filled with a welding flux.

3. Electro slag Welding is initiated by an arc between the electrode and the work piece (or starting plate). Heat, generated by the arc, melts the fluxing powder and forms molten slag. The slag, having low electric conductivity, is maintained in liquid state due to heat produced by the electric current.

4. The slag reaches a temperature of about 1950°C inside and outside . Temperature of about 1650°C. This temperature is sufficient to melt Both consumable electrode and work piece edges.

Electro slag Welding is used mainly for steels.

*Advantages of Electroslag Welding:*

High deposition rate - up to 45 lbs/h (20 kg/h);
Low slag consumption (about 5% of the deposited metal weight);
Low distortion;
Unlimited thickness of work piece.

*Disadvantages of Electroslag welding:*

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

Submerged Arc Welding ( SAW)

Uses a continuous, consumable bare wire electrode, with arc shielding provided by a cover of granular flux

Electrode wire is fed automatically from a coil
Flux introduced into joint slightly ahead of arc by gravity from a hopper

Completely submerges operation, preventing sparks, spatter, and radiation

**Submerged Arc Welding ( SAW)**

- Welding arc is shielded by a granular flux consisting of lime,silica,manganese oxide,calcium fluoride
- Flux: insulates weld area,allows deep thermal penetration
- Prevents spatter and spark over molten metal
- Shielded glass etc is unnecessary
- 300 –2000 Amp
- Speed 5 m/min
- Thick plate welding – 4 to 10 times more weld material than SMAW.
- Carbon, allow, stainless steel etc

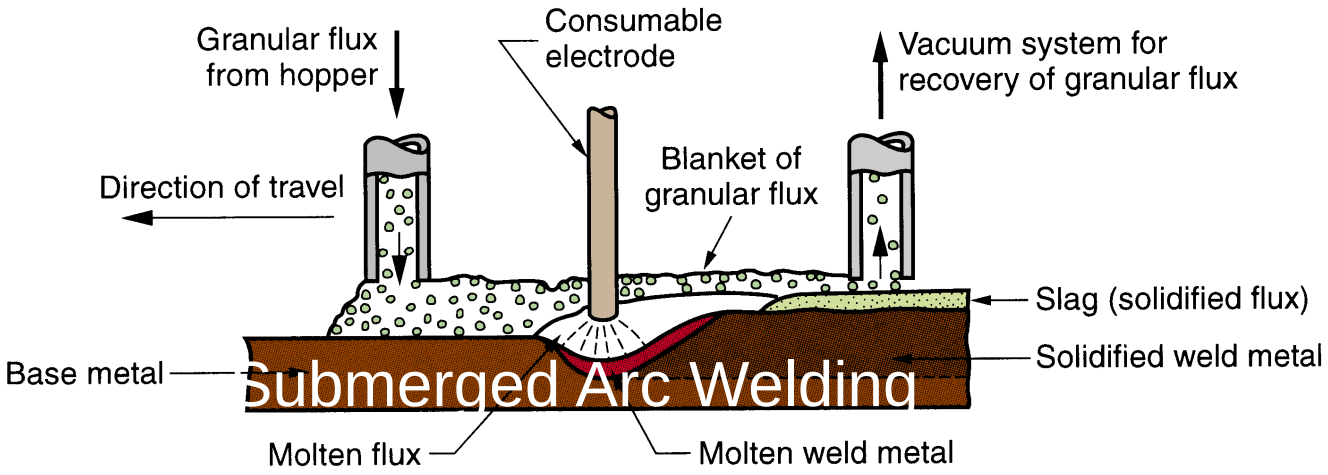
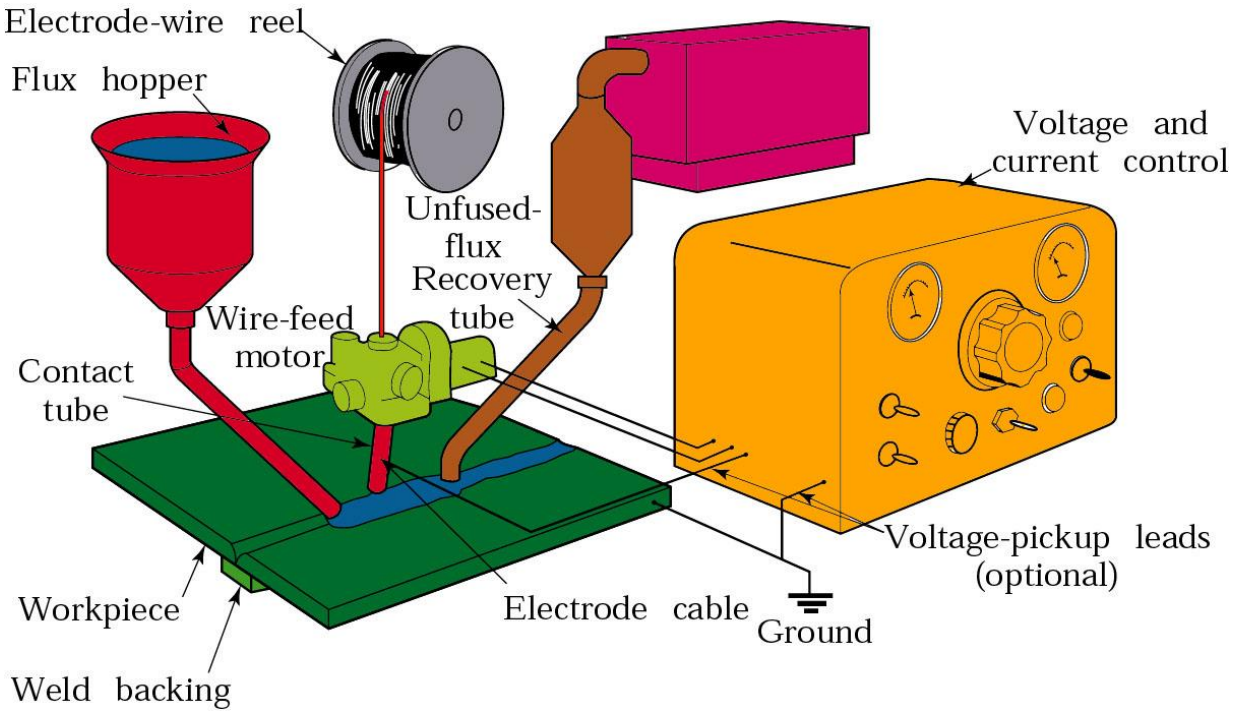
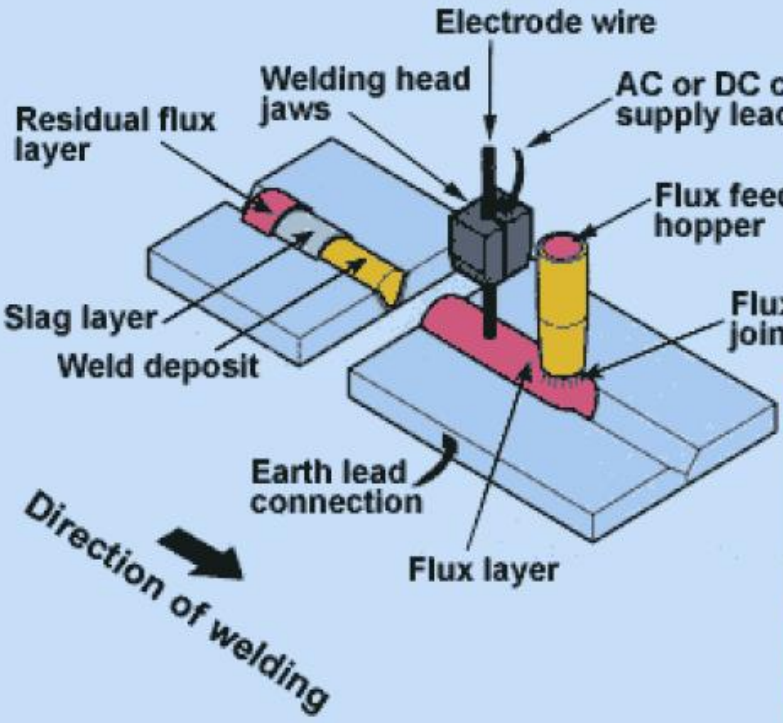


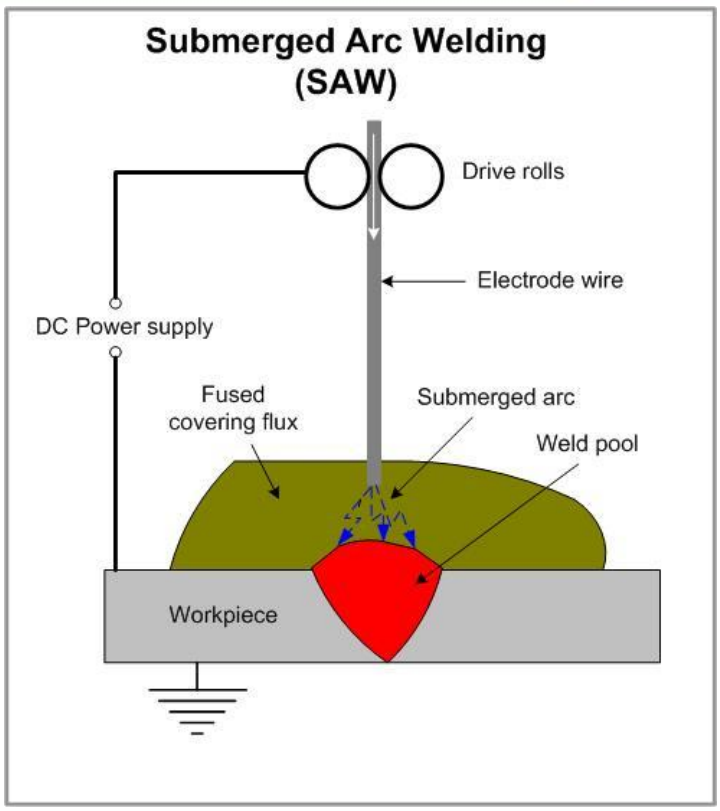

**Figure : Submerged arc welding.**



# Submerged Arc Welding





**Submerged Arc Welding**



# Submerged Arc Welding (SAW)

1. The flux containing calcium oxide, calcium fluoride, silica is crushed to form a coarse powder ( granulated flux powder ).
This powder is then spread over the point ( weld) to be formed.

2. A consumable electrode is fed into this flux.
Since the electrode is submerged into the flux, the arc is invisible.

3. When power supply is on, arc is formed , which is submerged under the layer of the powder. The intense heat of the arc produces a pool of molten metal in the joint ( weld) .
At this time, a portion of flux melts which protect the liquid weld pool from surrounding whereas rest of the flux ( which has not melted by the arc heat ) protects( shields) the arc ( from the surrounding )

4. This molten flux acts as a cleaner , absorbing impurities from the molten metal and producing slag, which floats on the top of molten metal. This slag solidifies with the molten metal and can be easily brushed off .

# Submerged Arc Welding

*Advantages of Submerged Arc Welding (SAW):*

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

*Disadvantages of Submerged Arc Welding (SAW):*

Weld may contain slag inclusions;
Limited applications of the process - mostly for welding horizontally located plates.

SAW Applications and Products

- Steel fabrication of structural shapes (e.g., I-beams)
- Seams for large diameter pipes, tanks, and pressure vessels
- Welded components for heavy machinery
- Most steels (except hi C steel)
- Not good for nonferrous metals

## Gas welding

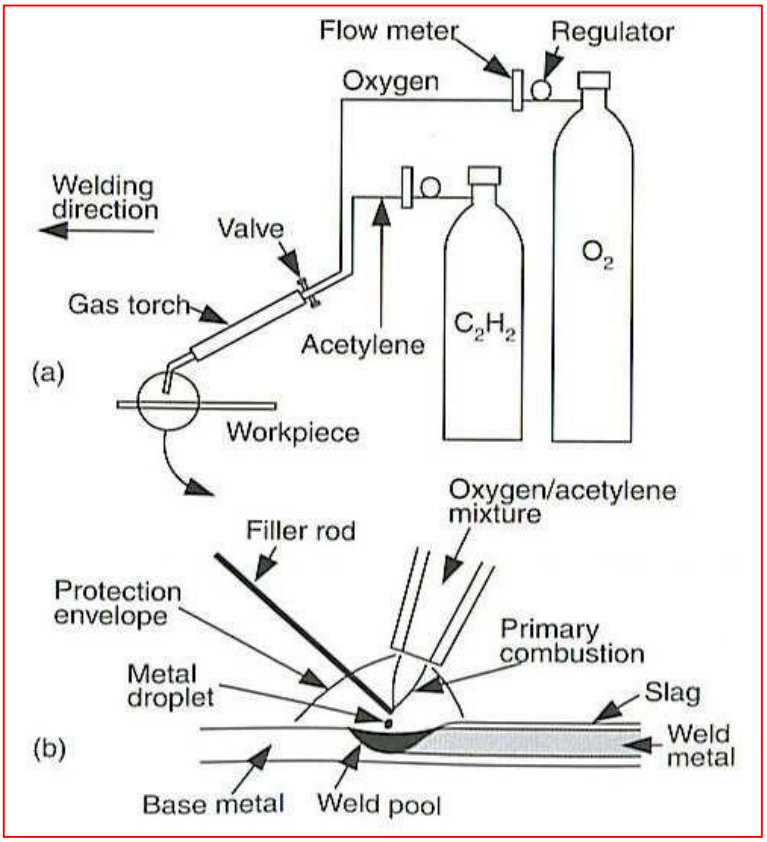
### •Gas welding Principles:

It is a welding process that melts and joints metals by *heating them with a flame* caused by a reaction of fuel gas and oxygen.

•The most commonly used method is *Oxyacetylene welding* ،.erutarepmet emalf hgih sti ot eud

•The *flux* may be used to deoxidize and clean the weld metal.

•The flux melts, solidifies and forms a *slag skin* on the resultant weld metal.




**Oxyacetylene welding (a) overall process ، (b) welding area.**

## Oxyacetylene welding

There are three types of flame in oxyacetylene welding:

- *Neutral flame*

Acetylene ($C_2H_2$) and $O_2$ are mixed in equal amounts and burn at the tip of the welding torch. The inner cone gives 2/3 of heat whereas the outer envelope provides 1/3 of the energy.

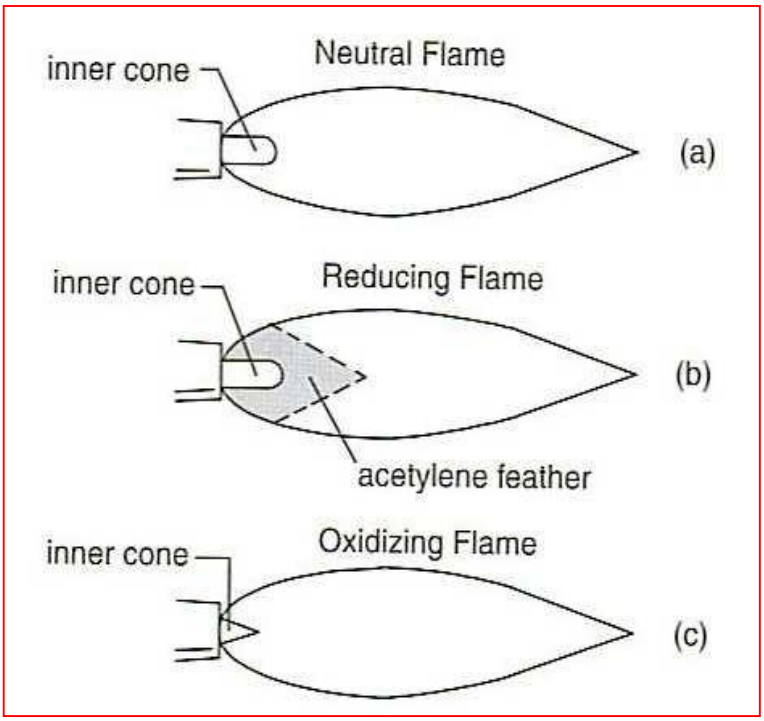
- *Reducing flame*

The excess amount of acetylene is used, giving a reducing flame. The combustion of acetylene is incomplete (greenish) between the inner con and the outer envelope.

Good for welding aluminium alloys, high carbon steels.

- *Oxidizing flame*

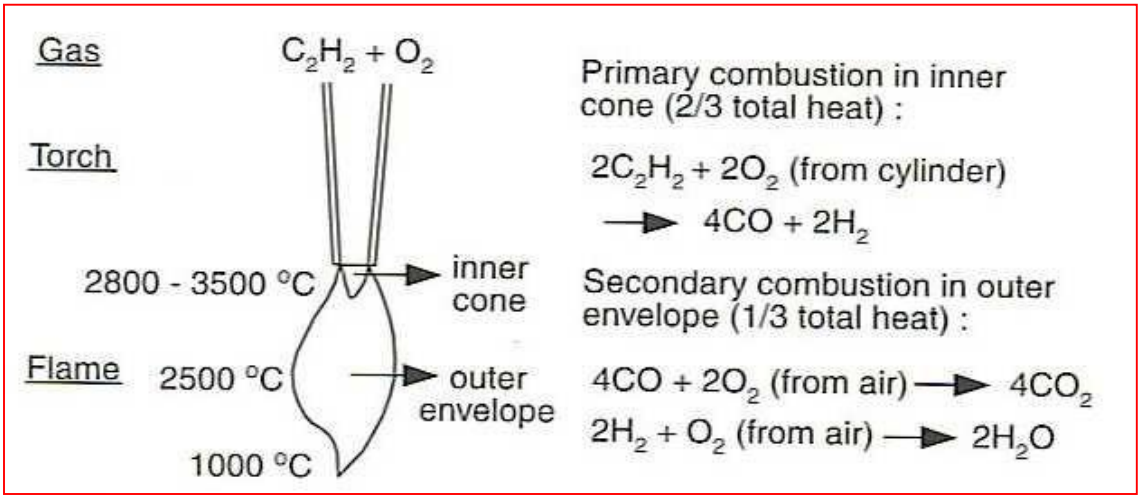
- The excess amount of $O_2$ is used, giving an oxidizing flame. Good for welding brass.




*Three types of flame in oxyacetylene welding*

*The secondary combustion is also called the protection envelope since CO and $H_2$ here consume the $O_2$ entering from surrounding air, thereby protecting the weld from oxidation.*

Chemical reactions and temperature distribution in a neutral oxyacetylene




Advantages and disadvantages

- *Advantages*
- Simple equipment
- Portable
- Inexpensive
- Easy for maintenance and repair
- *Disadvantages*Limited power density
- Very low welding speed
- High total heat input per unit length
- Large heat affected zone
- Severe distortion
- Not recommended for welding reactive metals such as titanium and zirconium.

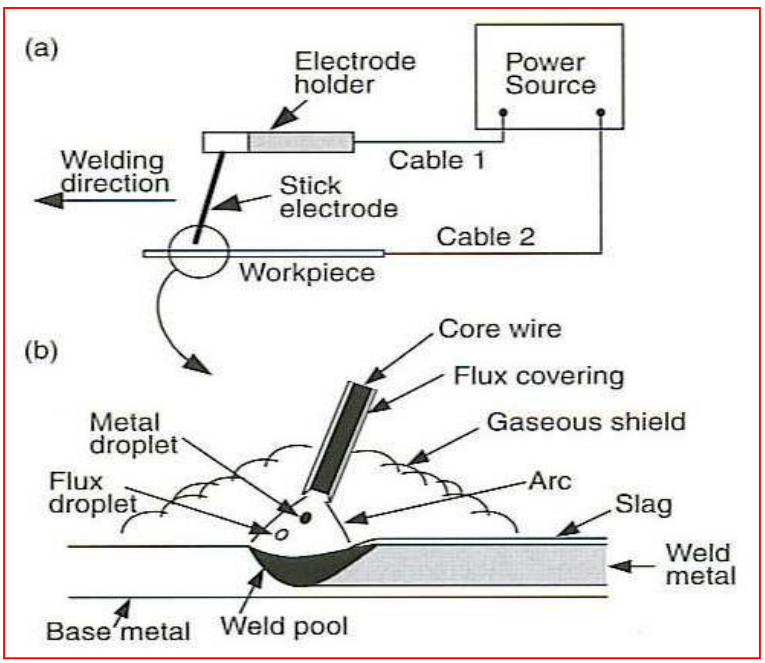
## Shield metal arc welding

Shield metal arc welding (*SMAW* snioj dna stlem taht ssecorp a si ( a neewteb dehsilbatse cra na htiw meht gnitaeh yb slatem*sticklike covered electrode* and the *metals*.

- The *core wire* conducts the *electric current* to the arc and provides *filler metal* for the joint.
- The *electrode holder* is essentially a metal clamp with an electrically insulated outside shell for the welder to hold safely.
- The heat of the arc melts the core wire and the flux covering at the electrode tip into *metal droplets*.
- Molten metal in the weld pool solidifies into the *weld metal* while the lighter molten flux floats on the top surface and solidifies as a *slag layer*.

## Shielding gas

Mixture of $H_2$, $CO$, $H_2O$ and $CO_2$




*Shield metal arc welding*

# Functions of electrode (flux) covering

## Protection

Provide the gaseous shield to protect the molten metal from air.

## Deoxidation

- e.g. Cellulose-type electrode $(C_6H_{10}O_5)_x$ , providing gas mixture of $H_2$ ،CO, $H_2O$ and $CO_2$.
- Limestone-type electrode ($CaCO_3$) – (low in hydrogen and it is used for welding metals that are susceptible to hydrogen cracking such as high-strength steels.

## Arc stabilization

Provide deoxidizers and fluxing agent to deoxidize and cleanse the weld metal .

The solid slag also protects the weld metal from oxidation.

## Metal addition

Provide arc stabilizers which are compounds such as potassium oxalate and lithium carbonate. They readily decompose into ions in an arc, which increase electrical conductivity.

Provide alloying elements (for composition control) and metal powder (increase deposition rate) to the weld pool.

# Advantages and disadvantages

## *Advantages*

- Simple welding equipment
- Portable
- Inexpensive
- Used for maintenance, repair, and field constructiona

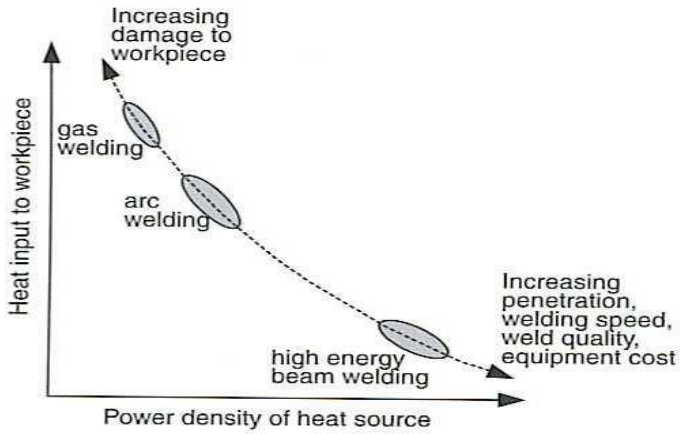
## *Disadvantages*

- Not clean enough for reactive metals such as aluminium and titanium.
- The deposition rate is limited because the electrode covering tends to overheat and fall off.
- The electrode length is ~ ٣٥ mm and requires electrode changing ⓪lower the overall production rate.

# Power density of heat sources

As the power density of the heat source increases, the heat input to the workpiece that is required for welding decreases.

Power density ⬆




- Deeper weld penetration
- Higher welding speeds
- Better weld quality
- Less damage to the workpiece

*Variation of heat input to the workpiece with power density of the heat source.*

Heat input ⬆

Weld strength ⬇

.-operations of fusion welding, specifications of welding, materials , electric resistance welding, soldering and brazing,

Welding processes andmaterials

. **Overview of Welding Processes**[a]

| Material | Thickness[b] | SMAW | SAW | GMAW | FCAW | GTAW | PAW | ESW | OFW | EBW | LBW |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Carbon steels | S | × | × | × | | × | | | × | × | × |
| | I | × | × | × | × | × | | | × | × | × |
| | M | × | × | × | × | | | | × | × | × |
| | T | × | × | × | × | | | × | × | × | |
| Low-alloy steels | S | × | × | × | | × | | | × | × | × |
| | I | × | × | × | × | × | | | | × | × |
| | M | × | × | × | × | | | | | × | × |
| | T | × | × | × | × | | | × | | × | |
| Stainless steels | S | × | × | × | | × | × | | × | × | × |
| | I | × | × | × | × | × | × | | | × | × |
| | M | × | × | × | × | | × | | | × | × |
| | T | × | × | × | × | | | × | | × | |
| Cast iron | I | × | | | | | | | × | | |
| | M | × | × | × | × | | | | × | | |
| | T | × | × | × | × | | | | × | | |
| Nickel and alloys | S | × | | × | | × | × | | × | × | × |
| | I | × | × | × | | × | × | | | × | × |
| | M | × | × | × | | | × | | | × | × |
| | T | × | | × | | | | × | | × | |
| Aluminum and alloys | S | | | × | | × | × | | × | × | × |
| | I | | | × | | × | | | | × | × |
| | M | | | × | | × | | | | × | |
| | T | | | × | | | | | | × | |

[a] Process code: SMAW, shielded metal arc welding; SAW, submerged arc welding; GMAW, gas–metal arc welding; FCAW, flux-cored arc welding; GTAW, gas–tungsten arc welding; PAW, plasma arc welding; ESW, electroslag welding; OFW, oxyfuel gas welding; EBW, electron beam welding; LBW, laser beam welding.

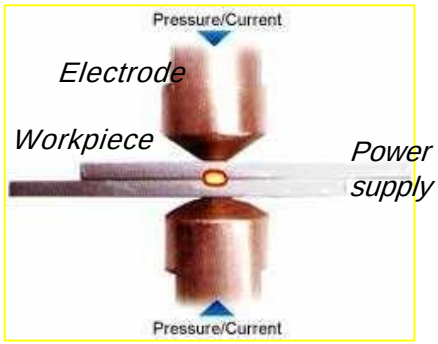
[b] Abbreviations: S, sheet, up to 3mm (⅛in.); I, intermediate, 3–6mm (⅛–¼in.); M, medium, 6–19mm (¼–¾in.); T, thick, 19mm (¾in.) and up; X,

# Resistance welding

*Resistance welding* is used to join two or more metal parts together in a localised area by the *application of heat and pressure* si taeh ehT . egarepma hgih a yrrac ot lairetam eht fo ecnatsiser eht yb decudorp .tnerruc

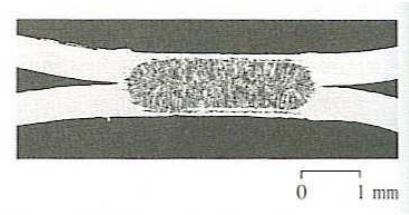
*There are at least seven different types of resistance welding:*

- *Flash welding*
- *High-frequency resistance welding*




*Projection welding*

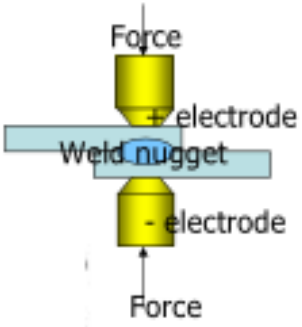
- *Percussion welding*
- *Projection welding*
- *Resistance seam welding*
- *Resistance spot welding*
- *Upset welding*

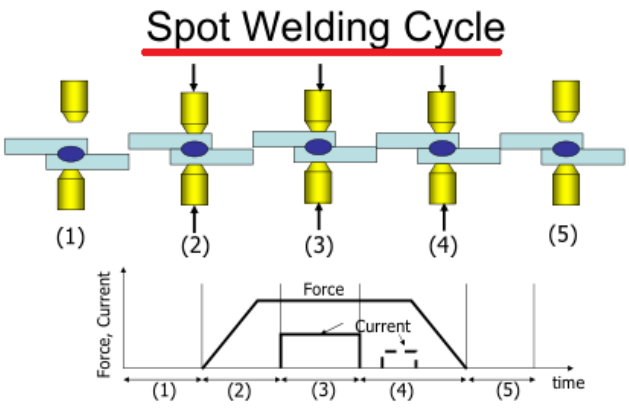



*Spot welding*



- Power source: heat generated: $H = I^2Rt$

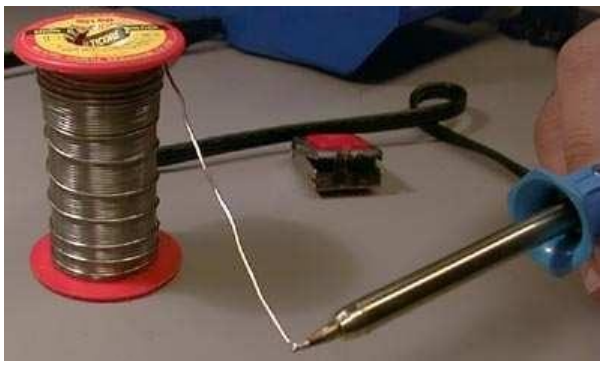


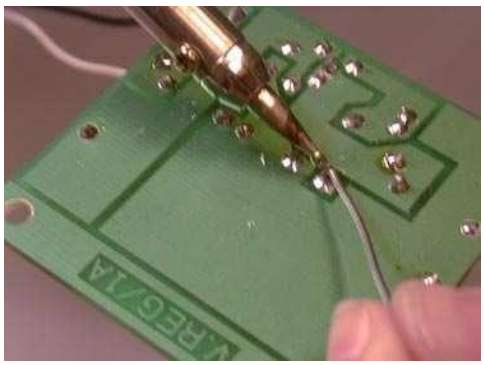




## Conventional joining techniques

- Soldering

  - A joining method using a low melting point *lead-tin alloy* (solder) to fill in a small gap between sheets.
  - The *solder* wets the metal and produce an intermetallic bond.
  - T ~ 183-–275 $^{o}$C depending on compositions.



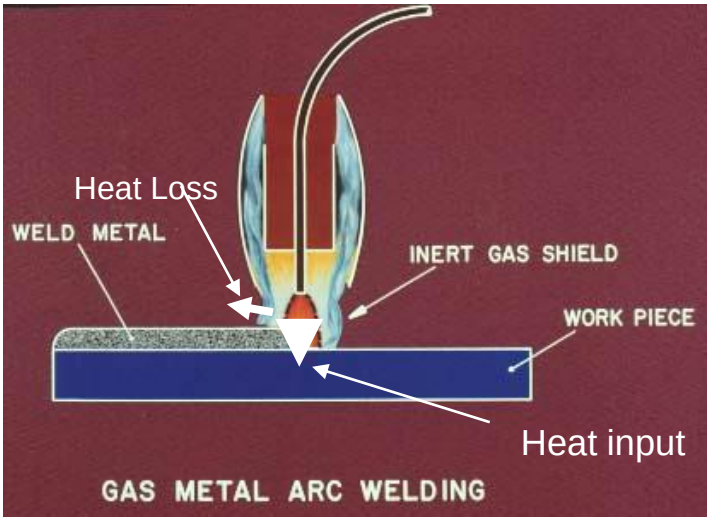


- Brazing

*Brazing* is similar to *soldering* but uses *fillers of higher* $T_m$) 450--800$^{o}$C).

1-Give *better strength* than soldering but might get oxidation problems or discoloration.

*2-Heating methods* such as gas torch, furnace, molten- flux bath, induction heating resistance heating are used.




# Heat Input

## Heat Input

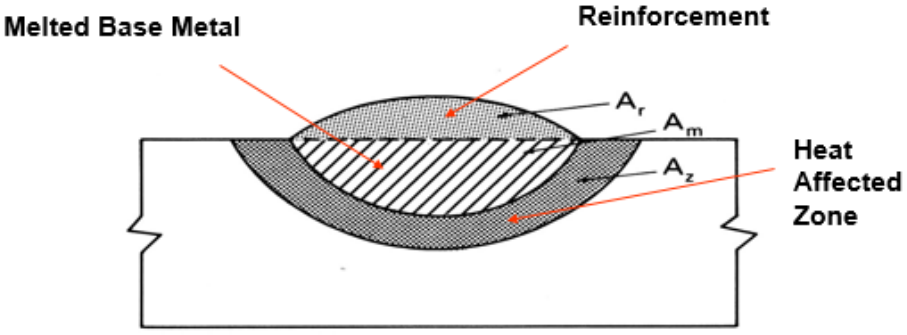
H = energy input, energy/unit length, joules /mm
H = Power/Travel Speed, = P/v
P = total input power, Watts
v = travel speed of heat source, mm/sec
Describes energy per unit length delivered, not rate of delivery Used in codes & specifications
This energy does not all go entirely to the work

## Heat Input for Arcs

H = P/v = EI/v
E = Arc Voltage (Volts)
I = Arc Current (Amps)
EI = Process power, converted to Heat
v = Welding Travel Speed

Not all the arc energy goes into the work

$H_{net} = f_1H = f_1P/v = f_1EI/v$
$f_1$ = Heat Transfer Efficiency




$A_w$ = Cross Section of Weld = $A_m + A_r$
For Autogenous Weld (no filler metal)
$A_w = A_m$

**Q = Heat Required to melt a Given Volume of Weld = Heat Required to elevate solid to MP + Latent Heat of Fusion**

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

$\rho = Density (mass / volume)$

$C_p = HeatCapacity (thermalenergy / mass^\circ C$

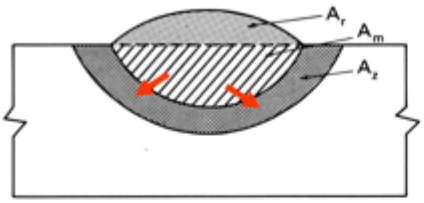
$T_m = MeltingTemperature$

$T_o = InitialTemperature, usuallyroomtemperature$

$L = LatentHeatofFusion$

**Not all the net heat transferred goes into melting**

## Melting Efficiency




**$f_2$ = Melting efficiency, the fraction of the process heat energy per unit length delivered to the metal which is required to melt the metal**

$$f_2 = QA_w/H_{net}$$

$$f_2 = QA_w v/f_1 EI$$

From previous slide:
$H_{net} = f_1 H = f_1 P/v = f_1 EI/v$

**Melting Efficiency Depends On:**

- Higher Thermal Conductivity - Lower Efficiency
- High Energy Density Heat Source - Higher Efficiency

# Other Energy Sources

Arc H = EI/v
Resistance: $H = I^2Rt$
Electroslag: H = EIt

Laser:

EB: $PD = \frac{4P_1}{\pi(f\theta)^2}$

$$PD = \frac{EI}{A}$$

H = Heat generated, joules
E = Voltage, volts
v = Travel Speed, mm/sec
I = Current, amps
R = Resistance, ohms
t = Time, sec
PD = Power Density
$P_1$ = Input power

$f$ = Focal lenght of lens

$\theta \cong \frac{\lambda}{\alpha}$ = angle of beam divergence

$\lambda$ = wavelength

$\alpha$ = laser constant

A = Area of focused beam

## Welded Joint

### Consists of:

Fusion zone

The area of base metal and filler metal that has been completely melted

Weld interface

A thin area of base metal that was melted or partially melted but did not mix with the filler metal

Heat affected zone

The surrounding area of base metal that did not melt, but was heated enough to affect its grain structure

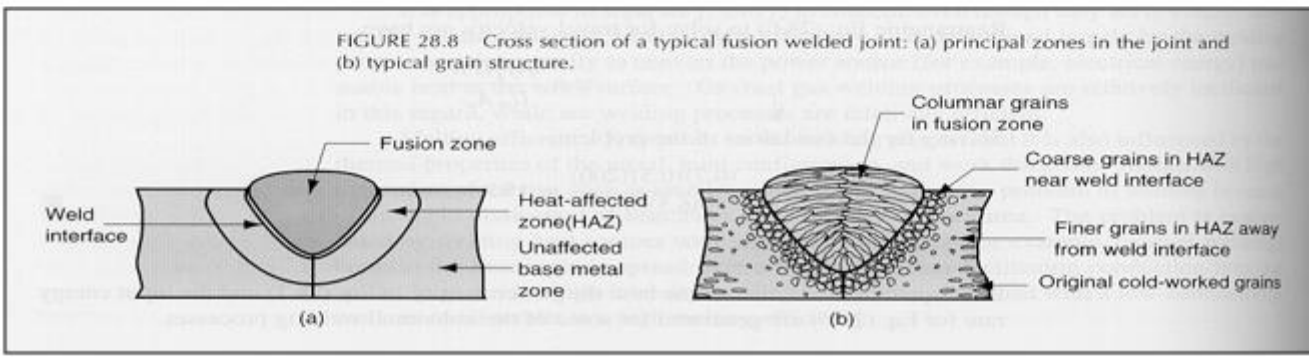


FIGURE 28.8 Cross section of a typical fusion welded joint: (a) principal zones in the joint and (b) typical grain structure.

# Welding Metallurgical changes

The base metal(s) and filler metal mix together during melting, forming an alloy when they solidify

The solidification of the metals can be considered as casting a small amount of metal in a metal mold

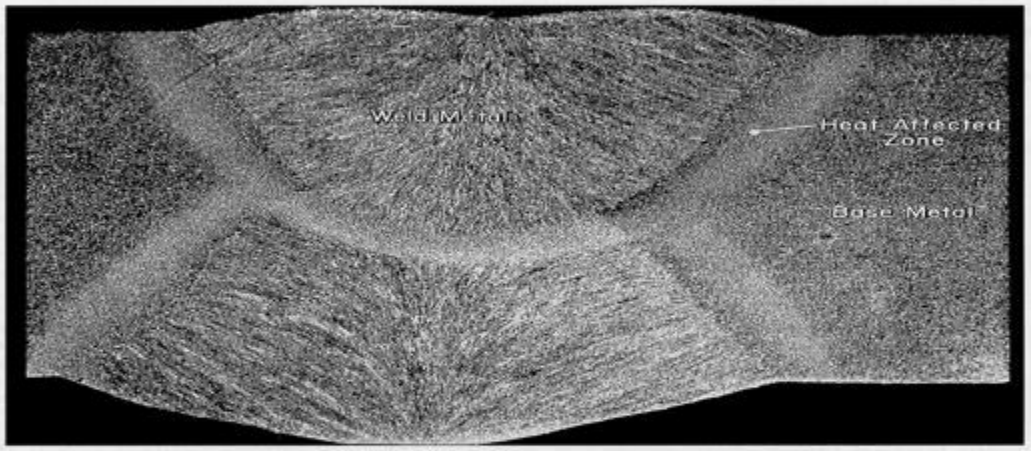



FIGURE 39-8 Grain structure and various zones in a fusion weld.

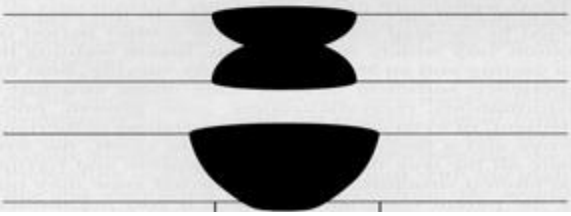
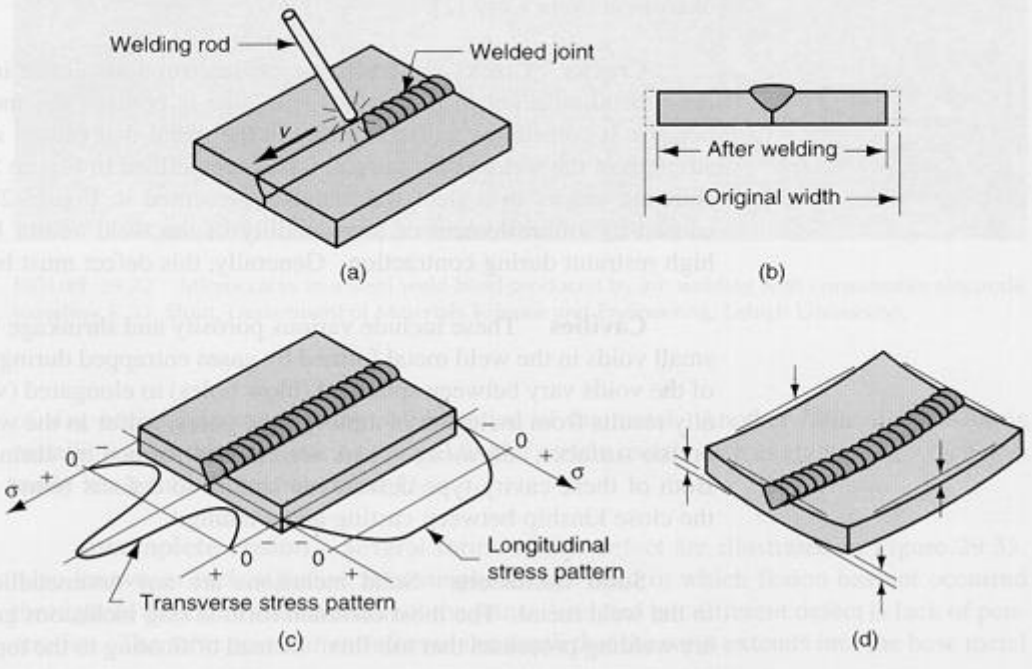


FIGURE 39-9 Comparison of two butt-weld designs. In the top weld, a large percentage of the weld pool is base metal. In the bottom weld, most of the weld pool is filler metal.

# Stresses and Distortion

FIGURE 29.30 (a) Butt welding two plates; (b) shrinkage across the width of the welded assembly; (c) transverse and longitudinal residual stress pattern; and (d) likely warpage in the welded assembly.



2,5,- welding defects, inspection and testing,

## Welding Defects

### Cracks

Fractures in the weld itself or in the metal adjacent to it

### Cavities

Porosity and shrinkage voids; similar to casting defects

### Solid inclusions

Nonmetallic solid material embedded in the weld metal

## Weld Inspection and Testing

Visual inspection

Visually examining the weld for surface defects

Nondestructive evaluation

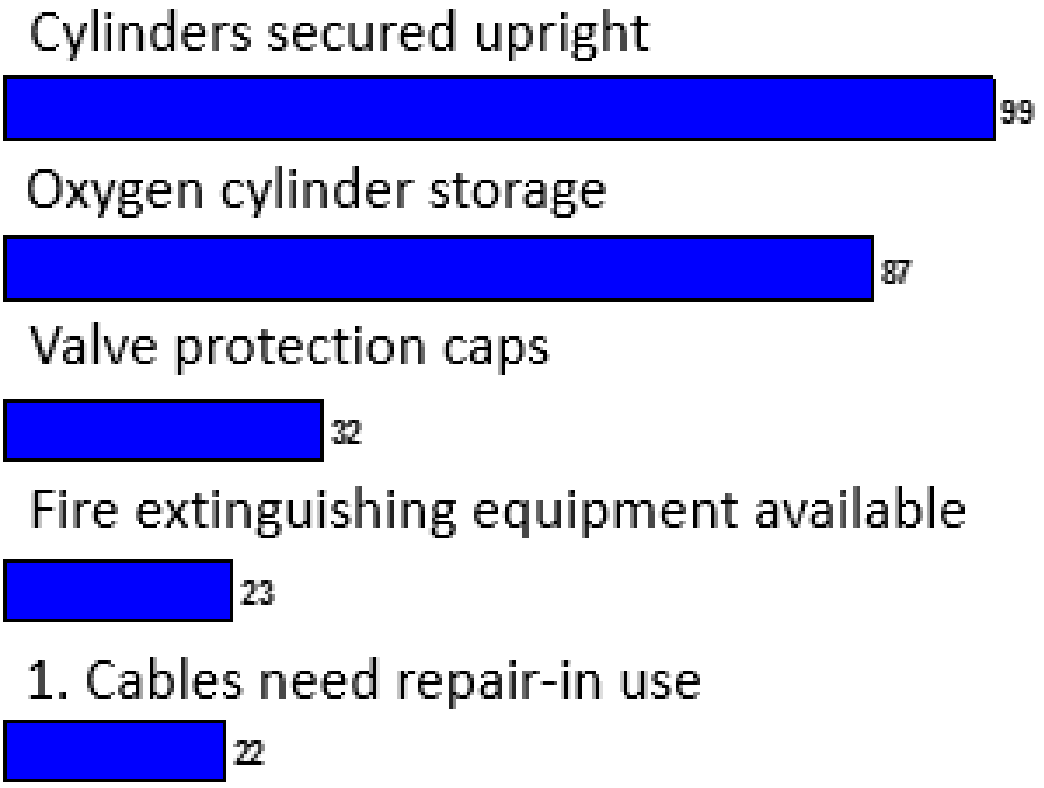
Uses various methods that do not damage the specimen

Destructive testing

Methods in which the weld is destroyed during the test or to prepare the specimen

2.6.- planning of welding processes
:

# Welding and Cutting




- Priorities

- Welding, cutting, and brazing are hazardous activities which pose both safety and health risks to over 500,000 workers in a wide variety of industries.
- The risk from fatal injuries is more than four deaths per thousand workers over a working lifetime.
- OSHA is developing an action plan which will reduce worker exposures to these hazards.

- Health Hazards
- There are numerous health hazards associated with exposure to fumes, gases and ionizing radiation formed or released during welding, cutting and brazing, including:

1. Heavy metal poisoning,
2. Lung cancer,
3. Metal fume fever,
4. Flash burns, and others