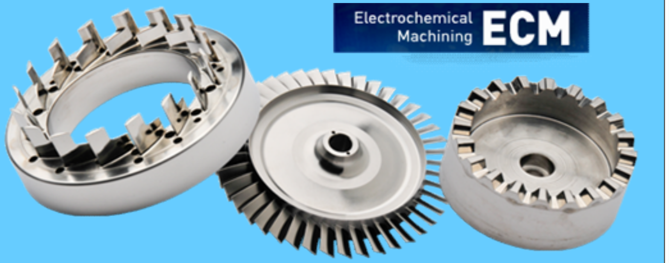
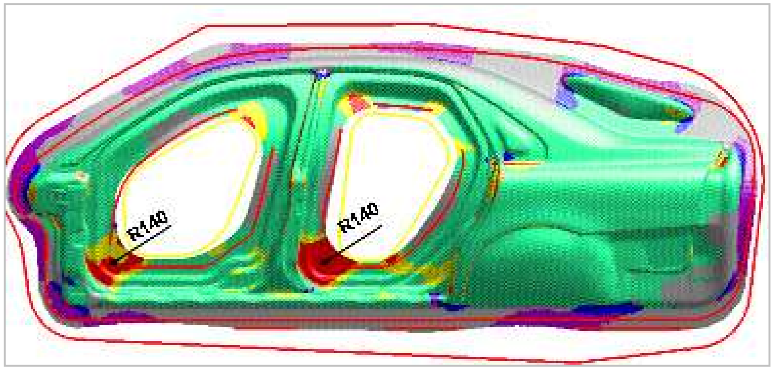
IPE-331: PRODUCTION PROCESSES





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Course Outlines

- **METAL CASTING PROCESSES**

  Introduction, Sand casting procedures, Pattern making, Material types and construction of patterns, Pattern allowances, Molding sand, Molding sand properties, Molding process, Molding materials, Casting processes, Sand casting defects etc.

- **THEORY OF METAL CUTTING**

  Tool geometry, Chip formation mechanism, Mechanics of metal cutting, Cutting tool material, Cutting fluid and Machining economics.

- **METAL JOINING METHODS**

  Introduction, Classification, Types of weld and weld joint, Different welding processes, Weld Symbols, Defects in Welds, Testing of welds, Quality control of welds, Robotic welding, Brazing and Soldering

References

- **Textbook**
  - Manufacturing Processes for Engineering Materials - S. Kalpakjian and et. al.
  - Metal Cutting: Theory & Practice- A. Bhattacharyya
  - Metal Cutting Theory and Cutting Tool Design - Ersinov and others
  - Metal Cutting Principles - M. C. Shaw
  - Materials and Processes in Manufacturing - E. P. DeGarmo and et. al.
  - Manufacturing Processes - M. L. Begeman and et. al.
- **Journals**
  - CIRP Annals
  - JSME International Journal
  - Journal of Advanced Manufacturing Technology
  - Journal of Material Processing Technology
  - ASME
  - Wear
  - IMechE

Marks Distribution

Total Marks: 400					
Class Test (20%)				Class Attendance (10%)	Final Examination (70%)
1	2	3	4		
20	20	20	20	40	280

Class Test-1	Metal Casting Processes
Class Test-2	Theory of Metal Cutting
Class Test-3	Joining Processes
Class Test-4	

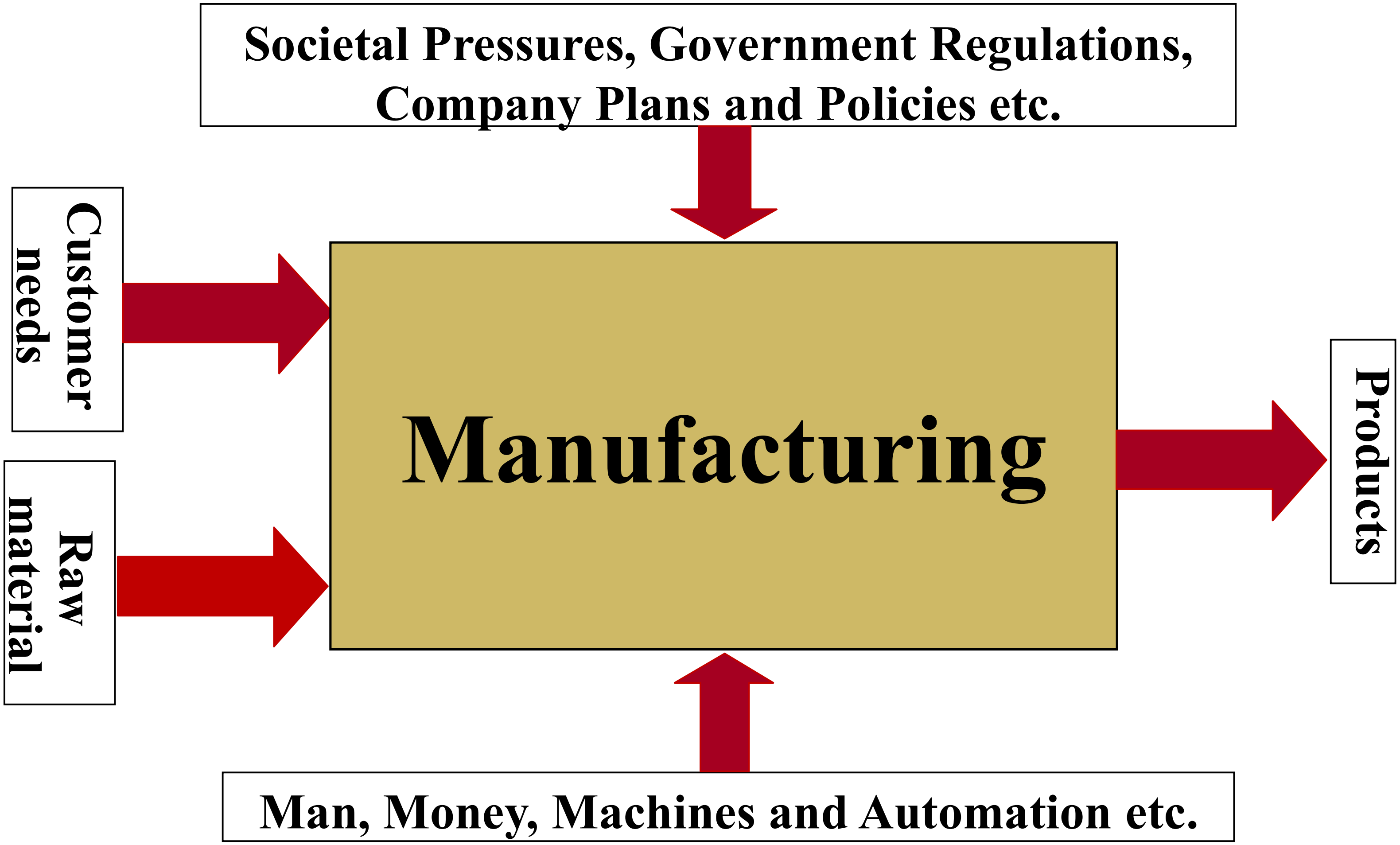
Manufacturing

Manufacturing is a process for converting ideas and market or customer needs into artifacts; includes design, procurement, test, finance, human resources, marketing, etc. Manufacturing is the conversion of raw materials into useful products

- Creating shapes by various means and assembling these shapes into a useful product. A physical product always has a shape
  - Function
  - Aesthetics
- These shapes are created by a wide variety of processes

Manufacturing Trends

- Products must meet specifications, design requirements, & regulatory standards.
- Product must be economic and environmentally friendly.
- Quality must be built into the design.
- Methods must be flexible.
- Manufacturers must listen to customer feedback.
- Productivity must be constantly improved.



Societal Pressures, Government Regulations, Company Plans and Policies etc.

Customer needs

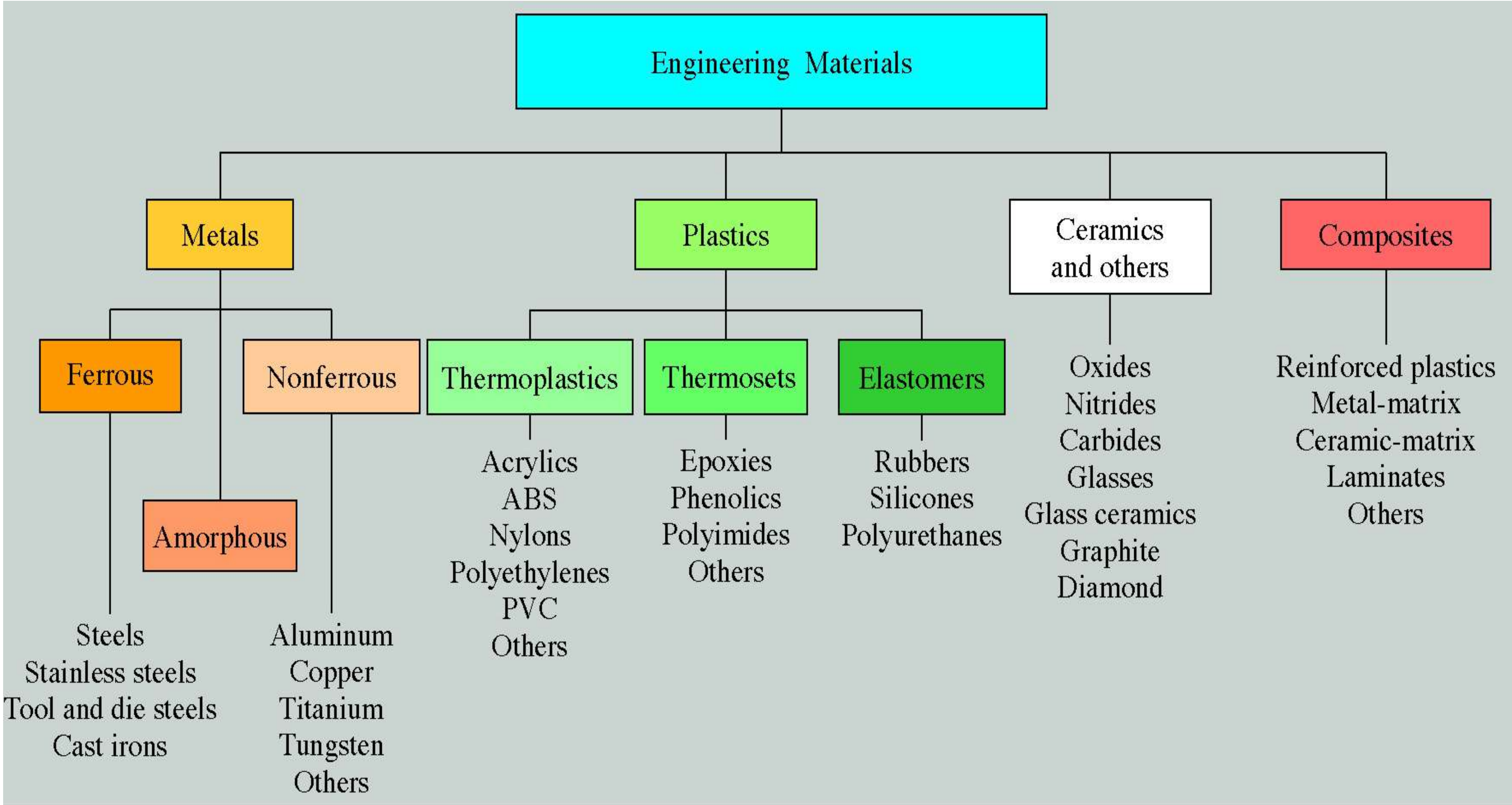
Raw material

Manufacturing

Products

Man, Money, Machines and Automation etc.

Engineering Materials



Engineering Materials

Metals

Ferrous

Nonferrous

Amorphous

Steels
Stainless steels
Tool and die steels
Cast irons

Aluminum
Copper
Titanium
Tungsten
Others

Plastics

Thermoplastics

Acrylics
ABS
Nylons
Polyethylenes
PVC
Others

Thermosets

Epoxies
Phenolics
Polyimides
Others

Elastomers

Rubbers
Silicones
Polyurethanes

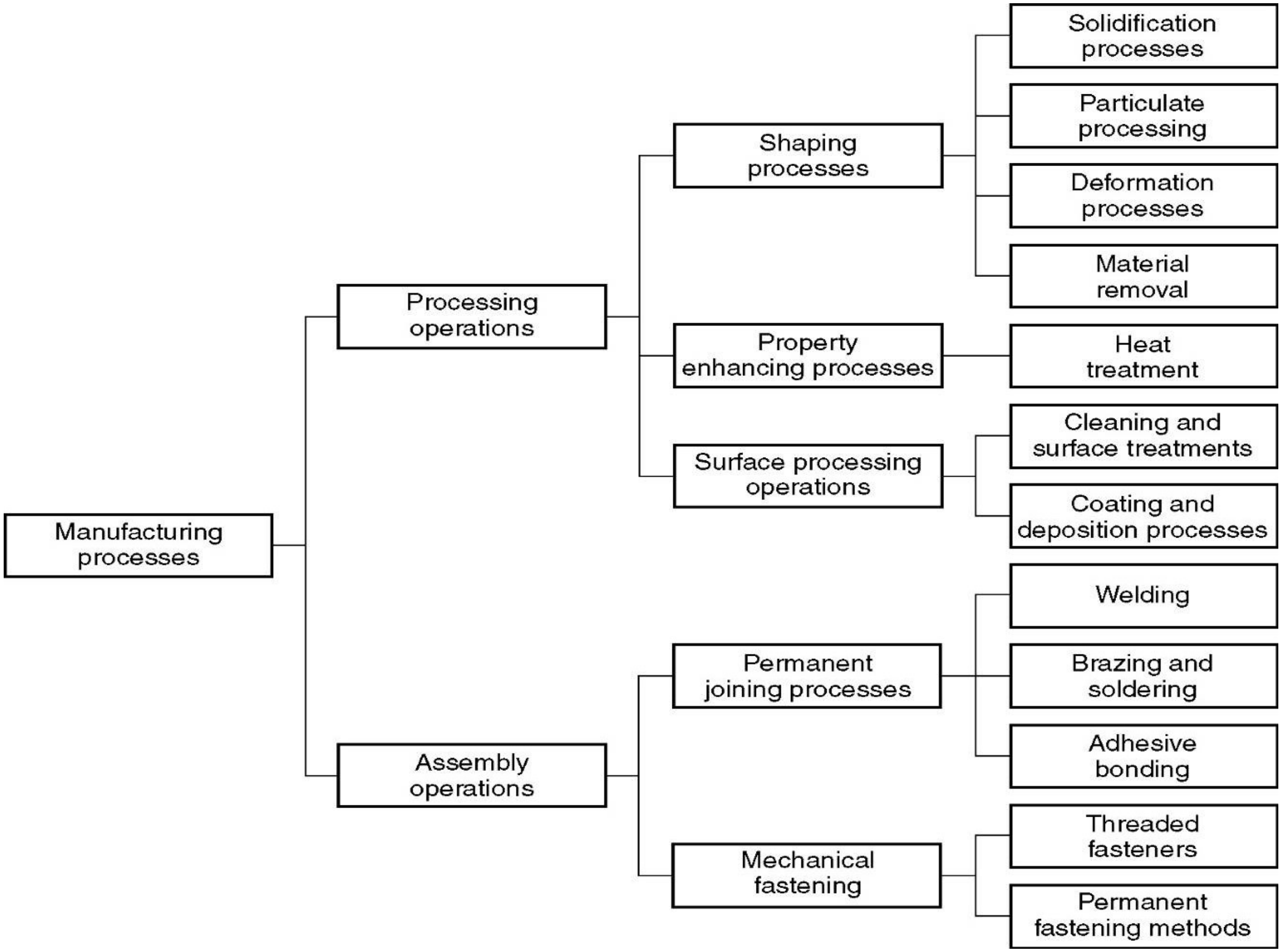
Ceramics and others

Oxides
Nitrides
Carbides
Glasses
Glass ceramics
Graphite
Diamond

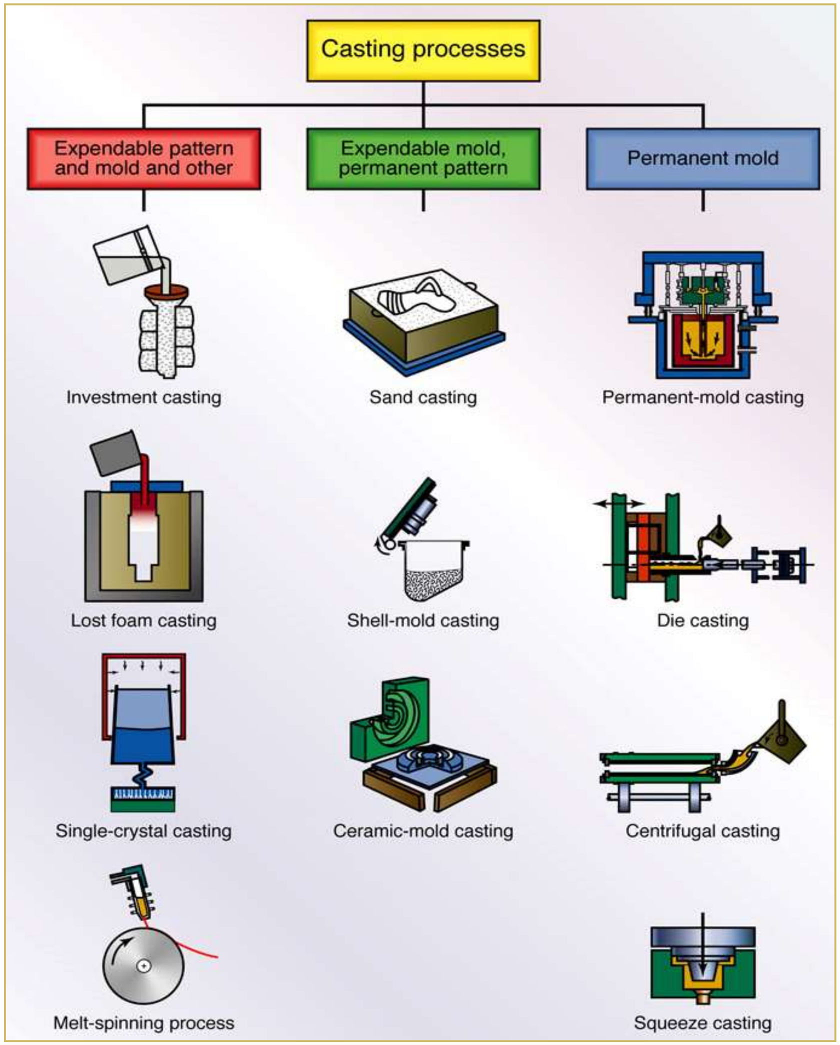
Composites

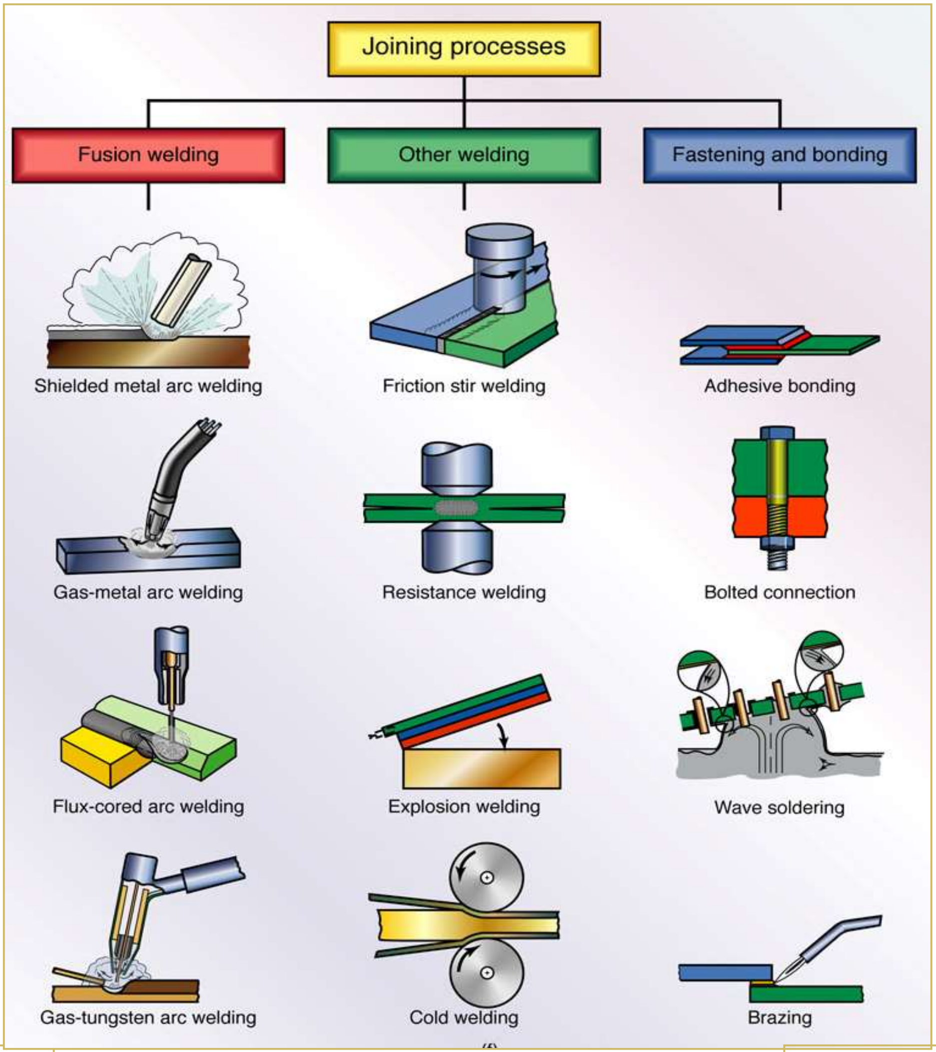
Reinforced plastics
Metal-matrix
Ceramic-matrix
Laminates
Others

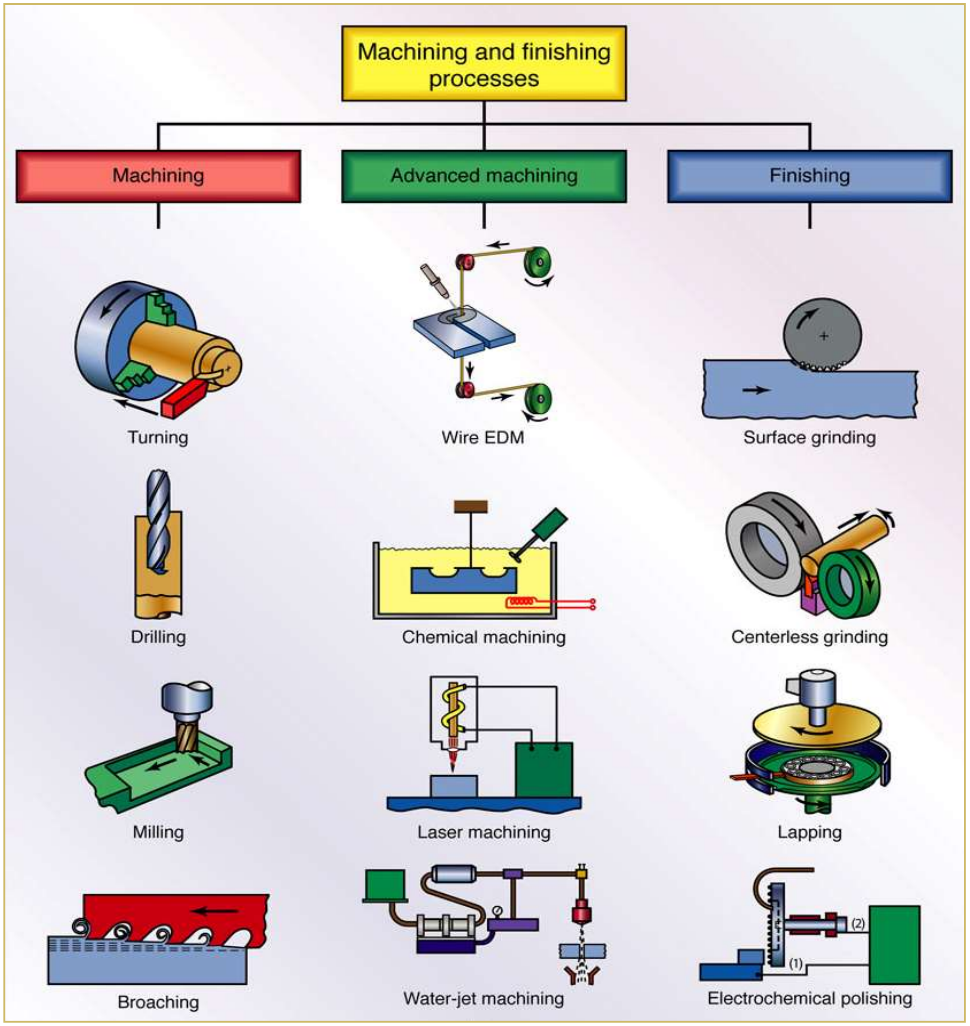
Manufacturing Processes

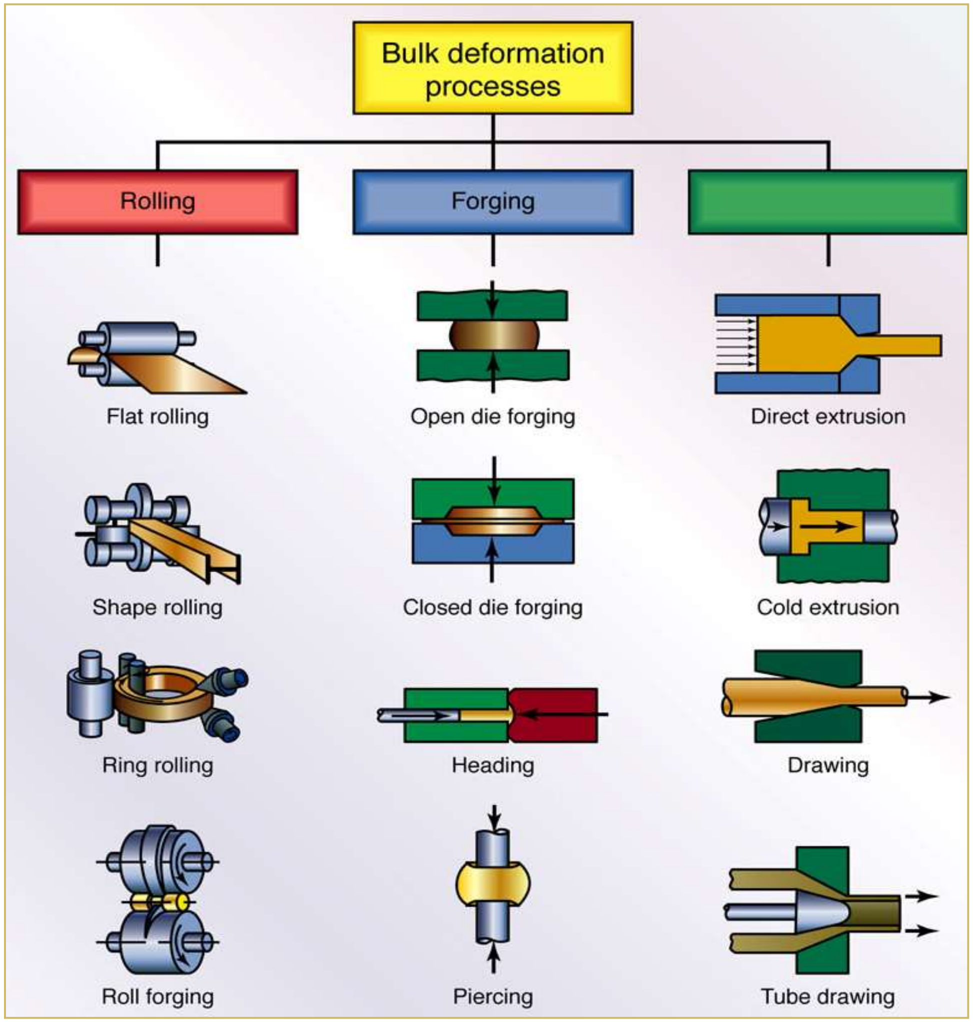


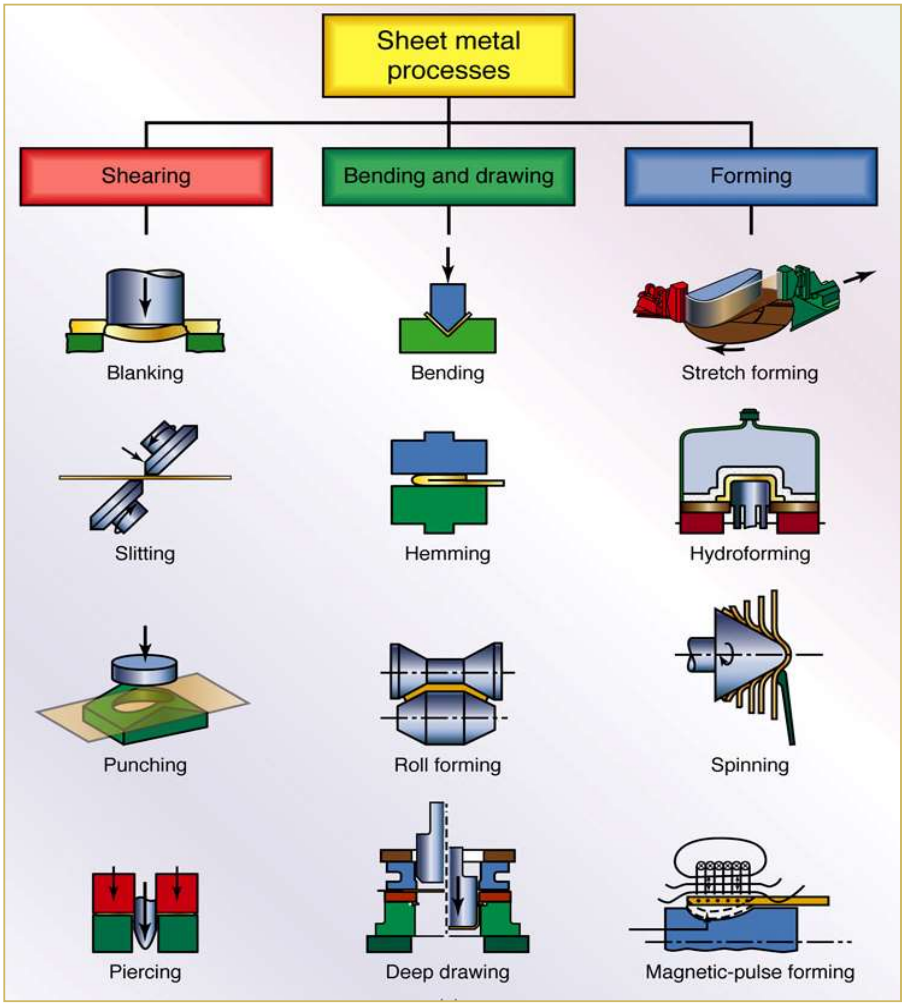
- Manufacturing processes
  - Processing operations
    - Shaping processes
      - Solidification processes
      - Particulate processing
      - Deformation processes
      - Material removal
    - Property enhancing processes
      - Heat treatment
    - Surface processing operations
      - Cleaning and surface treatments
      - Coating and deposition processes
  - Assembly operations
    - Permanent joining processes
      - Welding
      - Brazing and soldering
      - Adhesive bonding
    - Mechanical fastening
      - Threaded fasteners
      - Permanent fastening methods


Casting processes
Expendable pattern and mold and other
Expendable mold, permanent pattern
Permanent mold
Investment casting
Sand casting
Permanent-mold casting
Lost foam casting
Shell-mold casting
Die casting
Single-crystal casting
Ceramic-mold casting
Centrifugal casting
Melt-spinning process
Squeeze casting

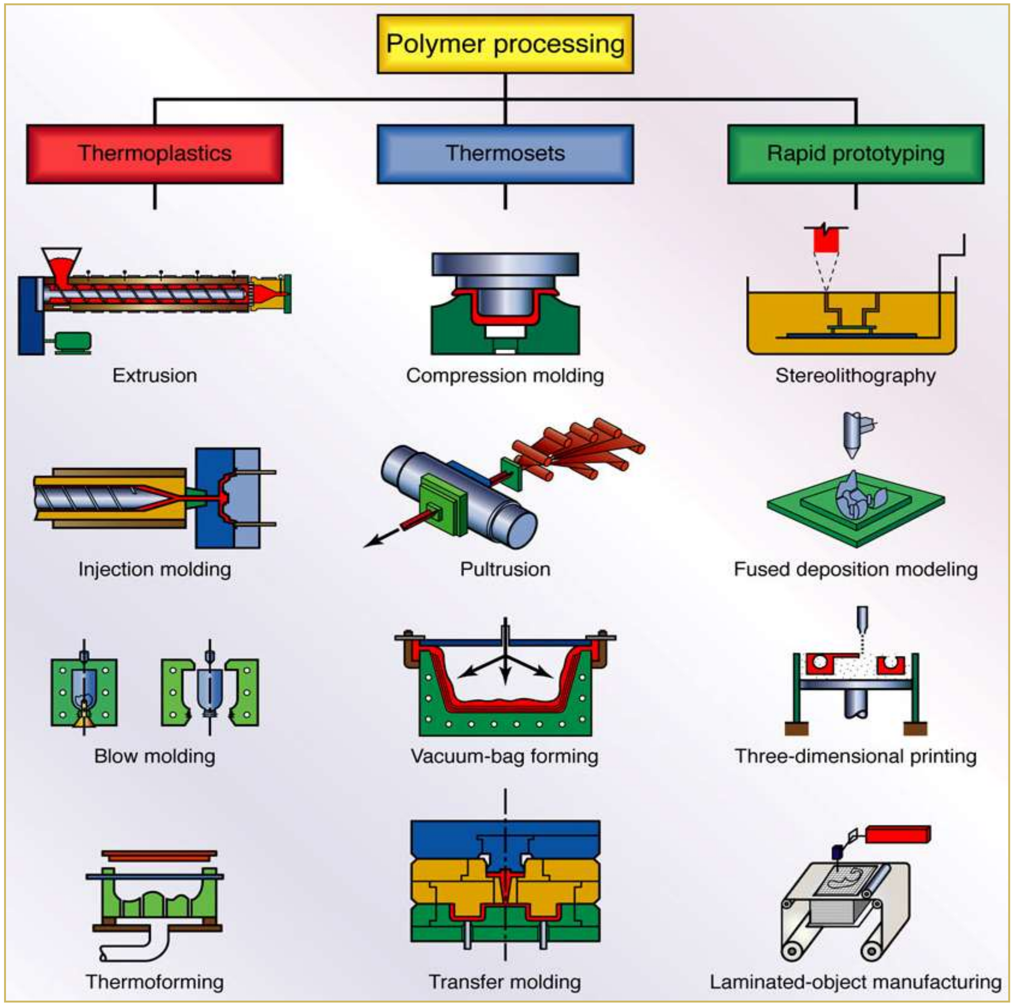

Joining processes
Fusion welding
Other welding
Fastening and bonding
Shielded metal arc welding
Friction stir welding
Adhesive bonding
Gas-metal arc welding
Resistance welding
Bolted connection
Flux-cored arc welding
Explosion welding
Wave soldering
Gas-tungsten arc welding
Cold welding
Brazing


Machining and finishing processes
Machining
Advanced machining
Finishing
Turning
Wire EDM
Surface grinding
Drilling
Chemical machining
Centerless grinding
Milling
Laser machining
Lapping
Broaching
Water-jet machining
Electrochemical polishing
(1)
(2)


Bulk deformation processes
Rolling
Forging
Flat rolling
Open die forging
Direct extrusion
Shape rolling
Closed die forging
Cold extrusion
Ring rolling
Heading
Drawing
Roll forging
Piercing
Tube drawing



- Sheet metal processes
  - Shearing
    - Blanking
    - Slitting
    - Punching
    - Piercing
  - Bending and drawing
    - Bending
    - Hemming
    - Roll forming
    - Deep drawing
  - Forming
    - Stretch forming
    - Hydroforming
    - Spinning
    - Magnetic-pulse forming



- Polymer processing
  - Thermoplastics
    - Extrusion
    - Injection molding
    - Blow molding
    - Thermoforming
  - Thermosets
    - Compression molding
    - Pultrusion
    - Vacuum-bag forming
    - Transfer molding
  - Rapid prototyping
    - Stereolithography
    - Fused deposition modeling
    - Three-dimensional printing
    - Laminated-object manufacturing

Manufacturing Products

Business and Industry

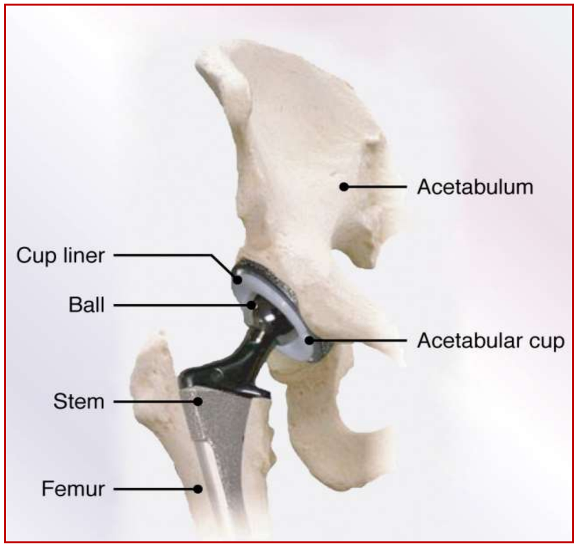
Computer Equipment

Furniture

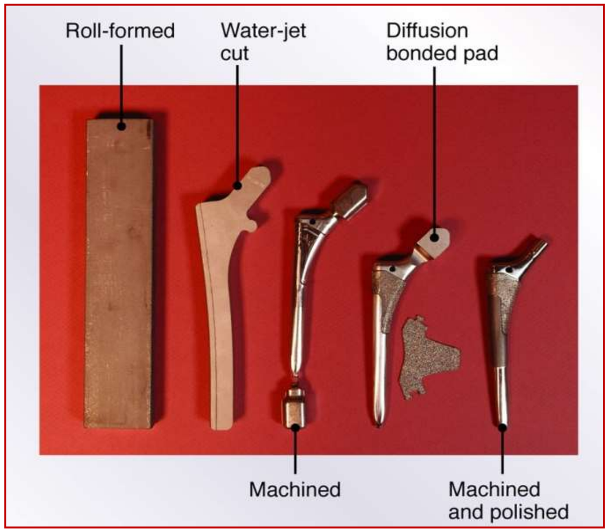
Medical and Scientific

Transportation

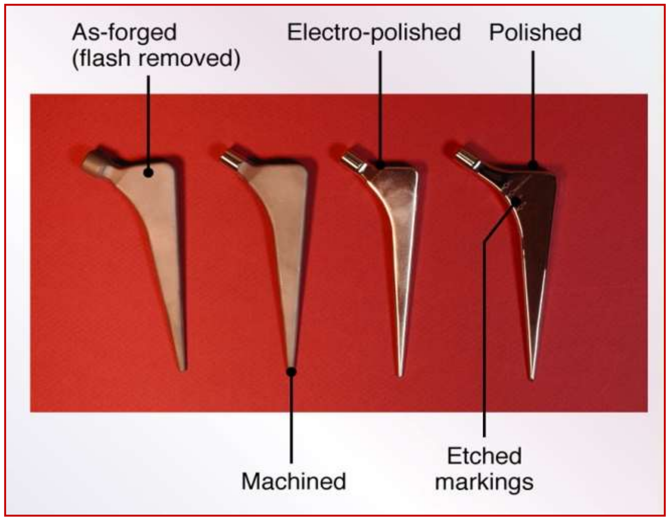
Hip Replacement



Components of a total hip replacement.

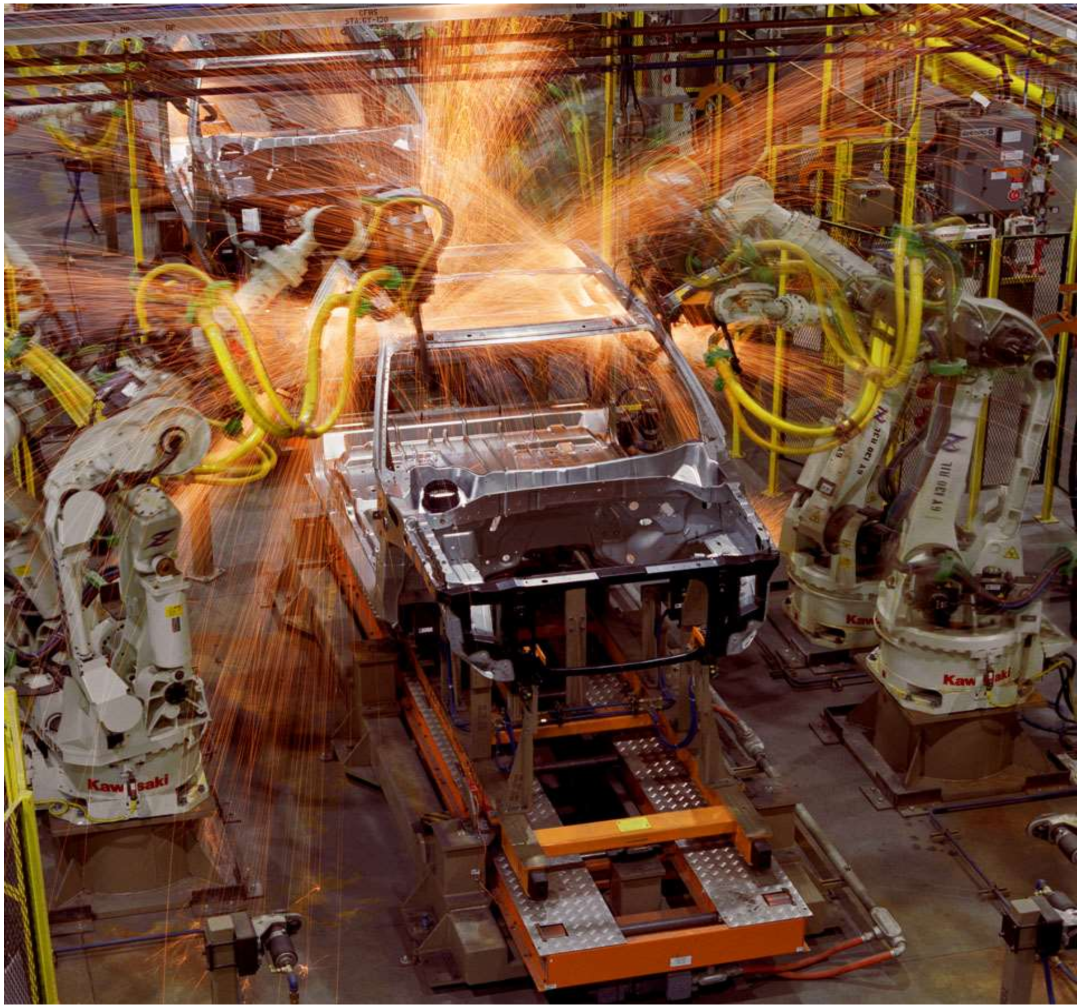


Manufacturing steps in the production of a roll-formed and machined total hip replacement stem



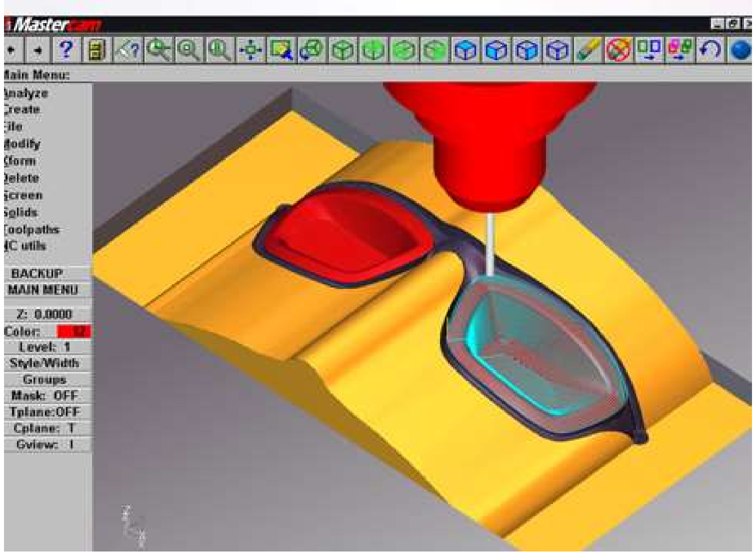
Manufacturing steps in the production of a forged stem. Hip stems can also be produced by investment casting, metal injection molding, insert injection molding, and other processes.

Automated welding of automobiles



Automated spot welding of automobile bodies in a mass production line.

CAD/CAM to Make Sunglasses Mold



Computer model of the sunglass as designed and viewed on the monitor.

Machine the die cavity using a CNC milling machine

Final product

LECTURE-01: METAL CASTING PROCESSES

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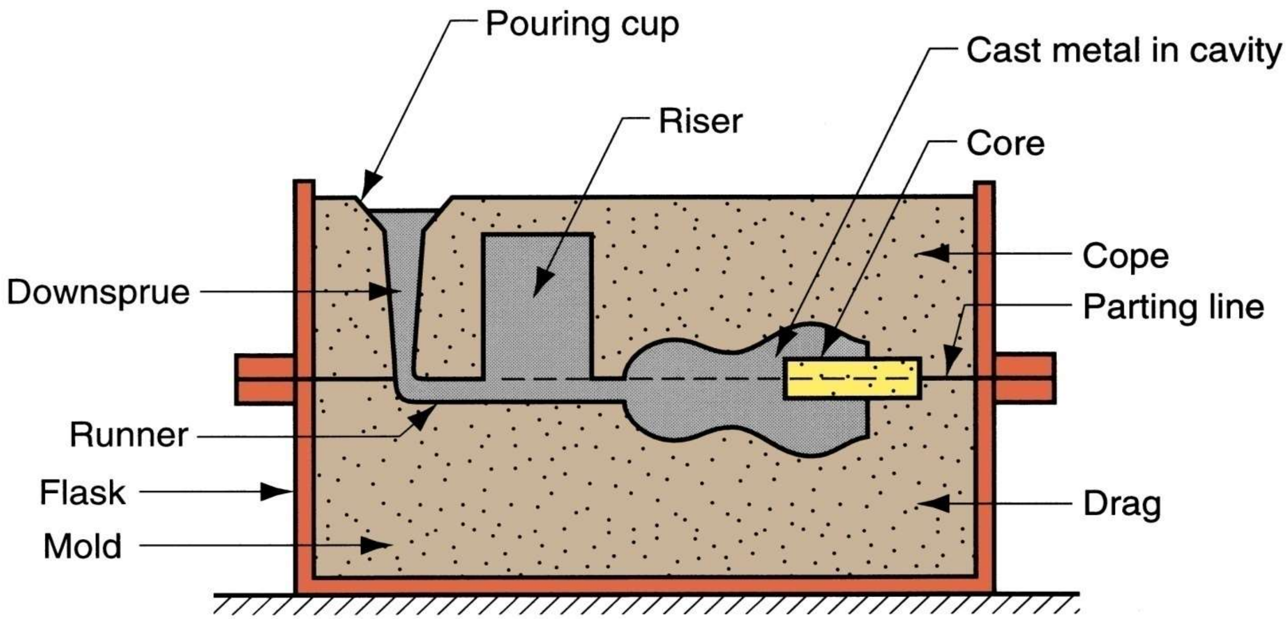
Introduction

Casting is the process of production of objects by pouring molten material in to a cavity called a **mold** which is the **negative of the object**, and allowing it to cool and solidify. Sand casting is a means of producing rough metal castings using a mold usually made from sand formed around a replica of the object to be cast that is removed once the sand has been compacted.



Pattern Materials for Casting

A pattern has been defined as a model of an object to form a cavity of a sand mold for casting. The pattern is like the original object with some dimensional allowances. The following material are used for making pattern:

- Wood
  - Advantages: (i) Easily available (ii) Cheap (iii) Light in weight (iv) Easy to work and (iv) Good finish.
  - Disadvantages: (i) readily affected by moisture (ii) wear out quickly by sand abrasion (iii) warp badly if not stored properly (iv) less strength, tends to break on miss-handling (v) shape changes when dries out and (vi) does not last long
- Metals: Aluminium, Cast iron, Brass, White metal etc.
  - Advantages: (i) no effect of moisture and (ii) no cracking, bending etc. due to improper storing
  - Disadvantages: (i) less easy to shape and work (ii) heavy in weight (iii) costly and (iv) affected by rust or corrosion
- Plaster-Gypsum Cement
- Plastic Compound
- Wax

Pattern Allowances

- **Shrinkage Allowance**: The pattern needs to incorporate suitable allowances for shrinkage; these are called contraction allowances, and their exact values depend on the alloy being cast and the exact sand casting method being used. Some alloys will have overall linear shrinkage of up to 2.5%, whereas other alloys may actually experience no shrinkage or increase in size in the casting process. The shrinkage amount is also dependent on the sand casting process employed, for example clay-bonded sand, chemical bonded sands, or other bonding materials used within the sand.
- **Draft or Taper Allowance**: The pattern needs to incorporate suitable allowances for draft, which means that its sides are tapered so that when it is pulled from the sand, it will tend not to drag sand out of place along with it. This is also known as taper which is normally between 1^0 and 3^0.
- **Distortion Allowance:** it is found that big castings tend to warp or distort during the cooling period due to their size, shape and type of metal. Uneven shrinkage also causes distortion. To overcome this effect, the pattern s made initially distorted in opposite direction. Such an allowances depends on the judgment and experience of the pattern maker who knows the shrinkage characteristics of the metal.

- **Finishing or Machining Allowance:** The rough surfaces of the casting are to be finished or machined. Therefore, the rough casting must be made bigger than the actual component in size and hence the pattern should also be bigger in size than the actual component.
- **Shaking or Rapping Allowance:** When the pattern is rapped or shaken for easy removal from the cavity, it is found the cavity in the mold is slightly increased in size. To compensate this increase, the pattern should be initially made slightly smaller. In small and medium sized castings, this allowance can be ignored, but in large sized castings or in those that must fit together without machining or where high precision is required, shaking allowance is provided by making the pattern slightly smaller.

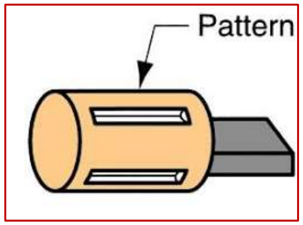
Types of Pattern

Variety of patters are used in casting and the choice depends on the configuration of casting and number of casting required. The type of pattern selected for a particular casting will depends on the following several conditions:

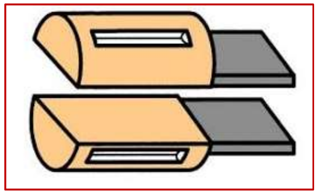
- Shape and size of casting
- Number of casting required
- Method of molding used
- Difficulty of the molding operation.
- Characteristics of castings

- Different types of patterns:
  - Single piece pattern
  - Split pattern
  - Loose piece pattern
  - Gated pattern
  - Match plate pattern
  - Sweep pattern
  - Cope and drag pattern
  - Skeleton pattern
  - Shell pattern
  - Follow board pattern

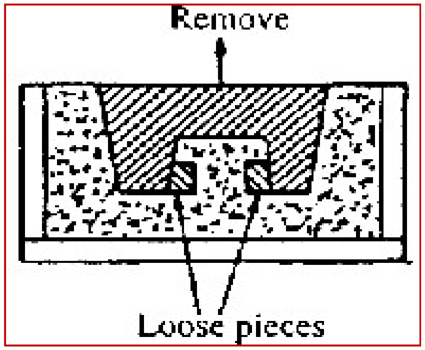
- **Single piece pattern**: This type of pattern is made without joints, partings or any loose pieces. The molder has to cut gates and users in the sand mold by hand by which process it is difficult to obtain uniformity in the casting. The single piece pattern is generally used for large casting of simple shape.

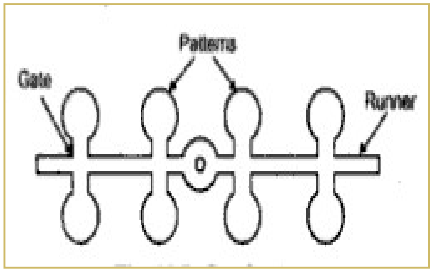


- **Split pattern** : A split pattern is made in two or more parts joined together by dowel pins. When the casting is of peculiar design and intricate shape, its pattern cannot be made in single piece, because it cannot be withdrawn from the mold. Therefore such a pattern is made split in two or more pieces.

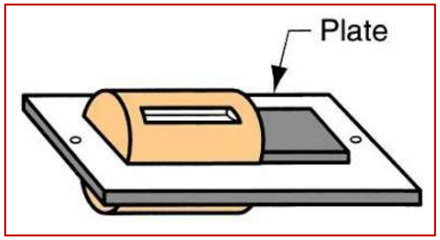


- **Loose piece pattern** : Loose piece pattern is made of loose component pieces assembled together by dowel pins. The whole pattern can be removed from the sand mold by taking out all the component pieces one by one. The main piece is usually removed first, after that the separate loose pieces, which may have to be turned or moved before taking out, are removed.

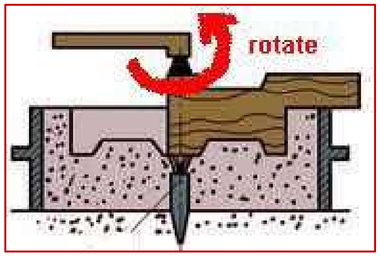




- **Gated pattern** : Gated pattern are used for mass production of small castings. The passage through which the molten metal flows into the mold is called gate. In mass production if the gate is made by hand for every small mold, it will take a lot of time. Therefore, a number of small castings are produced in a single multi-cavity mold by joining a number of patterns through gates.

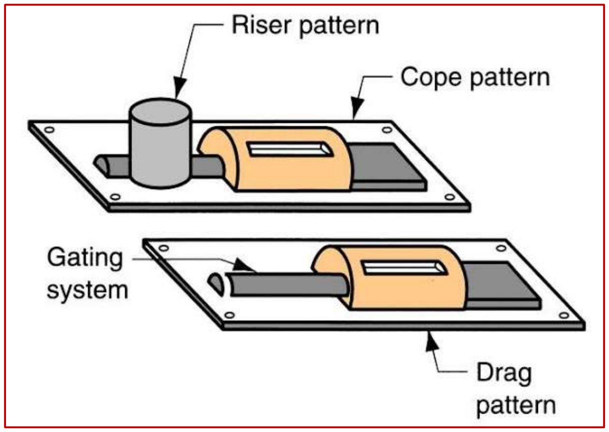


- **Match plate pattern** : When split patterns are mounted with one half on one side of a plate and the other half directly opposite on the other side of the plate, the pattern is called match plate pattern. On one plate, called the match plate, many patterns can be mounted.

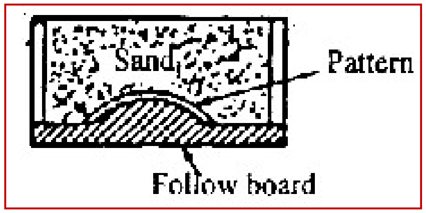


- **Sweep pattern** : The sweep pattern are used to prepare mold of symmetrical and regular shapes particularly in large sizes. A sweep pattern consists of a wooden board fixed to metal rod. The outer contour of the board is similar to the contour of the castings.

- **Cope and drag pattern**: If the casting is large, the complete mold is too heavy and difficult to handled by a single operator. For such castings the cope and drag patterns are made. The pattern is made in two halves, split on a convenient joint line. The first half is in cope and the other half in drag. After removing the two halves from the molding sand, the cope and drag are then assembled to make the complete mold.



- **Follow board pattern**: The pattern having thin sections, tend to get distorted or collapse during ramming. Sagging of thin pattern due to ramming can be easily overcome by constructing a supporting block (follow board) which may fit inside the pattern to serve as a support during ramming.



Molding Sand

Molding sand is the principal raw material used in molding because it possesses several major characteristics required for molding. The molding sands classified into two categories according to the nature of its origin.

- **Natural or Green sand**: It is collected from natural resources like river beds or is dug from pits. It contains the only binder as water. It has the advantages of maintaining moisture content for a long time, wide working range of moisture content and permits easy patching and finishing of molds
- **Synthetic sand**: It is an artificial sand prepared in the foundry by mixing clay free sand, binder and other materials as required. Its properties can be easily controlled by mixture content. Advantages of synthetics sand
  - Low sand maintenance cost
  - Improved permeability, lower moisture
  - Easier to work on mass production molding
  - Semi-skilled workers can work on machine molding
  - No sand dumping

Properties of Molding Sand

- **Refractoriness**: It is the property by virtue of which the sand can withstand high temperatures without fusing. This property is very important because always molten metals with high temperature are poured in it and poor refractoriness would cause fusion of the sand. As a result slag will form which will come on the surface of the casting to spoil it. The degree of refractoriness depends upon the casting metals.
- **Permeability**: Permeability is also called porosity. It is the property by virtue of which the molding sand permits the escape of gasses and steam through it. As the hot molten metal is poured in the cavity, steam and gasses are formed due to the heat of the metal. These gasses must escape to atmosphere otherwise if either the mold may burst or blow holes in the casting will be formed.
- **Cohesiveness**: It is property by virtue of which the sand particles stick together. So cohesiveness provides sufficient bond to hold together. It is also referred to as strength. This is also a very important property, that the molding sand must have. Because lack of this property would result in breaking of the mold when the molten metal is poured in it.

- **Adhesiveness**: The property to adhere with other materials is adhesiveness. It is this property by virtue of which the molding sand is held successfully in the molding flask and does not fall out of the flask when it is removed.
- **Plasticity or Flowability**: It is the property of the molding sand due to which it acquires a predetermined shape under pressure and retains the same when the pressure is removed. When once the mold is made by fixing the pattern in the sand and ramming it the shape of the mold should not disturb after the taking out the pattern from the sand.

Types of Moldings

Casting is a process in which a liquid is poured into a mold in order to produce a product. There are several types of molds that are used in the casting process. Some are temporary and are destroyed during the casting process. Others are permanent and are reused again and again. The type of mold are as follows:

- **Green sand molding**: Green sand molding is a type of molding in which the mold is in moist state while pouring the metal into it. Here the word green means wet or moist. Green sand molding is widely used for casting practically all ferrous and non ferrous alloys. It is suitable for small, medium and often large castings. The advantages and disadvantages of green sand molding are as follows:
  - **Advantages**:
    - It is cheap and least expensive method
    - Green sand molds do not require baking operation hence non-baking equipments
    - Green sand molding is less time consuming
  - **Disadvantages**:
    - It is not very strong hence liable to be damage during handling
    - The surface finish of the casting is not very good
    - The green sand molds cannot be stored for long time

- **Dry sand molding**: Dry sand molding is similar to the green sand molding but the mold is dried or baked before pouring, until the moisture is driven off. The drying of mold increases its strength, erosion resistance and improves surface condition. The dry sand molds are stronger and can be handled more easily with less damages and can be stored for a long time.
  - **Advantages**:
    - Dry sand molds are generally stronger than green sand molds and therefore can withstand much additional handling.
    - Better dimension control than if they were molded in green sand.
    - The improved quality of the sand mixture due to the removal of moisture can result in a much smoother finish on the castings than if made in green sand molds. Where molds are properly washed and sprayed with refractory coatings, the casting finish is further improved.
  - **Disadvantages**:
    - This type of molding is much more expensive than green sand molding and is not a high-production process. Correct baking (drying) times are essential.

- **Skin dry molding**: Skin-dried molding are sometimes preferred to green sand molding where assurance is desired that the surface moisture and other gas-forming materials are lowered. By skin drying the face of the mold after special bonding materials have been added to the sand molding mixture, a firm mold face is produced similar to that obtained in dry sand practice. Shakeout of the mold is almost as good as that obtained with green sand molding. Skin-dried molds are commonly employed in making medium-heavy and heavy castings.
  - **Advantages:**
    - Less equipments is needed than for making a dry sand molding
    - Skin dry molding takes less time than dry sand molding
    - This types of mold is stronger than green sand mold
    - This process reduces surface moisture and other gas-forming materials from mold
  - **Disadvantages:**
    - These molds are more expensive to produce. Mold sections must be completely dry and cool prior to assembly

- **Loam molding**: These molding are used for very large ferrous work. It is prepared with brick or large iron pieces. These pieces are plastered with a thick loam mortar and then dried. These molds are very strong and has all the advantages over dry sand molds.
  - **Disadvantages:**
    - It takes quite long time to prepare the mold
    - The material of the molds cannot be reused. So it is expansive.
- **Metal molding**: Metal molding consists of the molds made of metal. Metal mold are used for small and accurate castings. Die casting, centrifugal casting, permanent mold casting are the processes in which metal molds are used.
  - **Advantages:**
    - It has very long life and it does not get eroded on metal pouring
    - It can be stored for a long time
    - The castings have smooth surface and accurate shape
  - **Disadvantages:**
    - The metal mold is costly
    - Once the mold is made it is difficult to change its shape. It take longer time to make mold.

Casting Terminology

Flask : The box containing the mold
Cope : The top half of any part of a 2-part mold
Drag : The bottom half of any part of a 2-part mold
Core : A shape inserted into the mold to form internal cavities
Core Print : A region used to support the core
Mold Cavity : The hollow mold area in which metal solidifies into the part
Riser : An extra cavity to store additional metal to prevent shrinkage
Gating System : Channels used to deliver metal into the mold cavity
Pouring Cup : The part of the gating system that receives poured metal
Sprue : Vertical channel
Runners : Horizontal channels
Parting Line : Interface that separates the cope and drag of a 2-part mold
Core Box : Mold or die used to produce cores
Chaplets : Chaplets are small metal props, placed in the mold cavity to support the core.

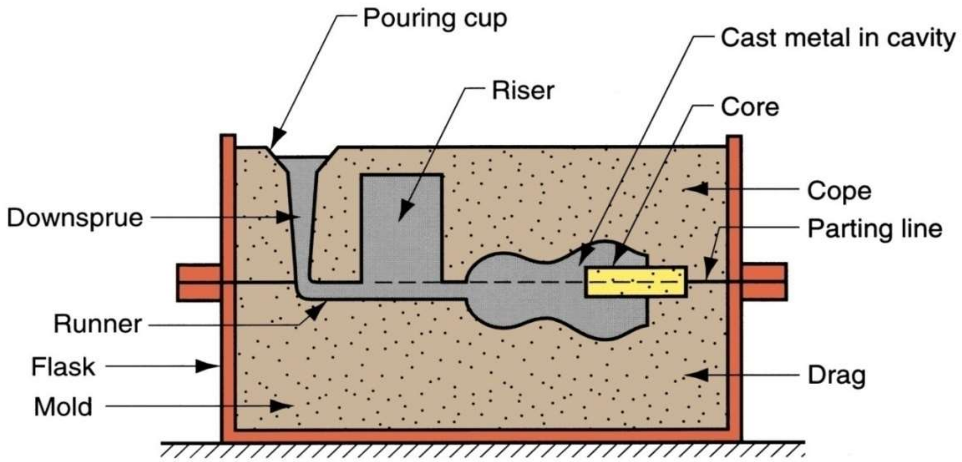
Casting Processes

- The different casting processes are as follows:
  - Sand casting
  - Permanent mold casting
  - Slush casting
  - Pressed casting
  - Die casting
  - Centrifugal casting
  - Pressure casting
  - Investment or lost-wax casting
  - Plaster casting
  - Continuous casting
  - Chill casting
  - Malleable casting

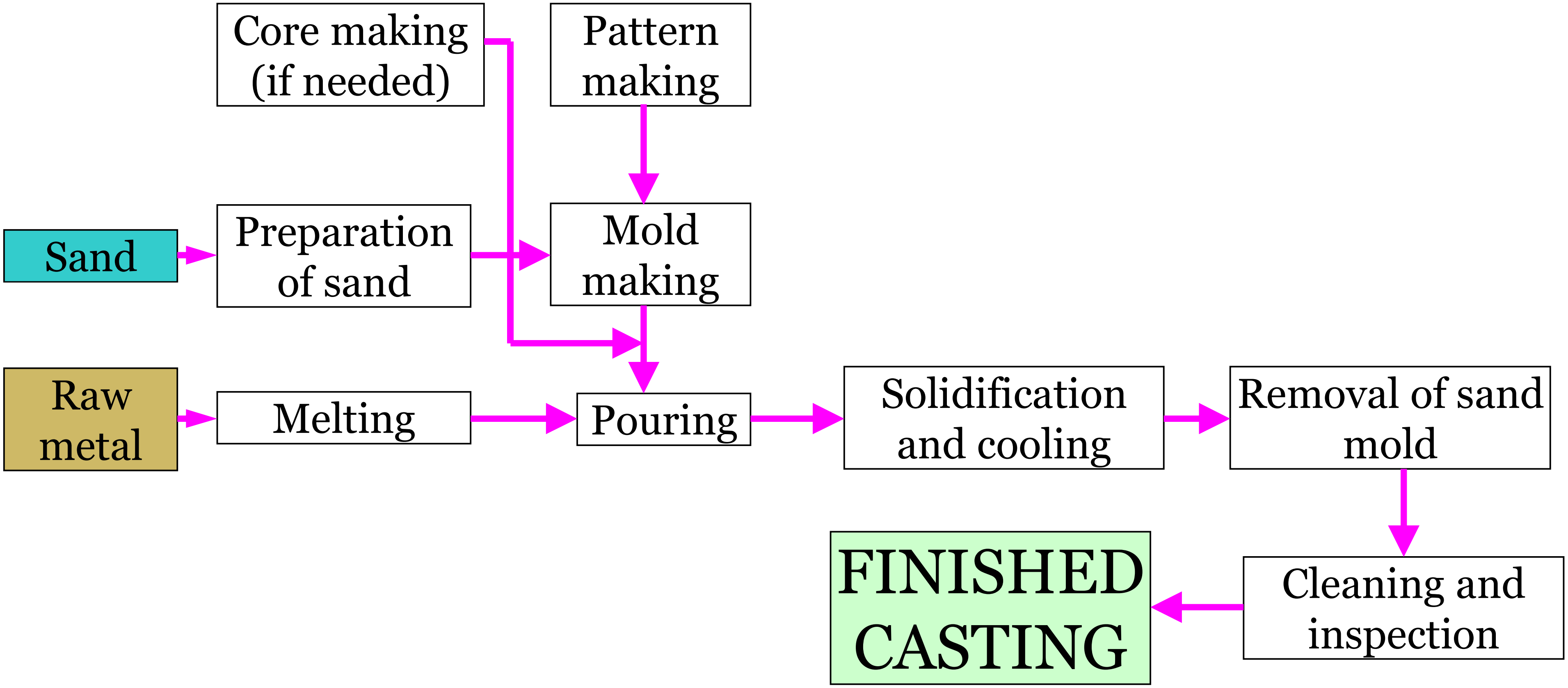
Sand Casting

A sand casting or a sand molded casting is a cast part produced by forming a mold from a sand mixture and pouring molten liquid metal into the cavity in the mold. The mold is then cooled until the metal has solidified. In the last stage the casting is separated from the mold. There are six steps in this process:

- Place a pattern in sand to create a mold.
- Incorporate a gating system.
- Remove the pattern.
- Fill the mold cavity with molten metal.
- Allow the metal to cool.
- Break away the sand mold and remov



Steps in Sand Casting



Core making (if needed)

Pattern making

Sand

Preparation of sand

Mold making

Raw metal

Melting

Pouring

Solidification and cooling

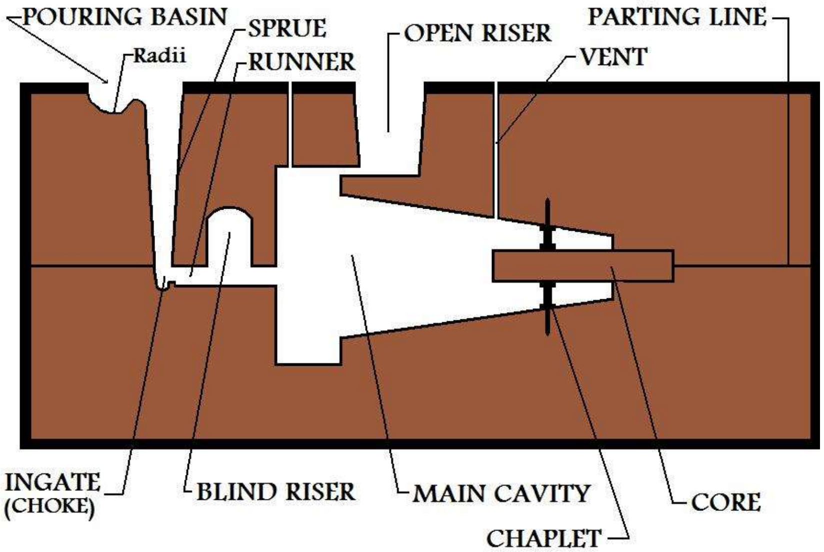
Removal of sand mold

Cleaning and inspection

FINISHED CASTING

Elements of a Gating System

- **Pouring Basin**: This is where the molten metal employed to manufacture the part enters the mold. The pouring basin should have a projection with a radius around it to reduce turbulence.
- **Down Sprue**: From the pouring basin, the molten metal for the casting travels through the down sprue. This should be tapered so its cross-section is reduced as it goes downward.
- **Sprue Base**: The down sprue ends at the sprue base. It is here that the casting's inner cavity begins.
- **Ingate/Choke Area**: Once at the sprue base, the molten material must pass through the ingate in order to enter the inner area of the mold. The ingate is very important for flow regulation during the metal casting operation.

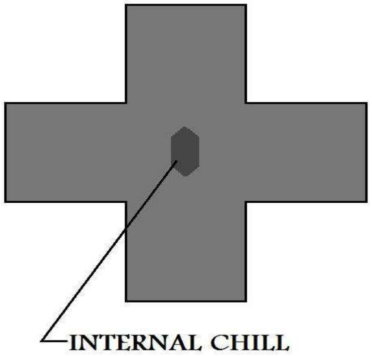


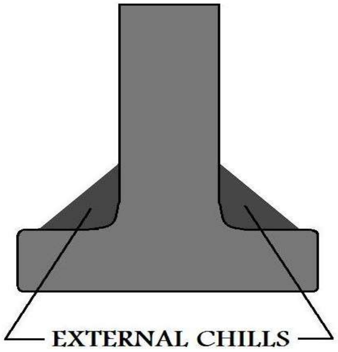
Gating System for Casting

- Runners: Runners are passages that distribute the liquid metal to the different areas inside the mold.
- Main Cavity: The impression of the actual part to be cast is often referred to as the main cavity.
- Vents: Vents help to assist in the escape of gases that are expelled from the molten metal during the solidification phase of the metal casting process.
- Risers: Risers are reservoirs of molten material. They feed this material to sections of the mold to compensate for shrinkage as the casting solidifies. There are different classifications for risers.
  - Top Risers : Risers that feed the metal casting from the top.
  - Side Risers : Risers that feed the metal casting from the side.
  - Blind Risers : Risers that are completely contained within the mold.
  - Open Risers : Risers that are open at the top to the outside environment.

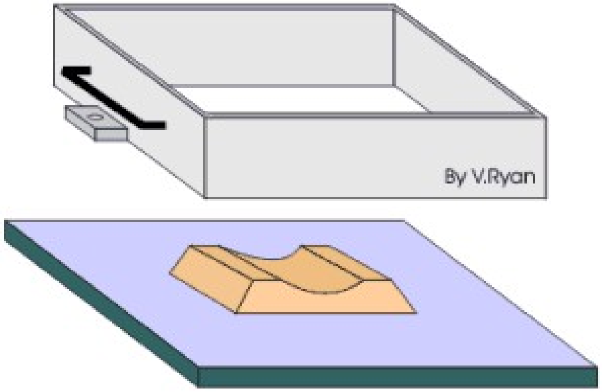
Chills

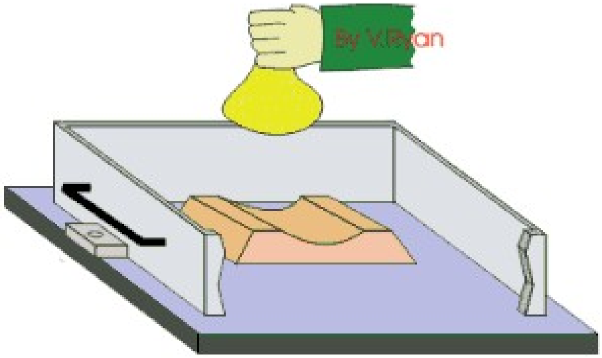
- **Chills**: Directional solidification is very important to the manufacture of a part during the metal casting process, in order to ensure that no area of the casting is cut off from the flow of liquid material before it solidifies. To achieve directional solidification within the metal casting, it is important to control the flow of fluid material and the solidification rate of the *different areas of the metal casting*. Chills are small pieces of metal, capable of quick heat absorption. They are placed inside the mold cavity before pouring. Chills are of two basic types.
  - Internal chills are located inside the mold cavity and are usually made of the same material as the casting. When the metal solidifies the internal chills are fused into the metal casting itself.
  - External chills are located just outside of the casting. External chills are made of a material that can remove heat from the metal casting faster than the surrounding mold material. Possible materials for external chills include iron, copper, and graphite.

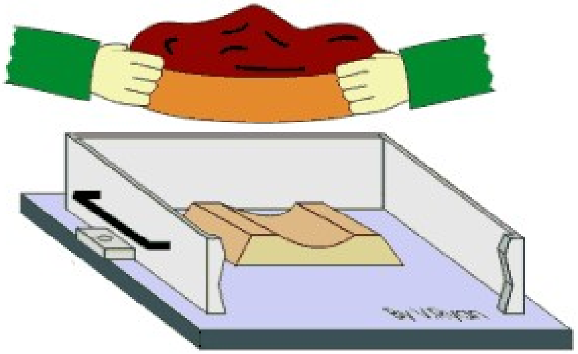


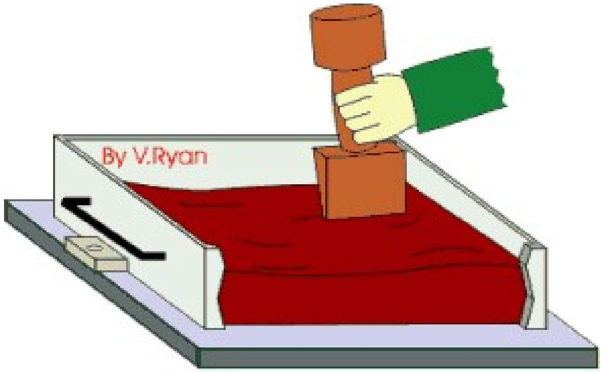


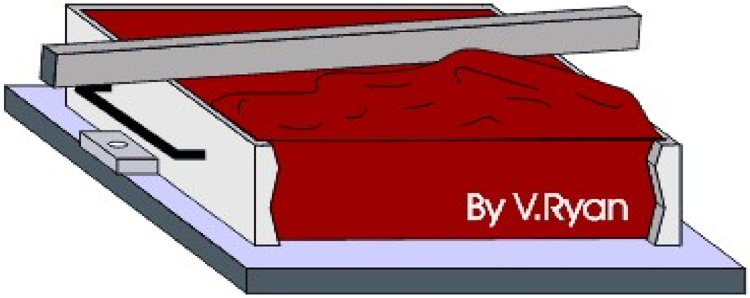
Animation of Sand Casting Step

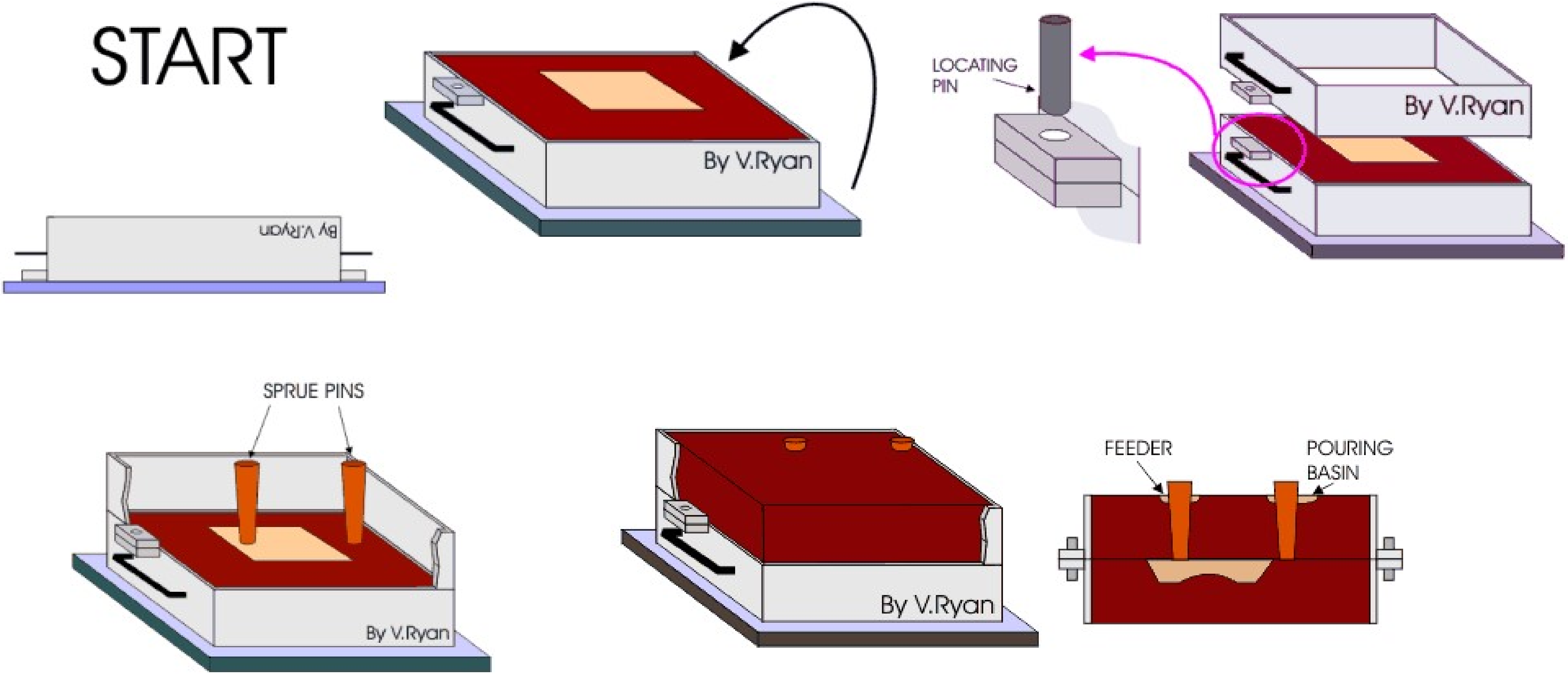








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By V.Ryan
By V.Ryan
LOCATING PIN
By V.Ryan
SPRUE PINS
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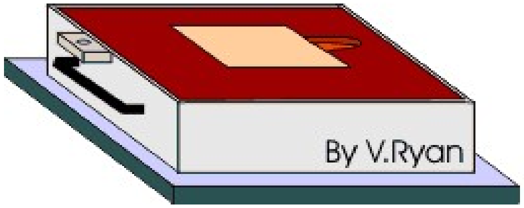
By V.Ryan
FEEDER
POURING BASIN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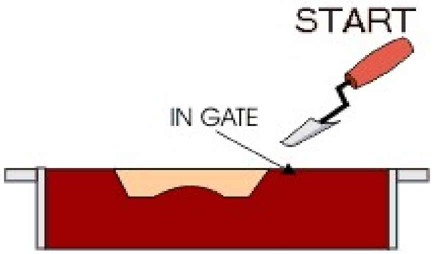
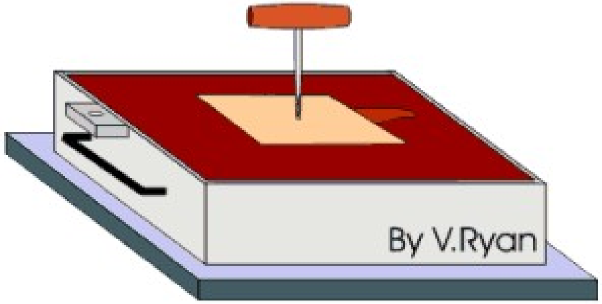

START
IN GATE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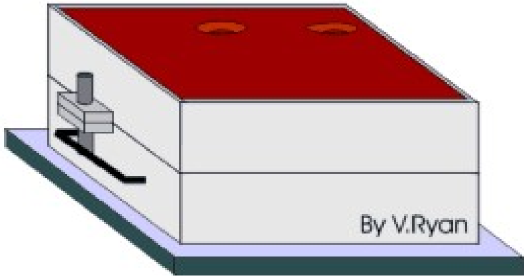
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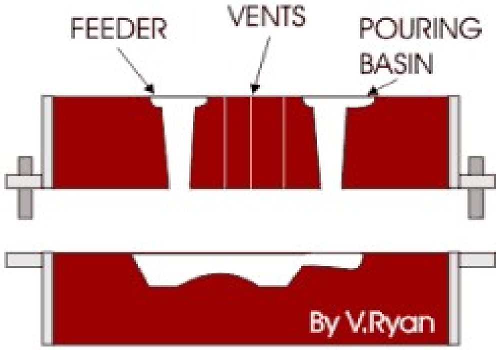
FEEDER
VENTS
POURING
BASIN
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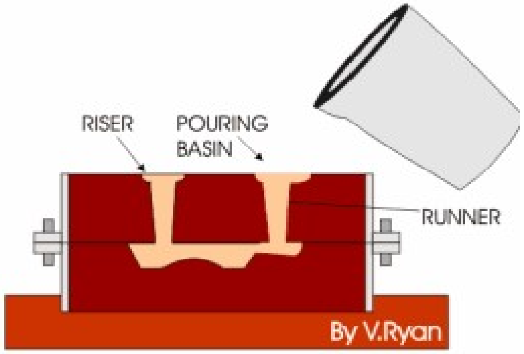
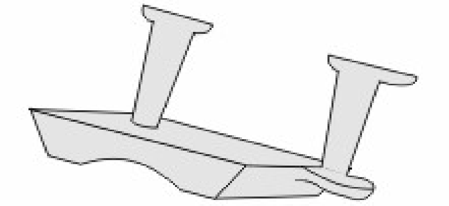
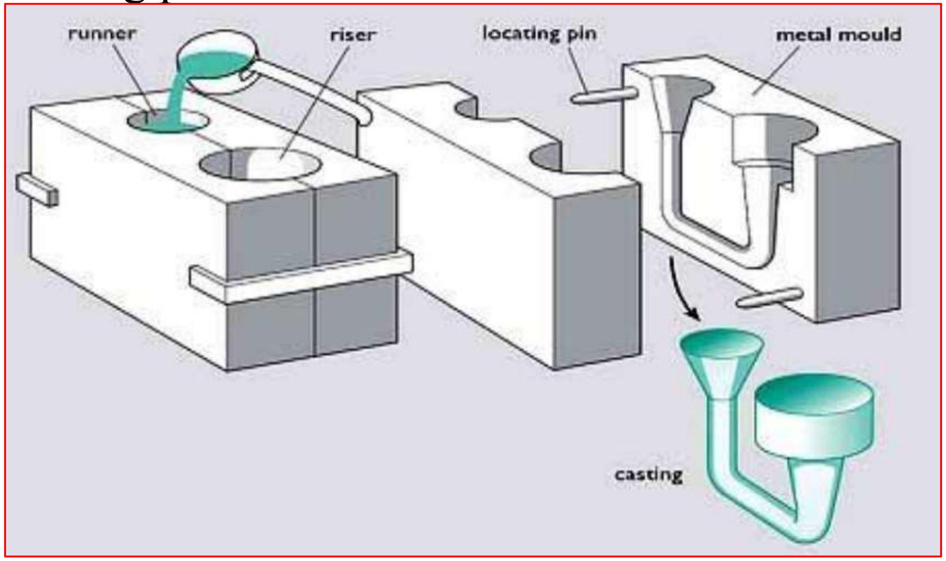

RISER
POURING
BASIN
RUNNER
By V.Ryan

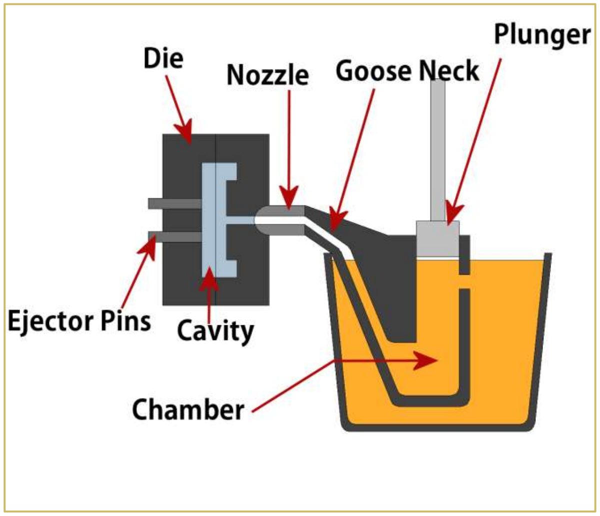


Die Casting

- **Gravity-Die Casting:** Following Figure, is similar to sand casting except that the mould is machined from solid metal, usually cast iron. This means that the mould and cavity are permanent. Being metal, the mould can be machined accurately and, having good thermal conductivity, it allows the casting to cool quickly. The surface finish is better than can be produced by sand casting, but as metal moulds are required, product sizes are generally smaller than those possible with sand casting. Typical products include bicycle cranks and engine pistons and rims for tubeless tyres. Of course, the metal being cast must have a lower melting point than the mould metal.



- **Pressure-Die Casting:** It is a development of gravity-die casting in which the molten metal is injected into a steel mould under pressure; it is the metal equivalent of injection molding. Again, the metal being cast must have a lower melting point than the mould material. Pressure-die casting is quicker than sand and gravity die casting and because the fluid is under pressure, finer surface details can be replicated. It is commonly used for door handles, electric iron bases and hollow sections requiring fine detail such as carburetor bodies.

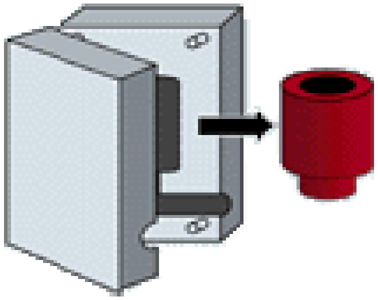


Break Drum Aluminum
Pressure Die Casting

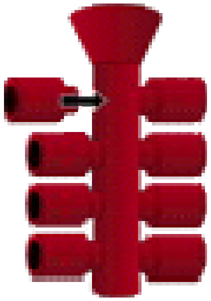
Pressure Die Casting-Engine block

- Advantages:
  - Cost of castings is relatively low with high volumes.
  - High degree of design complexity and accuracy.
  - Excellent smooth surface finish.
  - Suitable for relatively low melting point metals (871^0C) like lead, zinc, aluminum, magnesium and some copper alloys.
  - High production rates.
- Disadvantages:
  - Castings must be smaller than 600mm and the thickest wall section should be kept below 13mm
  - High initial cost (Cost of moulds and machine set up)
  - A large production volume is required to make the process cost effective
  - Some porosity is common with die casting
  - Die casting is limited to high fluidity metals (Zinc, Aluminium, Magnesium, Copper, Lead and Tin)

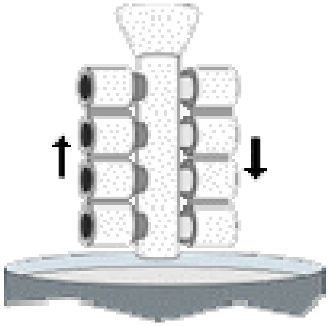
Investment or Lost-Wax Casting



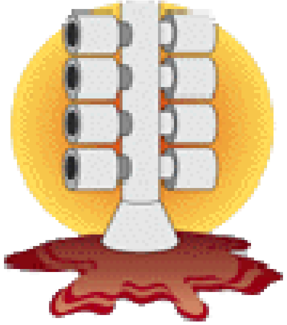
1. WAX INJECTION: Wax replicas of the desired castings are produced by injection molding. These replicas are called patterns.



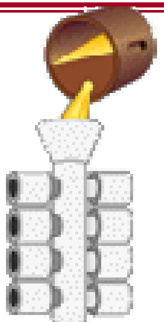
2. ASSEMBLY: The patterns are attached to a central wax stick, called a sprue, to form a casting cluster or assembly.



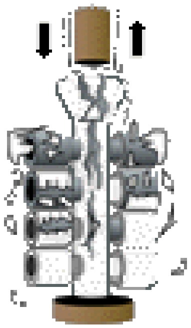
3. SHELL BUILDING: The shell is built by immersing the assembly in a liquid ceramic slurry and then into a bed of extremely fine sand. Up to eight layers may be applied in this manner.



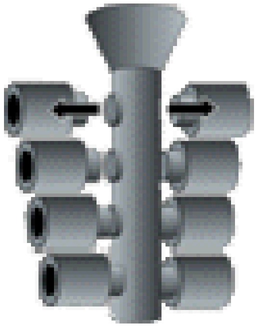
4. DEWAX: Once the ceramic is dry, the wax is melted out, creating a negative impression of the assembly within the shell.



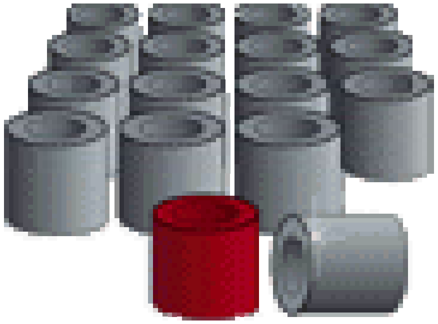
5. CONVENTIONAL CASTING: In the conventional process, the shell is filled with molten metal by gravity pouring. As the metal cools, the parts and gates, sprue and pouring cup become one solid casting.



6. KNOCKOUT: When the metal has cooled and solidified, the ceramic shell is broken off by vibration or water blasting.



7. CUT OFF: The parts are cut away from the central sprue using a high speed friction saw.

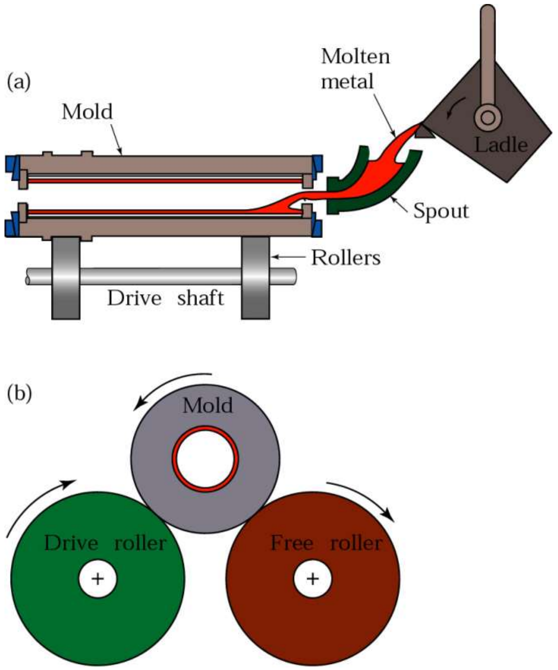


8. FINISHED CASTINGS: After minor finishing operations, the metal castings-identical to the original wax patterns-are ready for shipment to the customer.

- **Advantages**
  - Excellent accuracy and flexibility of design.
  - Useful for casting alloys that are difficult to machine.
  - Exceptionally fine finish.
  - Suitable for large or small quantities of parts.
  - Almost unlimited intricacy.
  - Suitable for most ferrous / non-ferrous metals.
  - No flash to be removed or parting line tolerances.
- **Disadvantages**
  - Limitations on size of casting.
  - Higher casting costs make it important to take full advantage of the process to eliminate all machining operations.

Centrifugal Casting

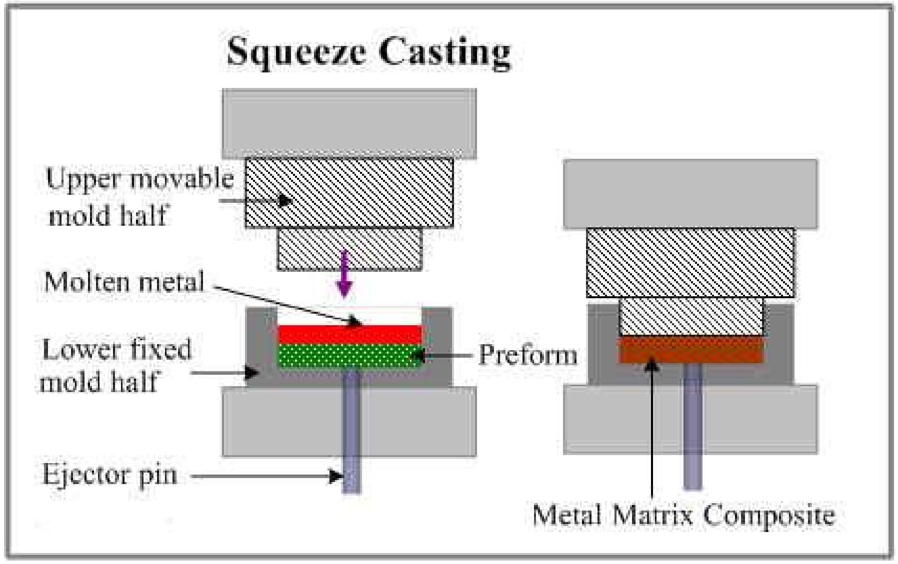
A permanent mold made of metal or ceramic is rotated at high speed (300 to 3000 rpm). The molten metal is then poured into the mold cavity and due to centrifugal action the molten metal conform to the cavity provided in the mould. Castings are known for their higher densities in the outer most regions. The process gives good surface finish. Applications: pipes, bushings, gears, flywheels etc.



Schematic illustration of the centrifugal casting process. Pipes, cylinder liners, and similarly shaped parts can be cast with this process.

Squeeze Casting

Squeeze casting, also known as liquid metal forging, is a combination of casting and forging process. The molten metal is poured into the bottom half of the pre-heated die. As the metal starts solidifying, the upper half closes the die and applies pressure during the solidification process. The amount of pressure thus applied is significantly less than used in forging, and parts of great detail can be produced. Coring can be used with this process to form holes and recesses. The porosity is low and the mechanical properties are improved. Both ferrous and non-ferrous materials can be produced using this method.



Comparison of Casting Process

Casting Processes	Advantages	Limitations
Sand Casting	■ Almost any metal can be cast ■ No limit on size and shape ■ Low equipment coat ■ Economical for low volume production	■ Coarse finish ■ Dimensional accuracy not so good ■ Finishing required ■ Low production rate
Investment Casting	■ Almost any metal can be cast ■ Good surface finish & dimensional accuracy ■ Fairly high production rate ■ Intricate shapes can be cast ■ Low finishing cost	■ Limitation on part size ■ Expensive pattern and mold ■ High labor cost
Die Casting	■ Excellent surface finish ■ Excellent dimensional accuracy ■ High production rate ■ Complex shape can be cast ■ Little or no finishing cost	■ Limitation on part size ■ High cost of die ■ Generally limited to casting of non-ferrous metals
Centrifugal Casting	■ High production rate ■ Good dimensional accuracy and surface finish	■ Expensive set-up ■ Good for production of cylindrical parts only

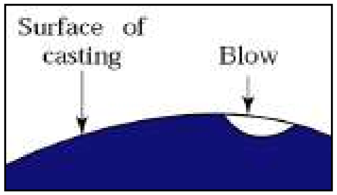
Casting Defects

- Defects may occur due to one or more of the following reasons:
  - Fault in design of casting pattern
  - Fault in design on mold and core
  - Fault in design of gating system and riser
  - Improper choice of molding sand
  - Improper metal composition
  - Inadequate melting temperature and rate of pouring

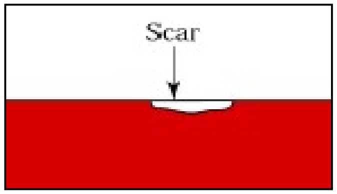
- Casting defects are mainly divided in three categories.
  - Major or most severe defects: They result in scrapping of the casting. Metal penetration and rough surfaces that interfere with machining and finishing operations and casting that fails either to meet physical requirements or functional requirements are some of the examples of this class.
  - Intermediate defects: They result in the high cost of repairs, but save castings from scrapping.
  - Minor defects: They permit the castings to be easily and economically repaired.

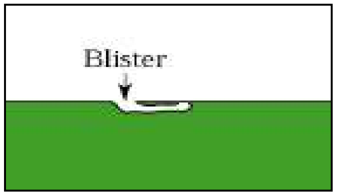
Surface Defect

Blow is relatively large cavity produced by gases which displace molten metal from convex surface.

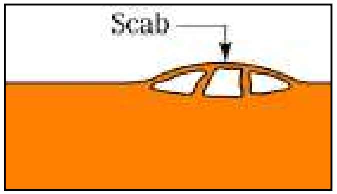


Scar is shallow blow generally occurring on a flat surface. A scar covered with a thin layer of metal is called **blister**. These are due to **improper permeability or venting**.

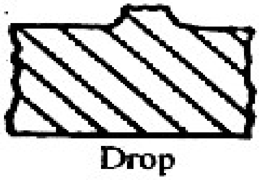




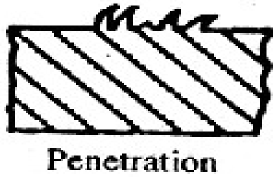
A **scab** when an up heaved sand gets separated from the mould surface and the molten metal flows between the displaced sand and the mold.



Drop is an irregularly-shaped projection on the cope surface caused by dropping of sand.



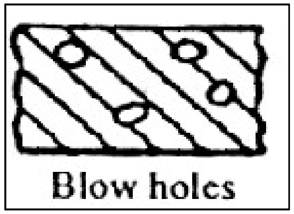
Penetration occurs when the molten metal flows between the sand particles in the mould. These defects are due to **inadequate strength of the mold** and high temperature of the molten metal adds on it.



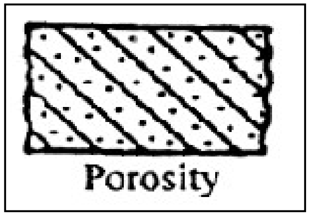
Internal Defects

The internal defects found in the castings are mainly due to trapped gases and dirty metal. Gases get trapped due to hard ramming or improper venting. These defects also occur when excessive moisture or excessive gas forming materials are used for mould making.

Blow holes are large spherical shaped gas bubbles, while **porosity** indicates a large number of uniformly distributed tiny holes.

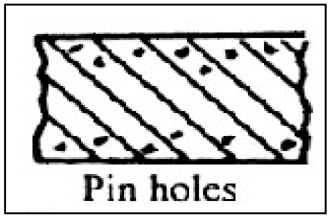


Blow holes



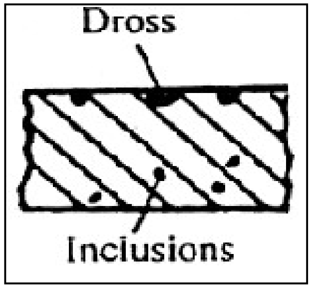
Porosity

Pin holes are tiny blow holes appearing just below the casting surface.



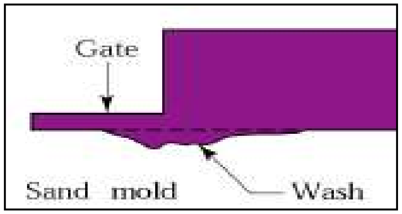
Pin holes

Inclusions are the non-metallic particles in the metal matrix, Lighter impurities appearing the casting surface are **dross**.

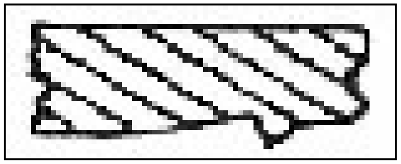


Visible Defects

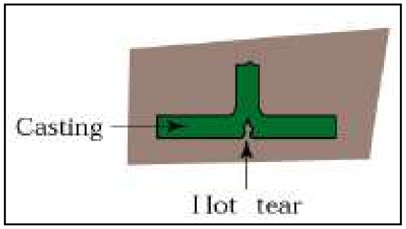
Wash is a low projection near the gate caused by erosion of sand by the flowing metal.



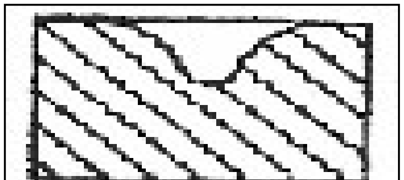
Rat tail is a long, shallow, angular depression caused by expansion of the sand.



Hot tear is the crack in the casting caused by high residual stresses.

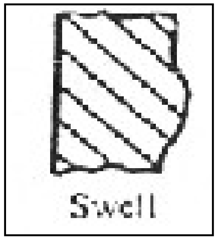


Shrinkage is essentially solidification contraction and occurs due to improper use of Riser.

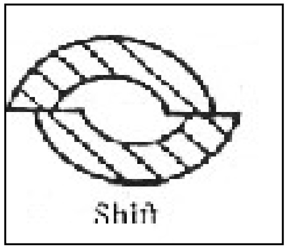


Shrinkage

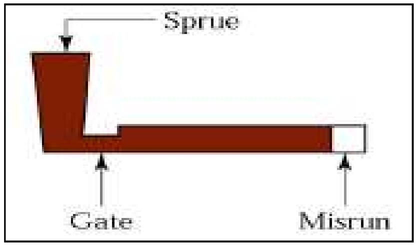
Swell is the deformation of vertical mould surface due to hydrostatic pressure caused by moisture in the sand.

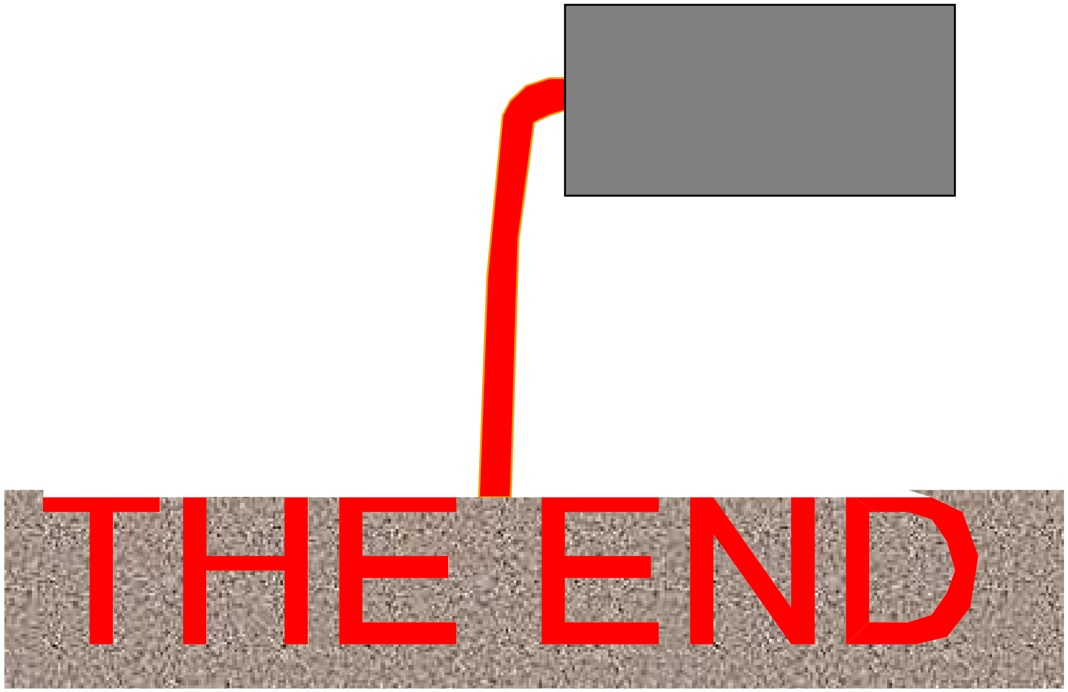


Shift is due to misalignment of two parts of the mould or incorrect core location.



Misrun are caused by insufficient superheat provided to the liquid metal.

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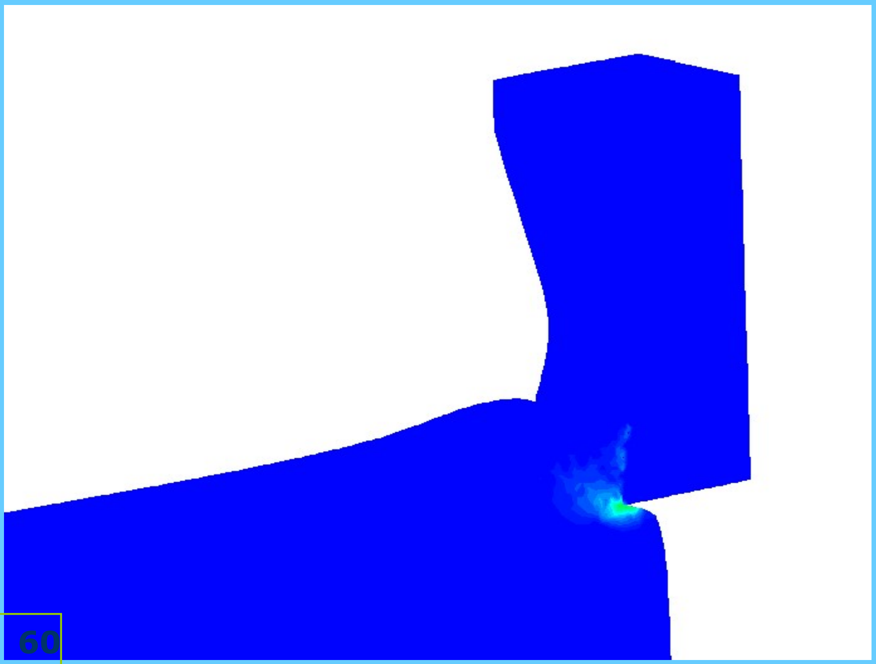
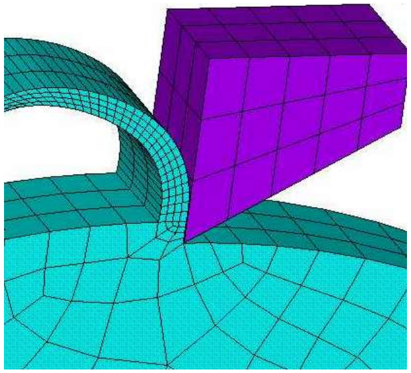
LECTURE-02: THEORY OF METAL CUTTING





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BUET

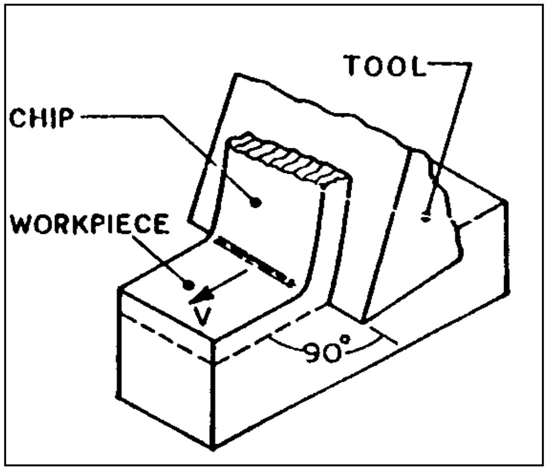
Introduction

- Production or manufacturing of any object is a value addition process by which raw material of low utility and value due to its irregular size, shape and finish is converted into a high utility and valued product with definite size, shape and finish imparting some desired functionability.
- Machining is an essential process of semi-finishing and often finishing by which jobs of desired shape and dimensions are produced by removing extra material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surfaces in machine tools.
- The chips are separated from the workpiece by means of a cutting tool that possesses a very high hardness compared with that of the workpiece, as well as certain geometrical characteristics that depend upon the conditions of the cutting operation.
- Among all of the manufacturing methods, metal cutting, commonly called machining; is perhaps the most important. Forgings and castings are subjected to subsequent machining operations to acquire the precise dimensions and surface finish required. Also, products can sometimes be manufactured by machining stock materials like bars, plates, or structural sections.

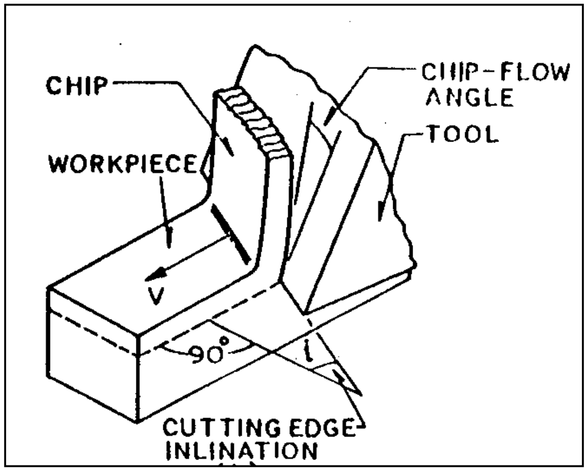
Methods of Machining

In the metal cutting operation, the tool is wedge-shaped and has a straight cutting edge. Basically, there are two methods of metal cutting, depending upon the arrangement of the cutting edge with respect to the direction of relative work-tool motion:

- **Orthogonal cutting or two dimensional cutting**
- **Oblique cutting or three dimensioning cutting**



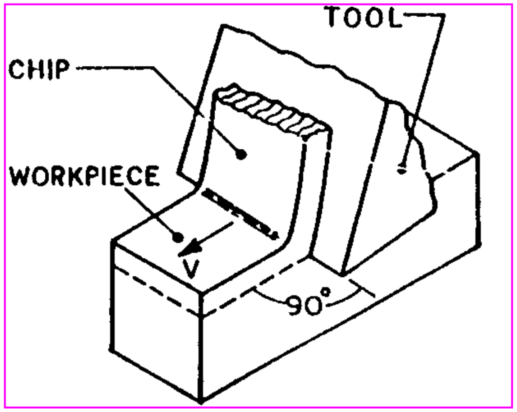
Orthogonal Machining



Oblique Machining

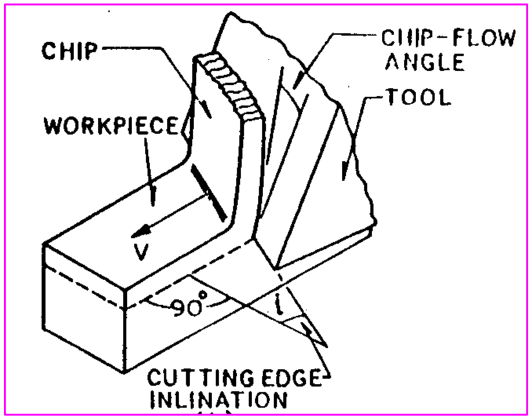
Orthogonal Cutting or Two Dimensional Cutting

- The cutting edge of the tool remains at 90^0 to the direction of feed
- The chip flows in a direction normal to the cutting edge of the tool
- The cutting edge of the tool has zero inclination with the normal to the feed
- The chip flows along the plane of the tool face. Therefore, it makes no angle with the normal (in the plane of the tool face) to the cutting.
- The shear force acts on a smaller area, so shear force per unit area is more.
- The tool life is smaller than obtained in oblique cutting
- There are two mutually perpendicular components of cutting forces on the tool
- The cutting edge is bigger than the width of cut.



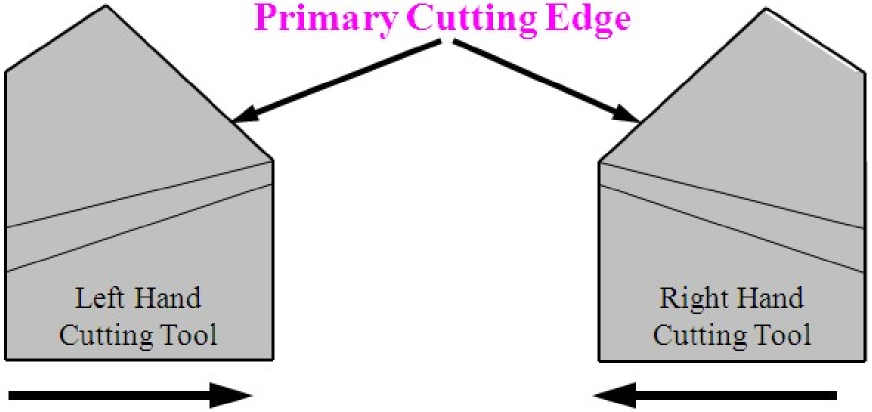
Oblique Cutting or Three Dimensioning Cutting

- Cutting edge of the tool remains inclined at an acute angle to the direction of feed
- The direction of the chip flow is not normal to the cutting edge.
- Cutting edge is inclined at an angle inclination angle (λ) to the normal to the feed.
- The chip flows at an angle shear angle (β) to the normal to the cutting edge.
- The shear force acts on a larger area, hence the shear force per area is smaller
- The tool life is higher than obtained in orthogonal cutting
- There are three mutually perpendicular components of cutting forces on the tool
- The cutting edge is smaller than the width of cut.



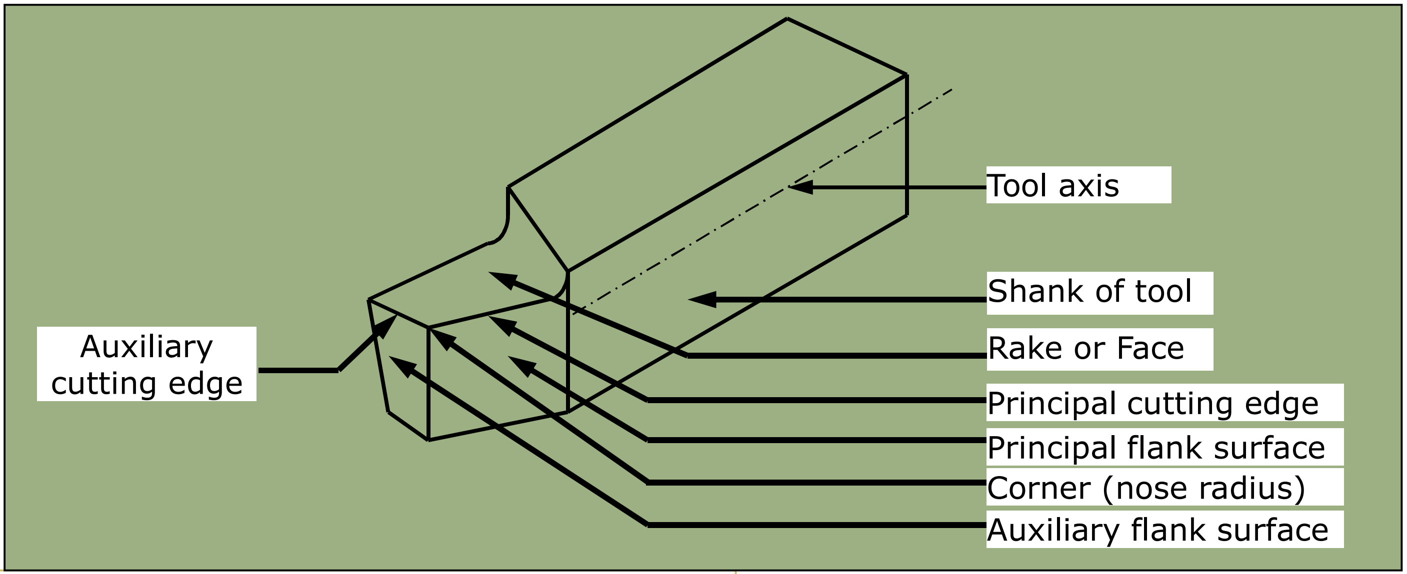
Cutting Tool Geometry

- Cutting tool is device with which a material could be cut to the desired size, shape or finish. So a cutting tool must have at least a sharp edge. There are two types of cutting tool.
  - The tool having only one cutting edge is called single point cutting tools. For example shaper tools, lathe tools, planer tools, etc.
  - The tool having more than one cutting edge is called multipoint cutting tools. For example drills, milling cutters, broaches, grinding wheel honing tool etc.
  - A single point cutting tool may be either right or left hand cut tool depending on the direction of feed.

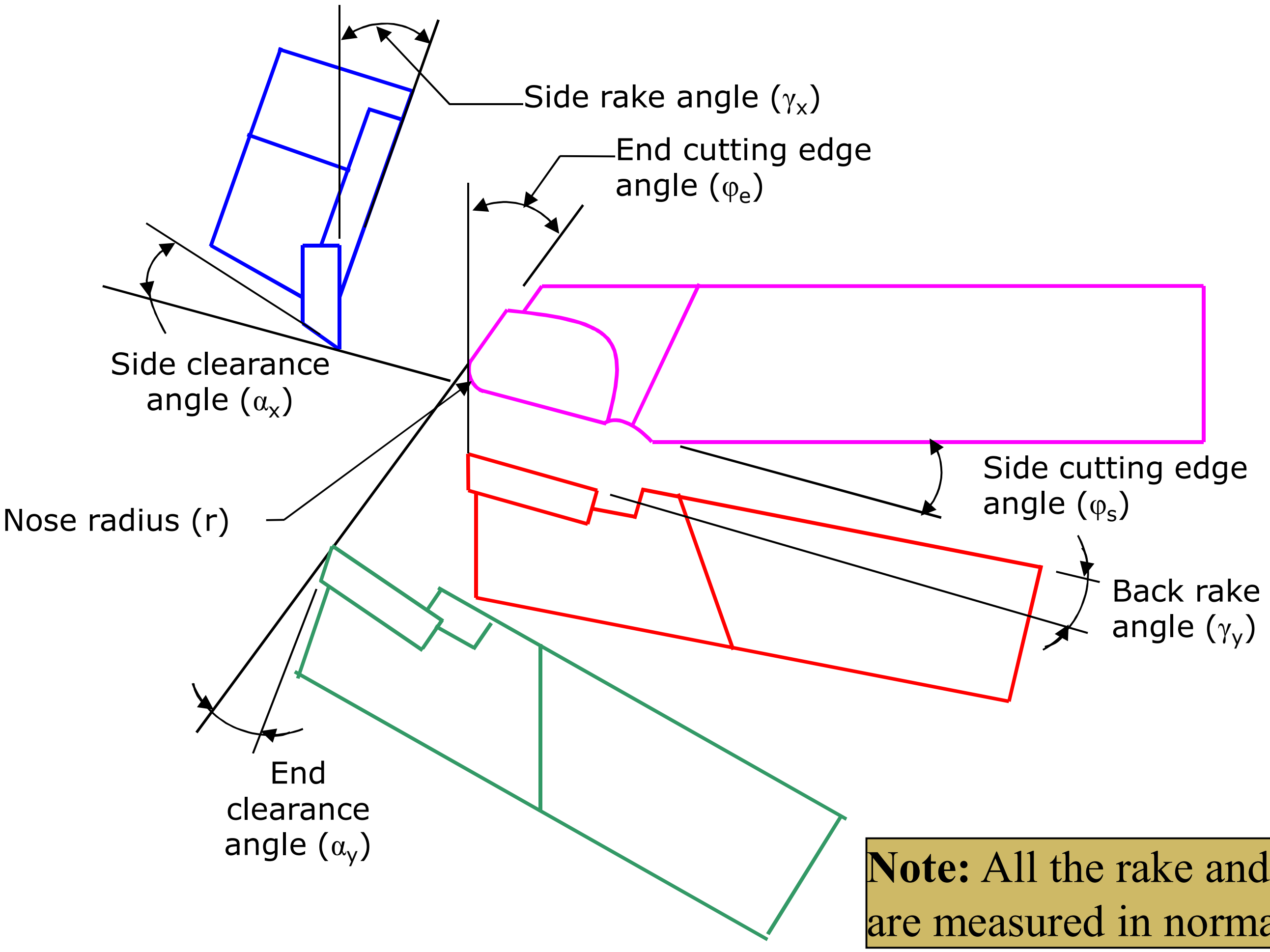


Cutting Tool Nomenclature

The geometry of a cutting tool consists of the following elements: **face or rake surface, flank, cutting edges and the corner (nose radius)**. Face or rake is the surface of the cutting tool along which the chips flow out. Flank surfaces are those facing the work piece. There are two flank surfaces, principal and auxiliary flank surfaces. Principal cutting edge performs the major portion of cutting and is formed by the intersecting line of the face with the principal flank surface. Auxiliary cutting edge (often called end cutting edge) is formed by the intersection of the rake surface with the auxiliary flank surface. Corner or cutting point is the meeting point of the principal cutting edge with the auxiliary cutting edge.



Single Point Cutting Tool



Note: All the rake and clearance angles are measured in normal direction

- **Side Cutting Edge Angle (φ_s):** The side cutting-edge angle is usually referred to as the lead angle. It is the angle enclosed between the side cutting edge and the longitudinal direction of the tool. The value of this angle varies between **0° and 90°,** depending upon the machinability, rigidity, and, sometimes, the shape of the workpiece. Usually, the recommended value for the lead angle should range between **15° and 30°.**
- **Auxiliary or End Cutting Edge Angle (φ_e):** The end cutting-edge angle serves to eliminate rubbing between the end cutting edge and the machined surface of the workpiece. Although this angle takes values in the range of **5° to 30°**, commonly recommended values are **8° to 15°.**
- **Side Clearance Angle (α_x) and End Clearance Angle (α_y):** Side and end clearance angles serve to eliminate rubbing between the workpiece and the side and end flank, respectively. Usually, the value of each of these angles ranges between **5° and 15°.**
- **Back Rake Angle (γ_y) and Side Rake Angle (γ_X):** Back and side rake angles determine the direction of flow of the chips onto the face of the tool. Rake angles can be positive, negative, or zero. Its value usually varies between **0° and 15°.**
- **Nose radius (r):** Nose radius is favorable to long tool life and good surface finish. There is an improvement in surface finish and permissible cutting speed as nose radius is increased from zero value.

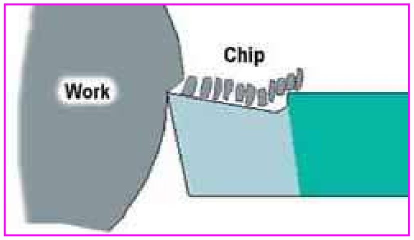
Chip Formation

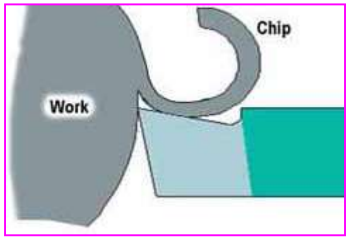
Every Machining operation involves the formation of chips. The nature of which differs from operation to operation, properties of work piece material and the cutting condition. Chips are formed due to cutting tool, which is harder and more wearer-resistant than the work piece and the force and power to overcome the resistance of work material. The chip is formed by the deformation of the metal lying ahead of the cutting edge by a process of shear. Four main categories of chips are:

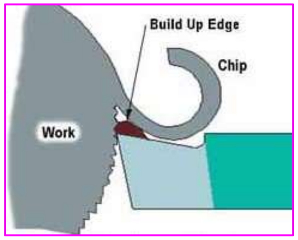
- Discontinuous Chips
- Continuous or Ribbon Type Chips
- Continuous Chip Built-up-Edge (BUE)
- Serrated Chips

Types of Chips

- Discontinuous Chips: These chips are small segments, which adhere loosely to each other. They are formed when the amount of deformation to which chips undergo is limited by repeated fracturing. Hard and brittle materials will produce such chips.
- Continuous or Ribbon Type Chips: In continuous chip formation, the pressure of the work piece builds until the material fails by slip along the plane. The inside on the chip displays steps produced by the intermittent slip, but the outside is very smooth. It has its elements bonded together in the form of long coils and is formed by the continuous plastic deformation of material without fracture ahead of the cutting edge of the tool and is followed by the smooth flow of chip up the tool face.
- Continuous Chip Built Up Edge: This type of chip is very similar to that of continuous type, with the difference that it is not as smooth as the previous one. This type of chip is associated with poor surface finish, but protects the cutting edge from wear due to movement of chips and the action of heat causing the increase in tool life.
- Serrated Chips: These chips are semicontinuous in the sense that they possess a saw-tooth appearance that is produced by a cyclical chip formation of alternating high shear strain followed by low shear strain. This chip is most closely associated with certain difficult-to-machine metals such as titanium alloys, nickel-base and austenitic stainless steels when they are machined at higher cutting speeds.



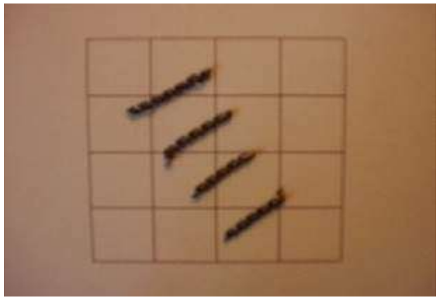




Actual Chip Forms and Classifications

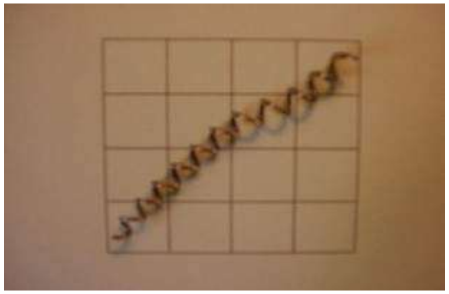
C-type and ε-type broken chips

Short helical broken chips



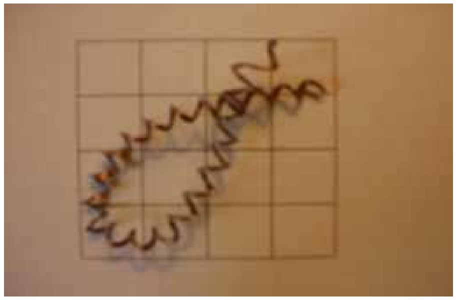
Medium helical broken chips

Long helical broken chips



Desired

Not Desired

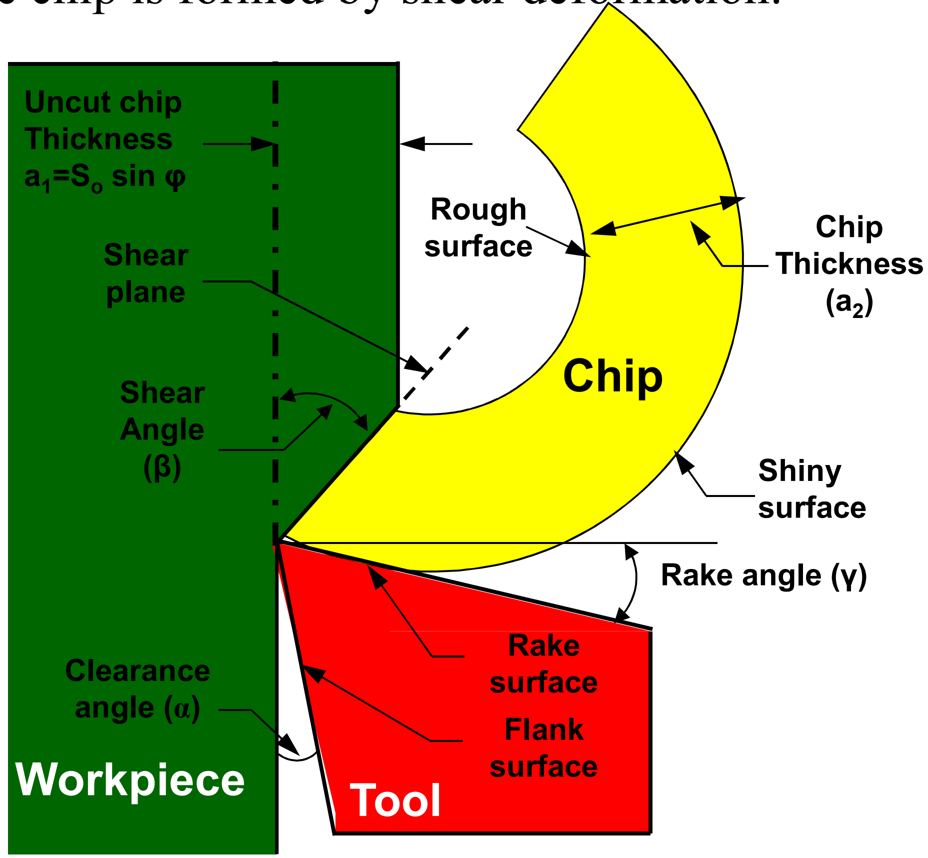


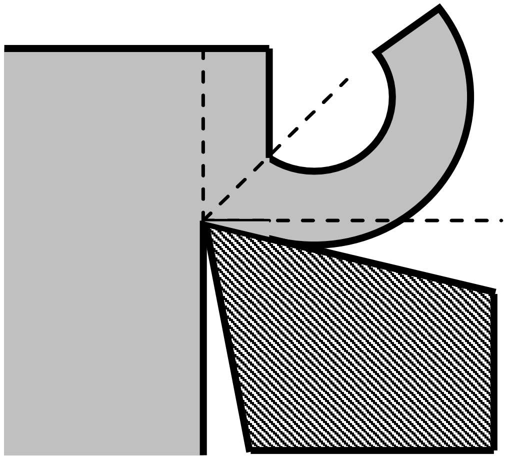
Long helical unbroken chips

Long and snarled unbroken chips

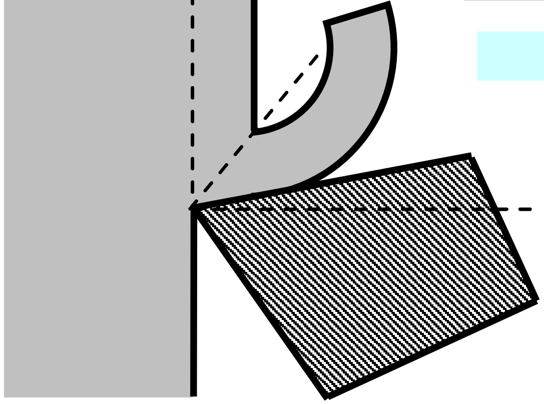
Chip Formation in Metal Machining

Since the practical machining is complex we use orthogonal cutting model to explain the mechanics.In this model we used wedge shaped tool. As the tool forced into the material the chip is formed by shear deformation.





Positive rake



Negative rake

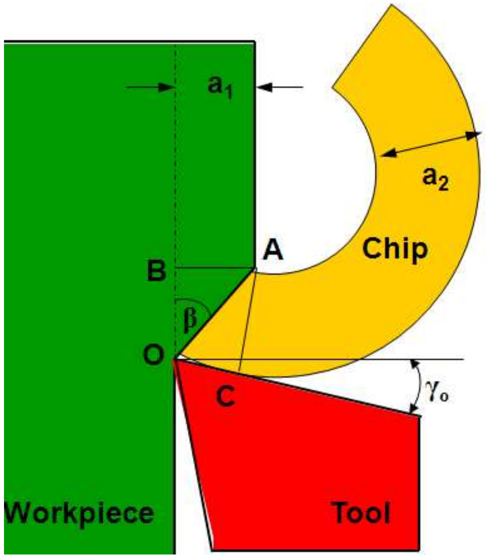
Chip Reduction Coefficient (ξ)

Chip reduction coefficient (ξ) is defined as the ratio of chip thickness (a_2) to the uncut chip thickness (a_1). This factor, ξ, is an index of the degree of deformation involved in chip formation process during which the thickness of layer increases and the length shrinks. In the USA, the inverse of ξ is denoted by r_c and is known as cutting ratio. The following **Figure** shows the formation of flat chips under orthogonal cutting conditions. From the geometry of the following **Figure**.

$$\xi = \frac{a_2}{a_1} = \frac{AC}{AB} = \frac{OA\cos(\beta - \gamma_0)}{OA\sin\beta} = \frac{\cos\beta\cos\gamma_0 + \sin\beta\sin\gamma_0}{\sin\beta}$$

$$= \frac{\cos\gamma_0}{\tan\beta} + \sin\gamma_0$$

$$\therefore \tan\beta = \frac{\cos\gamma_0}{\xi - \sin\gamma_o} \text{ and } \beta = \tan^{-1}\left(\frac{\cos\gamma_o}{\xi - \sin\gamma_o}\right) \text{ Shear angle}$$



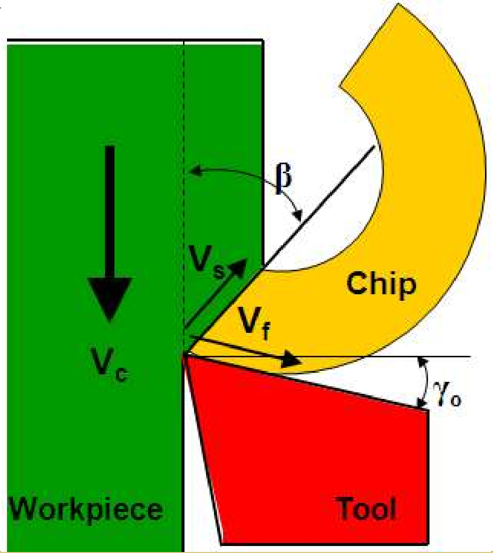
Velocity Relationships

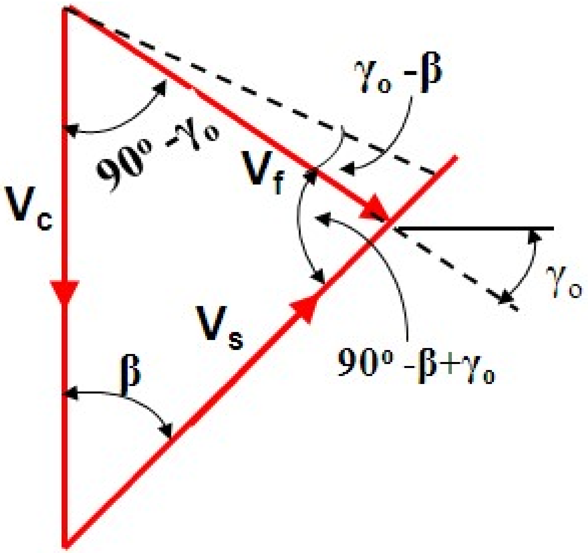
The following Figure shows the velocity relation in metal cutting. As the tool advances, the metal gets cut and chip is formed. The chip glides over the rake surface of the tool. With the advancement of the tool, the shear plane also moves. There are three velocities of interest in the cutting process which include:

V_c Cutting velocity

V_f Velocity of the chip relative to the tool. It is called chip flow velocity

V_s Velocity of displacement of formation of chip, relative to the workpiece along the shear plane. It is called velocity of shear





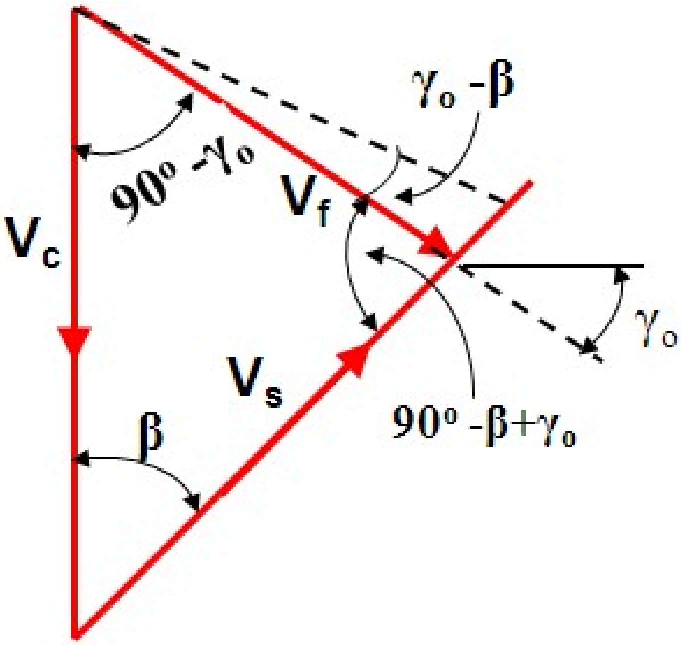
According to principles of kinematics, these three velocities, i.e. their vectors must form a closed velocity diagram. The vector sum of the cutting velocity, V_c, and the shear velocity, V_s, is equal to chip velocity, V_f. Thus,

$$\overline{V}_f = \overline{V}_c + \overline{V}_s$$

$$\frac{V_s}{\sin(90^o - \gamma_o)} = \frac{V_c}{\sin\left[90^o - (\beta - \gamma_o\right]} = \frac{V_f}{\sin\beta}$$

$$V_f = V_c \frac{\sin\beta}{\sin\left[90^0 - (\beta - \gamma_o)\right]} = \frac{V_c \sin\beta}{\cos(\beta - \gamma_o)} = \frac{V_c}{\xi}$$

$$\text{or, } \frac{V_c}{V_f} = \xi$$



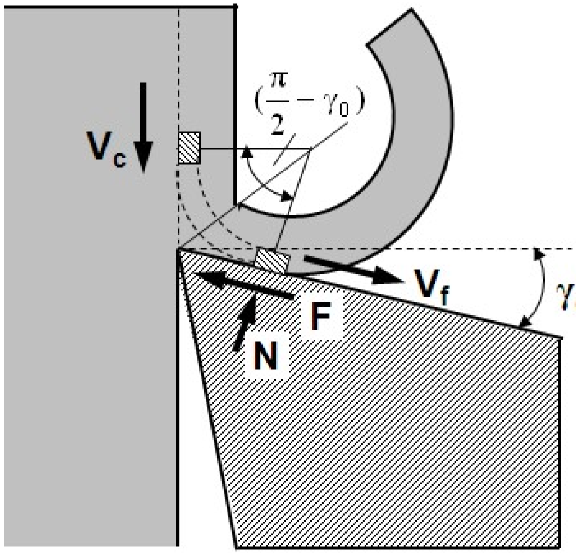
Kronenberg derived an interesting relation for chip reduction coefficient (ξ) which is of considerable physical significance. Considering the motion of any chip particle as shown in the following **Figure** to which principles of momentum change are applied:

$$F = -m\frac{dv}{dt} \text{ and } N = m\omega^2 r = mv\frac{d\theta}{dt} \Rightarrow \mu = \frac{F}{N} = -\frac{dv}{v\,d\theta}$$

$$-\frac{dv}{v} = \mu\, d\theta \Rightarrow \int_{V_c}^{V_f} -\frac{dv}{v} = \int_{0}^{(\frac{\pi}{2}-\gamma_o)} \pi d\theta$$

$$-\ln\left(\frac{V_f}{V_c}\right) = \mu\left(\frac{\pi}{2} - \gamma_o\right)$$

$$\frac{V_c}{V_f} = e^{\mu\left(\frac{\pi}{2}-\gamma_0\right)} \Rightarrow \xi = e^{\mu\left(\frac{\pi}{2}-\gamma_0\right)}$$

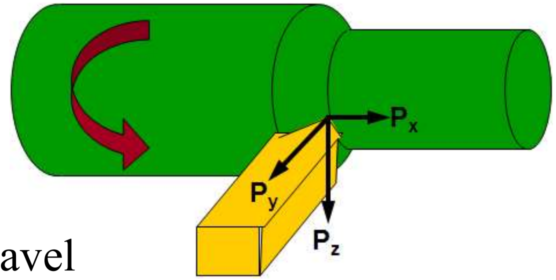


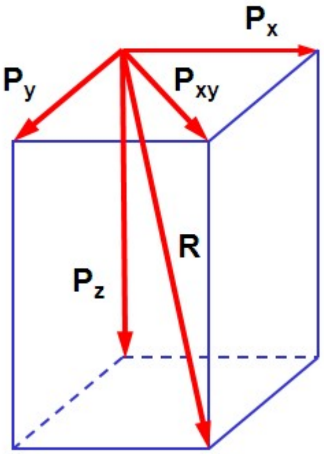
This equation demonstrates that the chip reduction coefficient and chip flow velocity is dependant on the frictional aspects at the interface as well as the orthogonal rake angle (γ_0). If γ_0 is increased, chip reduction coefficient decreases.

Mechanics of Metal Cutting

The force acting on a cutting tool during the process of metal cutting are the fundamental importance in the design of cutting tools. The determination of cutting forces necessary for deformation the work material is essential for several important requirements:

- to estimate the power requirements of a machine tool
- to estimate the straining actions that must be resisted by the machine tool components, bearings, jigs and fixtures
- to evaluate the role of various parameters in cutting forces
- to evaluate the performance of any new work material, tool material, environment, techniques etc. with respect to machinability



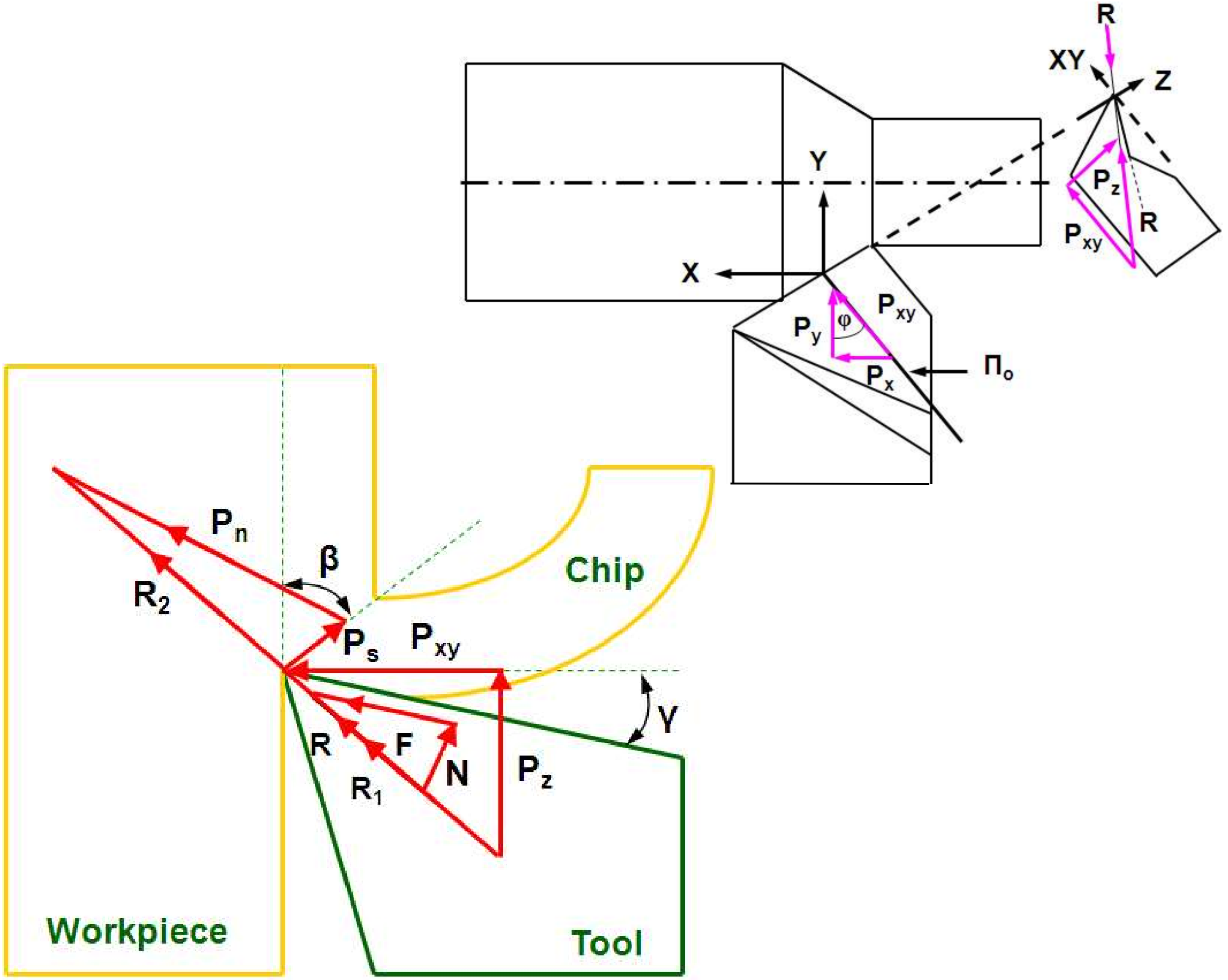


P_x = **Feed force** in the direction of the tool travel
P_y = **Thrust force** in the direction perpendicular to the produced surface
P_z = **Cutting force** or **main force** acting in the direction of the cutting velocity.

$$P_x = P_{xy} \sin\varphi \ldots\ldots\ldots\ldots\ldots\ldots [1]$$

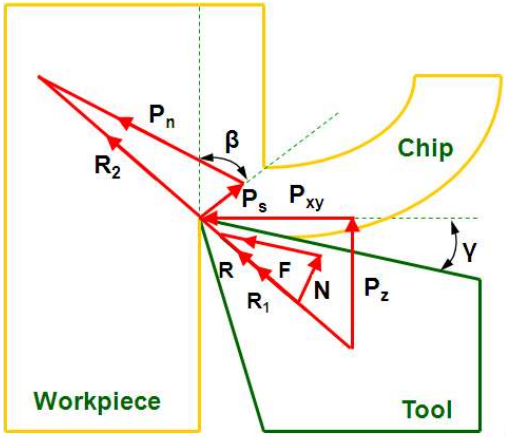
$$P_y = P_{xy} \cos\varphi \ldots\ldots\ldots\ldots\ldots [2]$$

Several forces can be defined relative to the orthogonal cutting model. Based on these forces, shear stress, coefficient of friction, and certain other relationships can be defined.



Merchant Circle Diagram (MCD)

The following relationships suggest a circle representation of forces as done by **Merchant** and indicated in the following **Figure**.



$$\overline{R} = \overline{F} + \overline{N} = \overline{P}_s + \overline{P}_n = \overline{P}_z + \overline{P}_{xy} \,.........[3]$$

$$F = P_z \sin\gamma_o + P_{xy}\cos\gamma_o ....\,..........\,.[4]$$

$$N = P_z \cos\gamma_o - P_{xy}\sin\gamma_o ....\,..........\,[5]$$

$$P_s = P_z \cos\beta - P_{xy}\sin\beta ....\,..........\,....[6]$$

$$P_n = P_z \sin\beta + P_{xy}\cos\beta ....\,..........\,...[7]$$

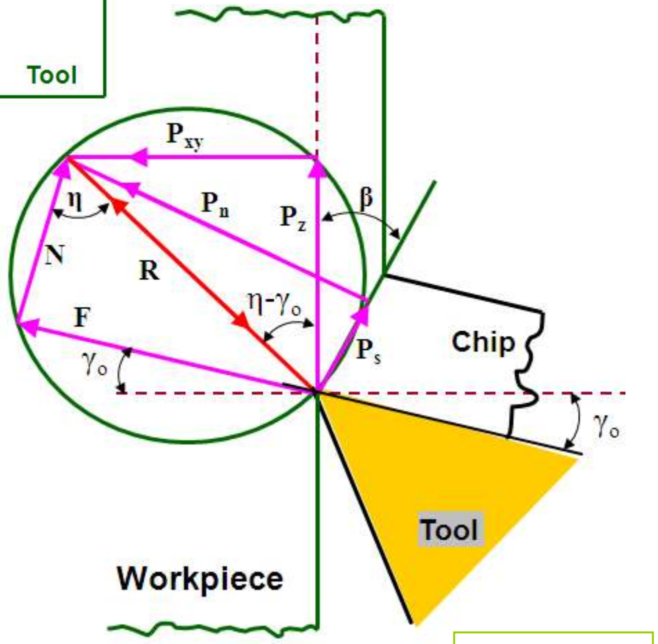
From Equation [4] and [5]

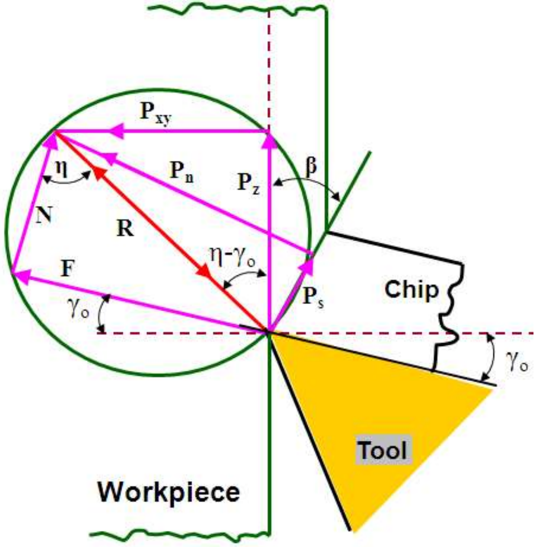
$$\mu = \frac{F}{N} = \frac{P_z \sin\gamma_o + P_{xy}\cos\gamma_o}{P_z \cos\gamma_o - P_{xy}\sin\gamma_o} = \tan\eta .....[8]$$

Where,

μ = kinetic coefficient of friction

η = mean angle of friction at the rake surface





From the geometry of force relations of MCD circle

$$P_z = R\cos(\eta - \gamma_0) \ldots\ldots\ldots\ldots\ldots [9]$$

$$P_s = R\cos(\beta + \eta - \gamma_0) \ldots\ldots\ldots\ldots [10]$$

Fron Equation [9] and [10] $P_z = P_s\left[\dfrac{\cos(\eta - \gamma_0)}{\cos(\beta + \eta - \gamma_o)}\right] \ldots\ldots\ldots [11]$

Based on the shear force, the shear stress (τ_s) which acts along the shear plane between the work and the chip is:

$$\tau_s = \frac{P_s}{A_s}, \text{where As} = \text{area of the shear plane} = \frac{S_o\, t}{\sin\beta} \Rightarrow \tau_s = \frac{P_s \sin\beta}{S_o\, t} \ldots\ldots\ldots [12]$$

From Equation [11]and [12]

$$P_z = \tau_s\, S_0\, t\left[\frac{\cos(\eta - \gamma_0)}{\sin\beta\,\cos(\beta + \eta - \gamma_o)}\right] \ldots\ldots\ldots\ldots [13]$$

$$\text{Similarly, } P_{xy} = \tau_s\, S_0\, t\left[\frac{\sin(\eta - \gamma_0)}{\sin\beta\,\cos(\beta + \eta - \gamma_o)}\right] \ldots\ldots [14]$$

Earnest-Merchant Theory

Ernst and Merchant extended their analysis and studied the relationship between the shear angle and the cutting conditions. They suggested that the shear angle always takes the value that reduces the total energy consumed in cutting to a minimum. Because the total work done in cutting is dependent upon and is a direct function of the component P_z of the cutting force, they developed an expression for P_z in terms of β and the constant properties of the workpiece material. Condition for maximum cutting force (P_z) from Equation [13]

$$\frac{dP_z}{d\beta} = 0, \text{ or, } \frac{dP_z}{d\beta} = \frac{d}{d\beta}\left[\frac{\tau_s S_0 t}{\sin\beta} \cdot \frac{\cos(\eta-\gamma_0)}{\cos(\beta+\eta-\gamma_o)}\right] = 0$$

$$\tau_s S_0 t \cos(\eta-\gamma_0)\left[\frac{\cos\beta\cos(\beta+\eta-\gamma_0)-\sin\beta\sin(\beta+\eta-\gamma_0)}{\{\sin\beta\cos(\beta+\eta-\gamma_0\}^2}\right] = 0$$

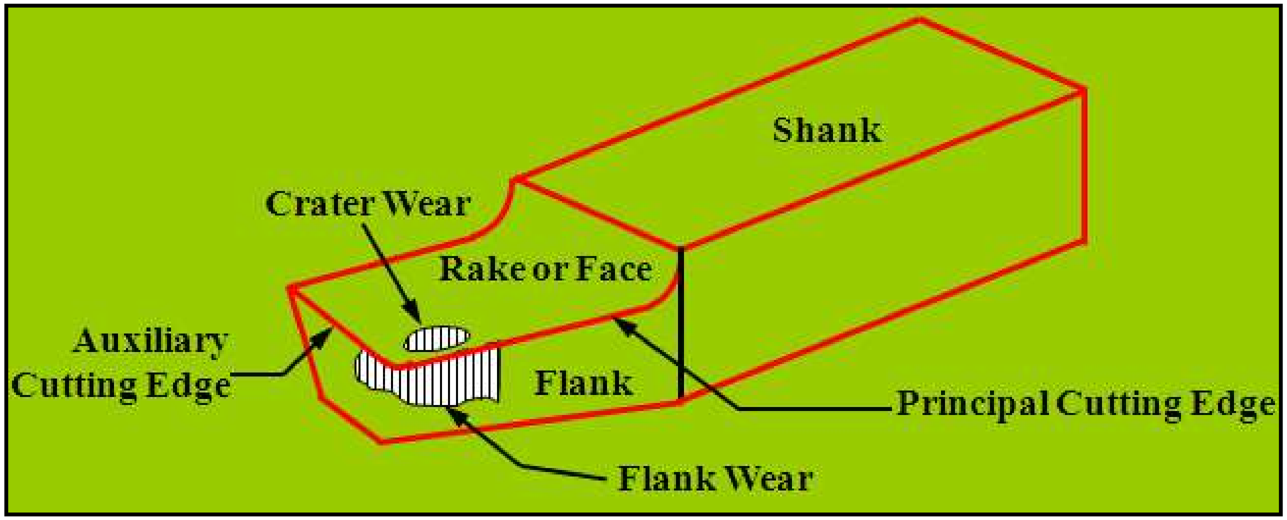
$$\cos\beta\cos(\beta+\eta-\gamma_0)-\sin\beta\sin(\beta+\eta-\gamma_0) = 0, \text{ or } \cos(\beta+\beta+\eta-\gamma_0) = 0 = \cos\left(\frac{\pi}{2}\right)$$

$$\beta = \frac{\pi}{4} - \frac{\eta}{2} + \frac{\gamma_0}{2} \text{.......... ....[1 5]}$$

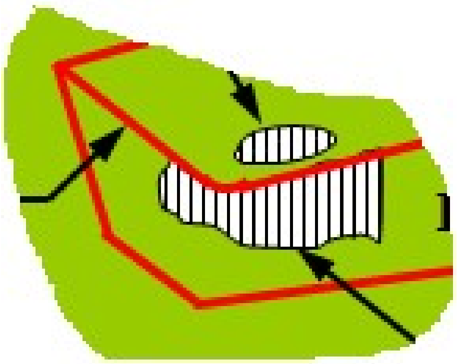
Combining Equation [13] and [15], $P_z = 2\tau_s S_0 t \cot\beta$

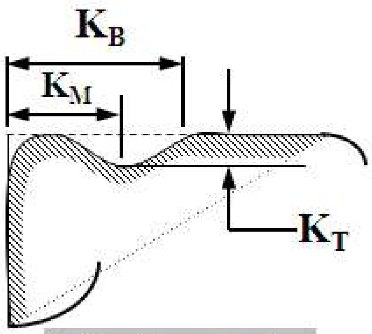
Tool Wear

Productivity and economy of manufacturing by machining are significantly affected by life of the cutting tools. Cutting tools may fail by brittle fracture, plastic deformation or gradual wear. Turning carbide inserts having enough strength, toughness and hot hardness generally fail by gradual wears. With the progress of machining the tools attain crater wear at the rake surface and flank wear at the clearance surfaces, as schematically shown in following Figure (next slide) due to continuous interaction and rubbing with the chips and the work surfaces respectively. Among the aforesaid wears, the principal flank wear is the most important because it raises the cutting forces and the related problems.

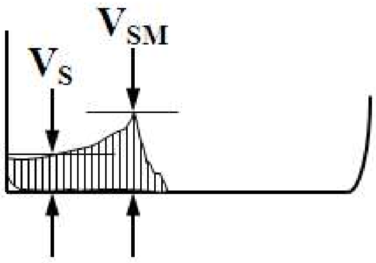


Features of Wear of Turning Tool



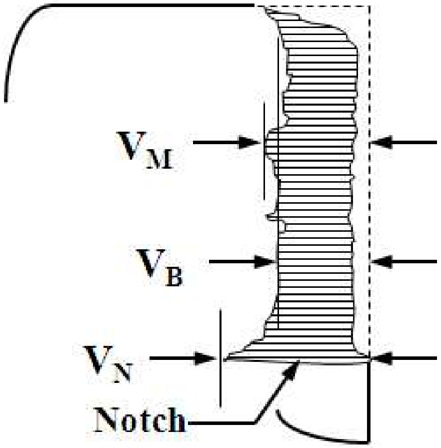


Section A-A

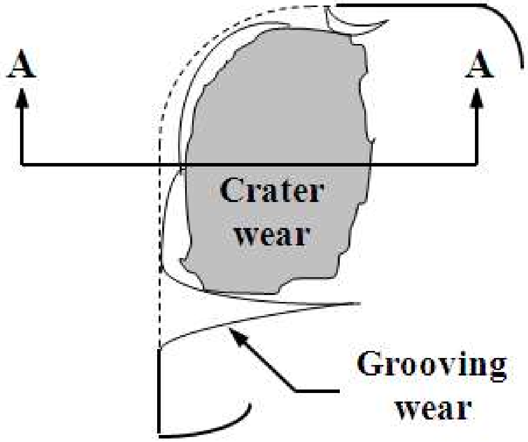


Auxiliary Flank

V_B = Average flank wear
V_N = Flank notch wear
V_M = Maximum flank wear
V_S = Average auxiliary flank wear
V_{SM} = Maximum auxiliary flank wear
K_T = Crater depth
K_M = Distance from center of crater
K_B = Crater width



Principal Flank



Rake Surface

- The life of the tools, which ultimately fail by systematic gradual wear, is generally assessed at least for R&D work, by the average value of the principal flank wear (V_B), which aggravates cutting forces and temperature and may induce vibration with progress of machining. The pattern and extent of wear of the auxiliary flank (V_S) affects surface finish and dimensional accuracy of the machined parts.
- However, tool rejection criteria for finishing operation were employed in this investigation. The values established in accordance with ISO Standard 3685 for tool life testing. A cutting tool was rejected and further machining stopped based on one or a combination of **rejection criteria**:

Average Flank Wear	$\geq$	0.3 mm
Maximum Flank Wear	$\geq$	0.4 mm
Nose Wear	$\geq$	0.3 mm
Notching at the depth of cut line	$\geq$	0.6 mm
Average surface roughness value	$\geq$	1.6 μm
Excessive chipping (flanking) or catastrophic fracture of cutting edge.		

Mechanism of Tool Wear

In general there are seven basic types of wear that affect a cutting tool:

- Abrasion: Mechanical wearing, hard particles in workpiece removes small portions of the tool, that cause flank and crater wear. This is the dominant cause of flank wear.
- Adhesion: Two metals contact under high pressure and temperature that cause welding between the materials.
- Diffusion: Atoms on the boundry of workpiece and tool changes place. This is the principle cause for crater wear.
- Chemical Reactions: The high temperatures and clean surfaces at the chip-tool interface in machining at high speeds can result in chemical reactions, in particular, oxidation, on the rake surface of the tool. The oxidized layer, being softer than the parent tool material, is sheared away, exposing new material to sustain the reaction process.
- Plastic Deformation: Cutting forces acting on the cutting edge at high temperature cause the edge to deform plastically. This cause flank wear.

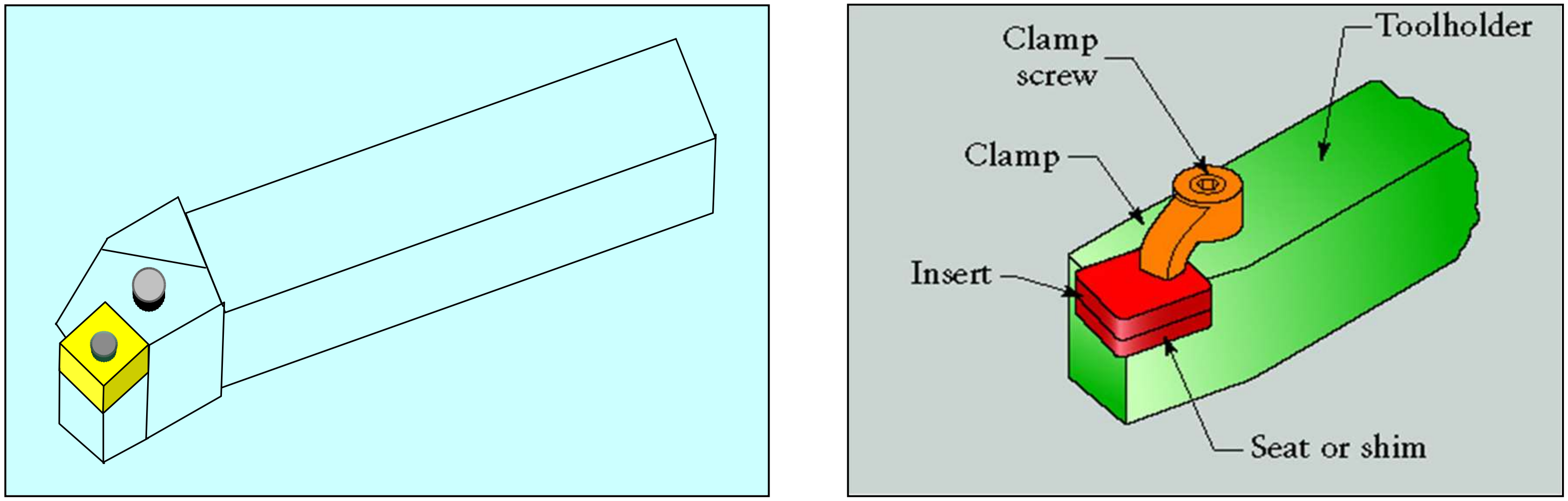
Cutting Tool Materials Properties

- A good type of tool material should possess certain desired properties such as
  - The material must remain harder than the work material at elevated operating temperature.
  - The material must withstand excessive wear even though the relative hardness of the tool-work materials changes.
  - The frictional coefficient at the chip-tool interface must remain low for minimum wear and reasonable surface finish.
  - The material must be sufficiently tough to withstand the shocks of intermittent cutting; if not reinforcement must be provided.
  - The tool material should also possess high thermal conductivity for quickly removing heat from the chip-tool interface, have a low coefficient of thermal expansion, not be distorted after heat treatment, be easy to regrind and also easy to weld to the tool holder

Cutting Tool Materials

- Carbon Tool Steels
  - Medium alloy steels
  - Poor properties above 200^{O}C and inexpensive
  - Uses: Taps and core drills for machining soft materials and wood working tools
- High Speed Steels (HSS)
  - Hot hardness is quite high, so the HSS cutting tools retain the cutting ability upto 600^{O}C
  - Wear resistance is high and hardenability is good
  - Uses: Drills, milling cutters, taps, lathe cutting tool, gear hobs etc. are made of HSS.
- Carbides: A hard material made of compacted binary compounds of carbon and heavy metals, used to make tools that cut metal.
  - Made using powder metallurgy and usually used as an insert
- Ceramics
  - High abrasion and high hot hardness
  - Not good for interrupted cutting
  - Requires dry, or constant profuse cutting fluids

All carbides, when finished, are extremely brittle and weak in their resistance to it impact and shock loading. Due to this, vibrations are very harmful for carbide tools. The machine tools should be rigid, faster and more powerful. Low feeds, low speeds and chatter are harmful. Due to the high cost of carbide tool materials and other factors, cemented carbides are used in the form of inserts or tips which are brazed or clamped to a steel shank as shown in the following Figure.



Methods of attaching inserts to tool shanks

Types of Cutting Fluids

Cutting fluids are used in metal machining for a variety of reasons such as improving tool life, reducing workpiece thermal deformation, improving surface finish and flushing away chips from the cutting zone. Practically all cutting fluids presently in use fall into one of four categories:

- Straight oils
- Soluble oils
- Semi-synthetic fluids
- Synthetic fluids

- **Straight oils** are non-emulsifiable and are used in machining operations in an undiluted form. They are composed of a base mineral or petroleum oil and often contain polar lubricants such as fats, vegetable oils and esters as well as extreme pressure additives such as Chlorine, Sulphur and Phosphorus. Straight oils provide the best lubrication and the poorest cooling characteristics among cutting fluids.

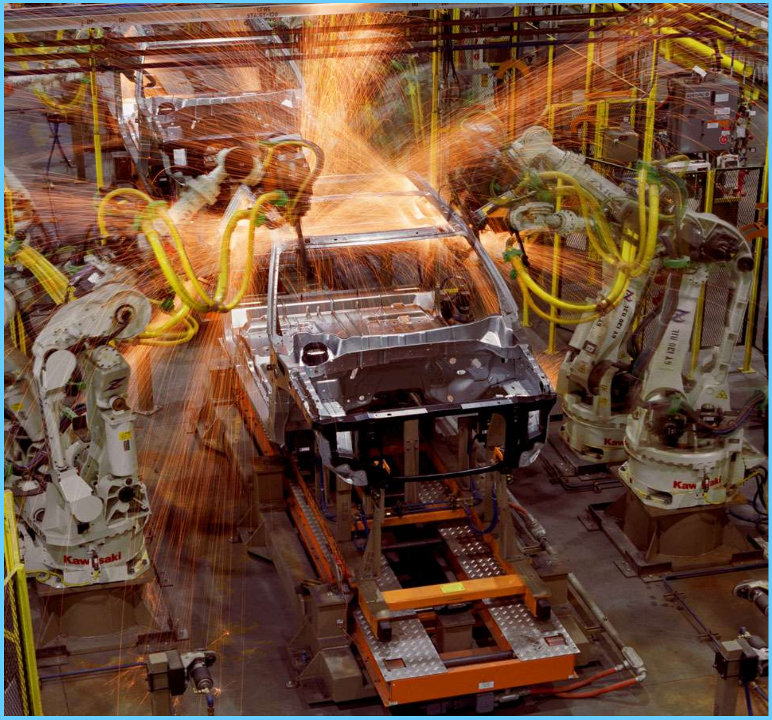
- **Soluble oil fluids** form an emulsion when mixed with water. The concentrate consists of a base mineral oil and emulsifiers to help produce a stable emulsion. They are used in a diluted form (usual concentration 3 to 10%) and provide good lubrication and heat transfer performance. They are widely used in industry and are the least expensive among all cutting fluids.
- **Semi-synthetic fluids** are essentially combination of synthetic and soluble oil fluids and have characteristics common to both types. The cost and heat transfer performance of semi-synthetic fluids lie between those of soluble oil fluids and synthetic fluid.
- **Synthetic fluids** contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition. They are generally used in a diluted form (usual concentration 3 to 10%). Synthetic fluids often provide the best cooling performance among all cutting fluids.

Properties of Cutting Fluid

A good type of cutting fluid should possess certain desired properties such as:

- Good cooling capacity and lubricating qualities
- Rust resistance and stability- for long life
- Resistance to rancidity and foaming
- Non-toxic
- Transparent-to allow the operator to see the work clearly during machining
- Relatively low viscosity-to permit the chips and dirt to settle quickly
- Nonflammable-to avoid burning easily and should be non-combustible
- Ability to disposed in an environmentally responsible way.
- In addition, it should not smoke excessively, form gummy deposit which may cause machine slide to become sticky, or clog the circulating system.

LECTURE-03: METAL JOINING METHODS



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Introduction

- Welding i.e. the action of the verb "To weld" is same as "To well" which means to boil or to heat to a high temperature. The weld may be defined as a localized union or consolidation of metals by the application of heat and with or without the application of pressure.
- Welding is usually employed to unite metals where the joining is permanent and is required to transmit stress and sometimes to develop pressure tightness. In recent past remarkable advances have given welding a dominant place in the metal industries and different techniques of welding were developed to achieve certain goals.
- The American Welding Society (AWS) definition for a welding process is "a materials joining process which produces coalescence of materials by heating them to suitable temperatures with or without the application of pressure or by the application of pressure alone and with or without the use of filler material".

Welding Classification

METAL JOINING PROCESSES

Arc Welding

➢ Gas Metal Arc	(GMAW)
➢ Gas Tungsten Arc	(GTAW)
➢ Plasma Arc	(PAW)
➢ Shielded Metal Arc	(SMAW)
➢ Submerged Arc	(SAW)

Solid State Welding

➢ Diffusion Welding	(DFW)
➢ Explosion Welding	(EXW)
➢ Friction Welding	(FRW)
➢ Hot Pressure Welding	(HPW)
➢ Ultrasonic Welding	(USW)

Resistance Welding

➢ Flash Welding	(FW)
➢ Percussion Welding	(PEW)
➢ Projection Welding	(RPW)
➢ Resistance-Seam Welding	(RSEW)
➢ Resistance-Spot Welding	(RSW)

Other Welding Processes

➢ Electron Beam Welding	(EBW)
➢ Laser Beam Welding	(LBW)
➢ Thermit Welding	(TW)

Oxyfuel Gas Welding

➢ Oxyacetylene Welding	(OAW)
➢ Oxyhydrogen Welding	(OHW)
➢ Pressure Gas Welding	(PGW)

Brazing

➢ Diffusion Brazing	(DFB)
➢ Induction Brazing	(IB)
➢ Resistance Brazing	(RB)

Soldering

➢ Infrared Soldering	(IRS)
➢ Iron Soldering	(INS)
➢ Resistance Soldering	(RS)

Advantages, Disadvantages & Applications

Advantages of Welding

- A good weld is as strong as the base metal
- General welding equipment is not very costly
- Portable welding equipments are available
- Welding permits considerable freedom in design
- Welding can join metals/alloys both similar and dissimilar
- Welding can be mechanized

Disadvantages of Welding

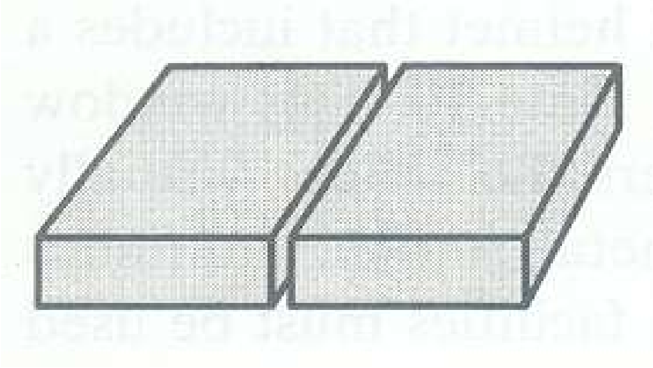
- Welding gives out harmful radiation (light), fumes and spatter
- Welding results in residual stresses and distortion of the work-pieces
- Jigs and fixtures are generally required to hold the parts to be welded
- Edge preparation of the workpiece is generally required before welding
- A skilled welder is a must to produce a good welding job
- Welding heat produces metallurgical changes
- A welded joint, for many reasons, needs stress-relief heat-treatment.

Application of Welding

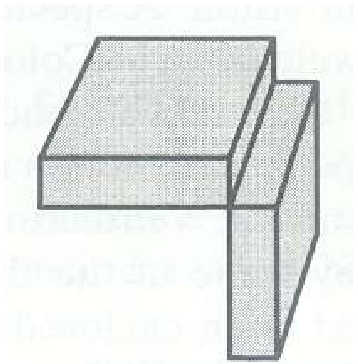
- Aircraft construction and Automobile construction
- Bridges and Buildings, Household and Office furniture
- Pressure vessels, Tanks and Storage tanks, Rail, Road equipment, Piping and Pipelines
- Ships, Trucks and Trailers, Machine tool frames, Cutting tools and dies
- In addition, arc welding are also used in repair and maintenance work

Types of Weld Joint

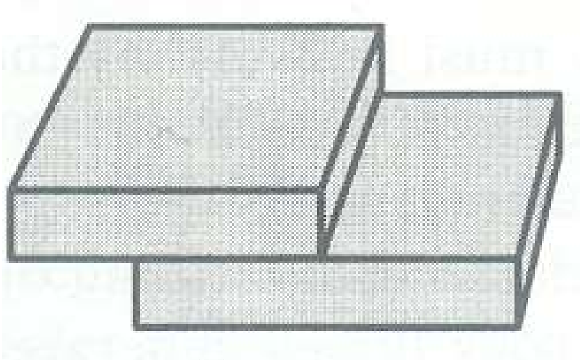
Welding produces a solid connection between two pieces called a **weld joint**. a weld joint is the junction of the edges or surfaces of parts that have been joined by welding. There are five basic types of joints for bringing two parts together for joining.



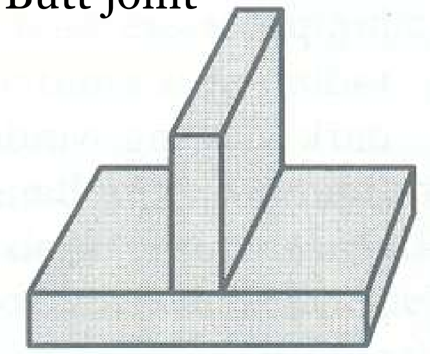
(a) Butt joint



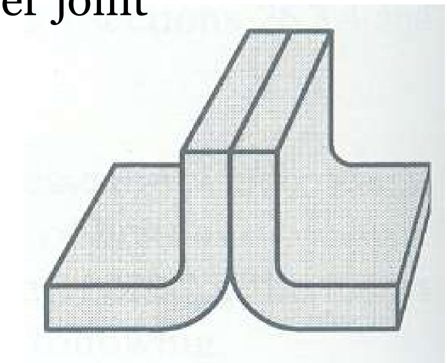
(b) Corner joint



(c) Lap joint

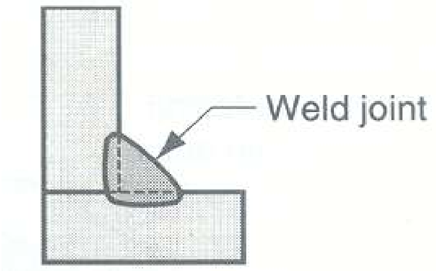


(d) Tee joint

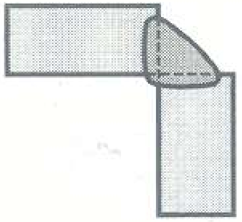


(e) Edge joint

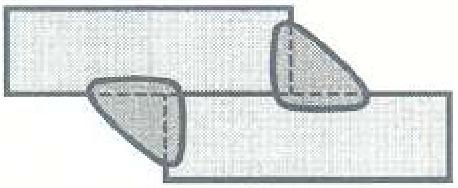
Types of Welds



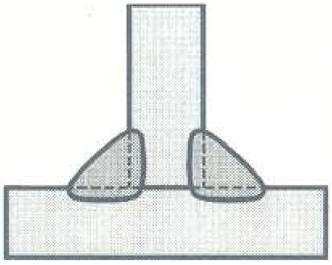
Inside single fillet corner joint



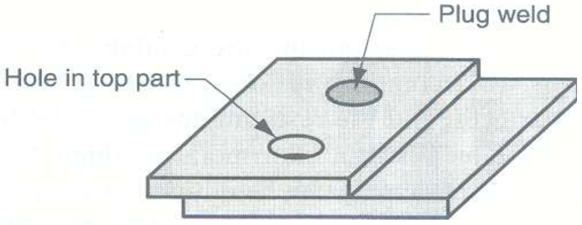
Outside single fillet corner joint



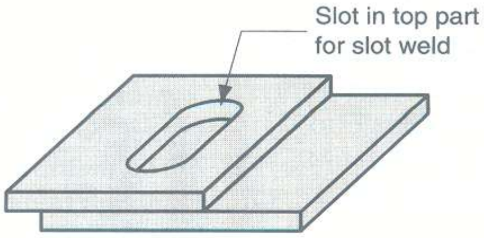
Double fillet lap joint



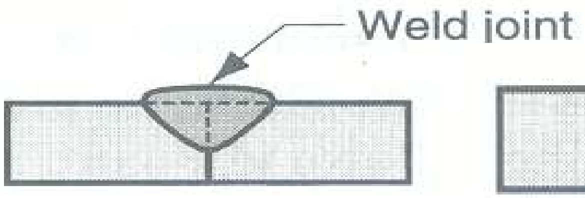
Double fillet tee joint



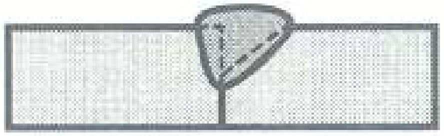
Plug weld



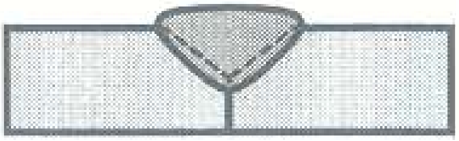
Slot weld



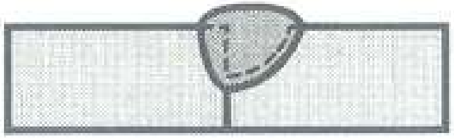
Square groove weld



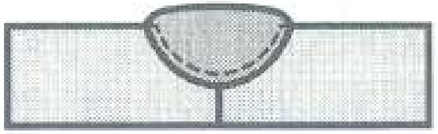
Single bevel groove weld



Single V-groove weld



single J-groove weld



Single U-groove weld

Double V-groove weld for
thicker sections

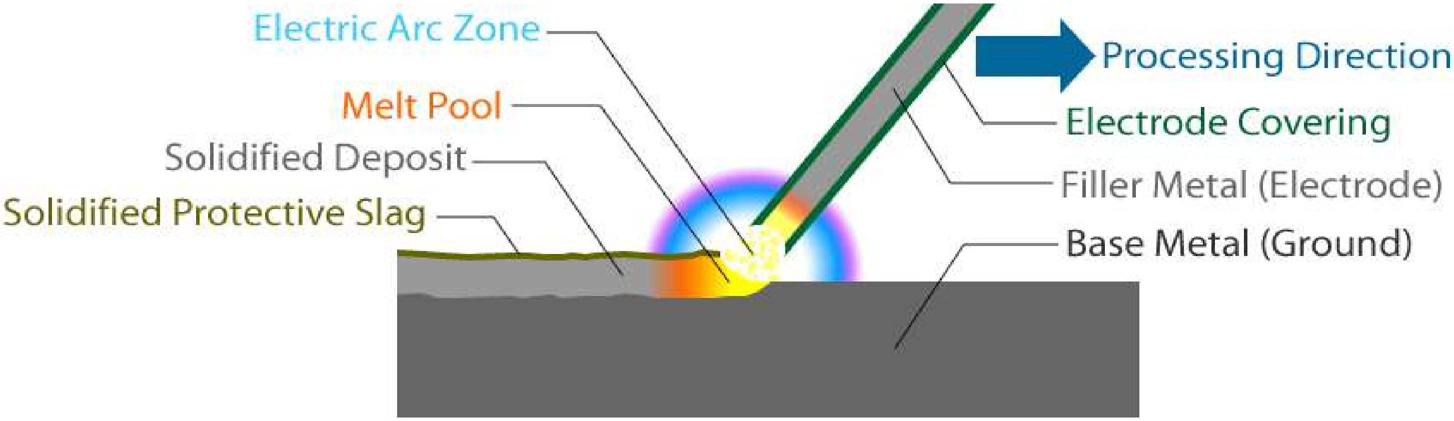
- A heterogeneous weld corresponds to a weld that is realized with a different filler alloy than the base metal. At the opposite, a homogeneous weld is realized with same filler alloy than the base metal. Finally, an autogenous weld is done without filler alloy. The joining is realized by melting only the base metal.
- Heterogenous welding is done using an alloy quite different from the metal parts being jointed, or alternatively the parts themselves may differ significantly in composition.

Shielded Metal Arc Welding (SMAW)

Shielded Metal Arc Welding (SMAW), also known as Manual Metal Arc welding or informally as stick welding, is a manual arc welding process that uses a consumable electrode coated in flux to lay the weld.

An electric current, in the form of either alternating current or direct current from a welding power supply, is used to form an electric arc between the electrode and the metals to be joined.

As the weld is laid, the flux coating of the electrode disintegrates, giving off vapors that serve as a shielding gas and providing a layer of slag, both of which protect the weld area from atmospheric contamination.



Advantages, Disadvantages & Applications

Advantages

- SMAW is the simplest of all the arc welding processes.
- The equipment can be portable and the cost is fairly low.
- This process finds innumerable applications, because of a wide variety of electrodes.
- A big range of metals and their alloys can be welded.
- Welding can be carried out in any position with highest weld quality.

Disadvantages

- Because of the limited length of each electrode and brittle flux coating on it mechanization is difficult.
- In welding long joints (e.g., in pressure vessels), as one electrode finishes, the weld is to be progressed with the next electrode. Unless properly cared, a defect may occur at the place where welding is restarted with the new electrode.
- The process uses stick electrodes and thus it is slower as compared to M1G welding.
- Because of flux coated electrodes, the chances of slag entrapment and other related defects are more as compared to MIG or TIG welding.
- Because of fumes and particles of slag, the arc and metal transfer is not very clear and thus welding control in this process is a bit difficult as compared to MIG welding.

Applications

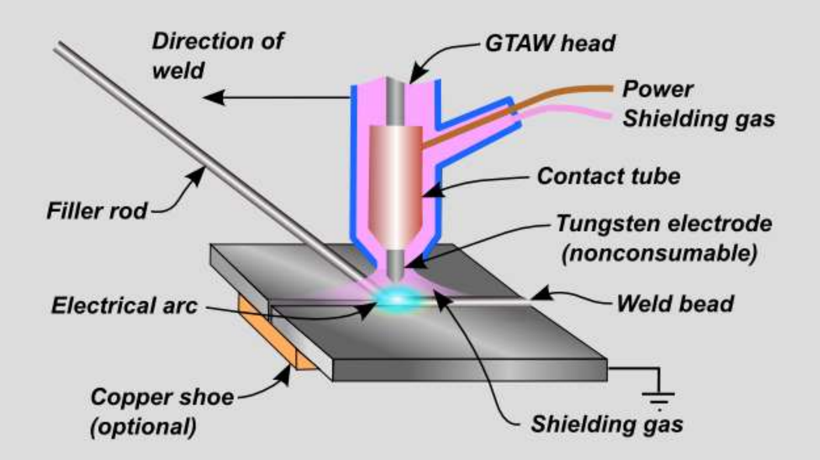
- Almost all the commonly employed metals and their alloys can be welded by this process.
- SMAW is used both as a fabrication process and for maintenance and repair jobs.
- The process finds applications in (a) Air receiver, tank, boiler and pressure vessel fabrications; (b) Ship building; (c) Pipes and Penstock joining; (d) Building and Bridge construction; and (e) Automotive and Aircraft industry, etc.

Tungsten Inert Gas (TIG) Welding

Gas Tungsten Arc Welding (GTAW), also known as Tungsten Inert Gas (TIG) welding, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. The weld area is protected from atmospheric contamination by a shielding gas (usually an inert gas such as argon), and a filler metal is normally used, though some welds, known as autogenous welds, do not require it.

A constant-current welding power supply produces energy which is conducted across the arc through a column of highly ionized gas and metal vapors known as plasma.

Manual gas tungsten arc welding is often considered the most difficult of all the welding processes commonly used in industry. Because the welder must maintain a short arc length, great care and skill are required to prevent contact between the electrode and the workpiece.



Advantages, Disadvantages & Applications

Advantages

- No flux is used; hence there is no danger of flux entrapment
- Because of clear visibility of the arc and the job, the operator can exercise a better control on the welding process
- Weld in all positions and produces smooth and sound welds with fewer spatters
- It is very much suitable for high quality welding of thin (0.125mm) materials
- It is a very good process for welding nonferrous metals and stainless steel.

Disadvantages

- Under similar applications, MIG welding is a much faster process as compared to TIG welding, since TIG welding requires a separate filler rod
- Tungsten if it transfers to molten weld pool can contaminate the same.
- Filler rod end if it by chance comes out of the inert gas shield can cause weld metal contamination
- Equipment costs are higher than that for flux shielded metal arc welding.

Applications

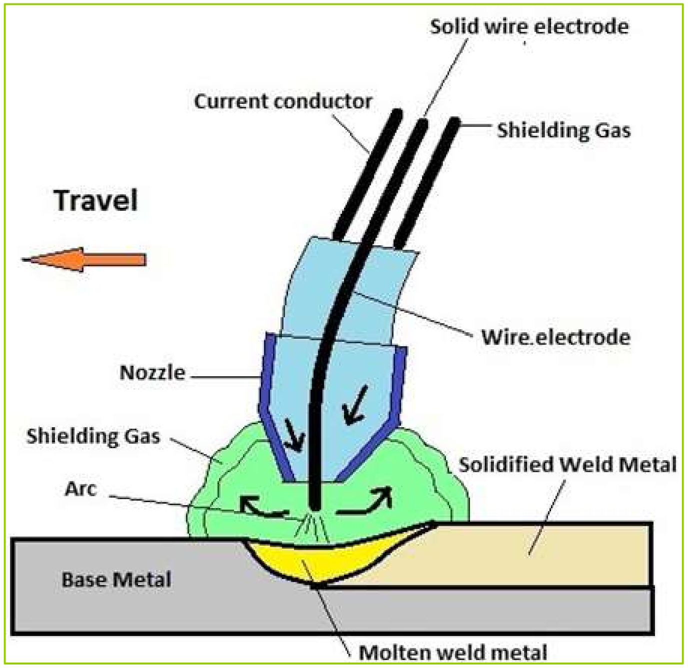
- Welding aluminum, magnesium, copper and their alloys, carbon steels, stainless steels, high temperature and hard surfacing alloys like zirconium etc.
- Welding sheet metal and thinner sections
- Welding of expansion bellows, transistor cases, instrument diaphragms, and can-sealing joints
- Precision welding in atomic energy, aircraft, chemical and instrument industries
- Rocket motor chamber fabrications in launch vehicles.

Metal Inert Gas (MIG) Welding

Gas Metal Arc Welding (GMAW) is frequently referred to as Metal Inert Gas (MIG) welding is a commonly used high deposition rate welding process. Wire is continuously fed from a spool. MIG welding is therefore referred to as a semiautomatic welding process. Before igniting the arc, gas and water flow is checked. Proper current and wire feed speed is set and the electrical connections are ensured. The arc is struck by any one of the two methods.

In the first method current and shielding gas flow is switched on and the electrode is scratched against the job as usual practice for striking the arc.

In the second method, electrode is made to touch the job, is retracted and then moved forward to carry out welding; but. before striking the arc, shielding gas, water and current is switched on. About 15 mm length of the electrode is projected from the torch before striking the arc. During welding, torch remains about 10-12 mm the job and length is kept between 1.5 to 4 mm. Arc length is maintained constant by using the principles of self-adjusted arc, and self-controlled arc in semi-automatic and automatic welding sets respectively.



Advantages, Disadvantages and Applications

Advantages

- Because of continuously fed electrode, MIG welding process is much faster as compared to TIG
- It can produce joints with deep penetration
- Thick and thin, both types of workpieces can be welded effectively
- Large metal deposition rates are achieved by MIG welding process
- The process can be easily mechanized
- No flux is used. MIG welding produces smooth, neat, clean, and spatter free welded surfaces, which require no further cleaning and reducing welding cost.
- Higher arc travel speeds associated with MIG welding reduce distortion considerably.

Disadvantages

- The process is slightly more complex as compared to TIG because a number of variables (like electrode stick out, torch angle, welding parameters, type and size of electrode, welding torch manipulation, etc.) are required to be controlled effectively to achieve good results.
- Welding equipment is more complex, more costly and less portable
- Since air drafts may disperse the shielding gas, MIG welding may not work well in outdoor welding applications
- Weld metal cooling rates are higher than with the processes that deposit slag over the weld metal

Applications

- The process can be used for welding of carbon and low alloy steels, stainless steels, aluminum, magnesium, copper, nickel, and their alloys, titanium, etc.
- For welding tool steels and dies
- For the manufacture of refrigerator parts
- MIG welding has been used successfully in industries like aircraft, automobile and shipbuilding.

Shielding Gas

The shielding gas, forms the arc plasma, stabilizes the arc on the metal being welded, shields the arc and molten weld pool, and allows smooth transfer of metal from the weld wire to the molten weld pool. The primary shielding gasses used are:

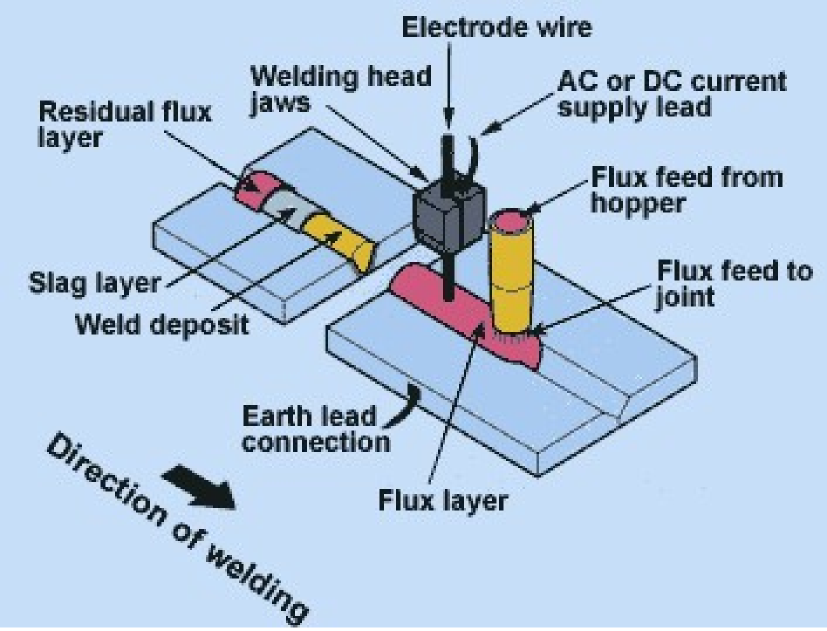
- Argon
- Argon - 1 to 5% Oxygen
- Argon - 3 to 25% CO2
- Argon/Helium

CO_2 is also used in its pure form in some MIG welding processes. However, in some applications the presence of CO_2 in the shielding gas may adversely affect the mechanical properties of the weld.

Submersed Arc Welding (SAW)

Submerged Arc Welding (SAW) is a common arc welding process. It requires a continuously fed consumable solid or tubular (flux cored) electrode. The molten weld and the arc zone are protected from atmospheric contamination by being “submerged” under a blanket of granular fusible flux. When molten, the flux becomes conductive, and provides a current path between the electrode and the work.

SAW is normally operated in the automatic or mechanized mode, however, semi-automatic SAW guns with pressurized or gravity flux feed delivery are available. The process is normally limited to the 1F, 1G, or the 2F positions (although 2G position welds have been done with a special arrangement to support the flux). DC or AC power can be utilized, and combinations of DC and AC are common on multiple electrode systems. Constant Voltage welding power supplies are most commonly used, however Constant Current systems in combination with a voltage sensing wire-feeder are available.



Advantages, Disadvantages and Applications

Advantages

- High deposition rates (over 45 kg/h) have been reported
- Deep weld penetration and Sound welds are readily made
- High speed welding of thin sheet steels at over 100 in/min (2.5 m/min) is possible
- Minimal welding fume or arc light is emitted
- Practically no edge preparation is necessary
- The process is suitable for both indoor and outdoor works.
- Welds produced are sound, uniform, ductile, corrosion resistant and have good impact value.
- Single pass welds can be made in thick plates with normal equipment.
- The arc is always covered under a blanket of flux, thus there is no chance of spatter of weld.

Disadvantages

- Limited to ferrous (steel or stainless steels) and some nickel based alloys;
- Normally limited to the 1F, 1G, and 2F positions;
- Normally limited to long straight seams or rotated pipes or vessels;
- Flux and slag residue can present a health & safety issue;
- Requires inter-pass and post weld slag removal.

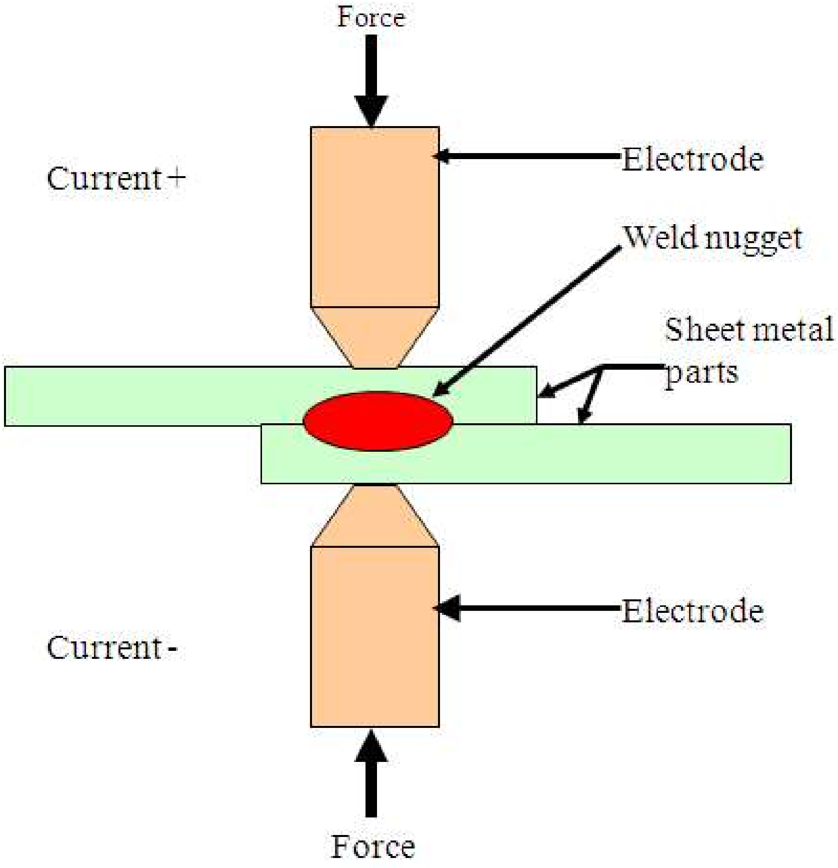
Applications

- Fabrication of pipes, pressure vessels, boilers, structural shapes, rail road and earth moving equipment, cranes and under structure of railway coaches and locomotives.
- Automotive, aviation, ship-building and nuclear power industry
- Rebuilding of worn out parts and depositing wear resisting alloys. Hard facing of tractor rollers and idlers and crane pulleys.

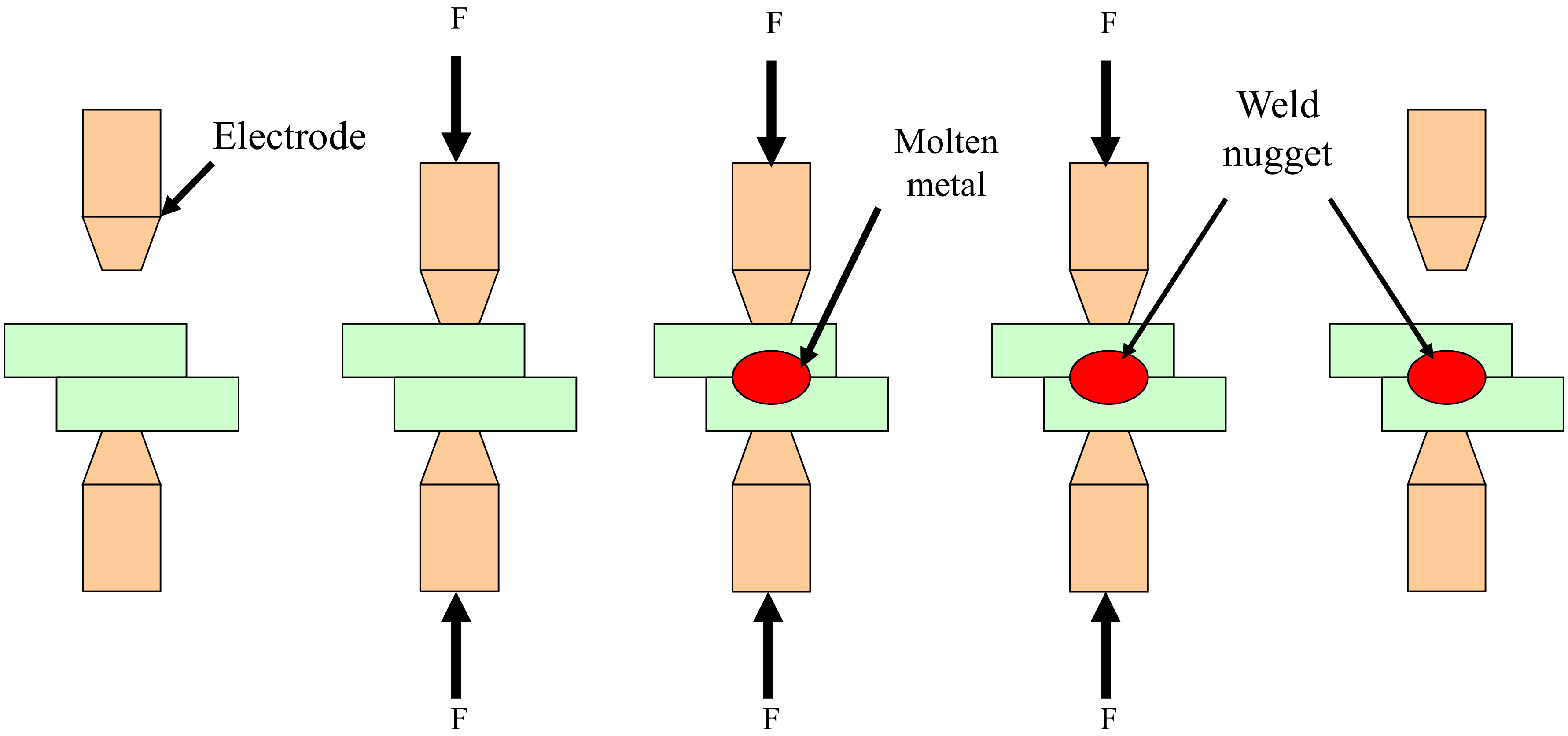
Resistance Spot Welding (RSW)

Spot welding is a popular resistance welding method used to join two to four overlapping metal sheets which are up to 3 mm thick each. In some applications with only two overlapping metal sheets, the sheet thickness can be up to 6 mm. Two copper electrodes are simultaneously used to clamp the metal sheets together and to pass current through the sheets.

When the current is passed through the electrodes to the sheets, heat is generated in the air gap at the contact points. At the contact points between electrodes and workpiece the heat dissipates throughout the copper electrodes quickly, since the copper is an excellent conductor. However at the air gap between metal sheets the heat has no where to go, as the metal is a poor conductor of heat by comparison. Therefore the heat remains in the one location, which melts the metal at that spot. As the heat dissipates throughout the workpiece over a second or so, it cools the spot weld, causing the metal to solidify.



The steps in a spot welding cycle are



Advantages, Disadvantages and Applications

Advantages

- Low cost
- High speed of welding
- Less skilled worker will do
- More general elimination of warping or distortion of parts
- High uniformity of products
- Operation may be made automatic or semi-automatic, and
- No edge preparation is needed

Disadvantages

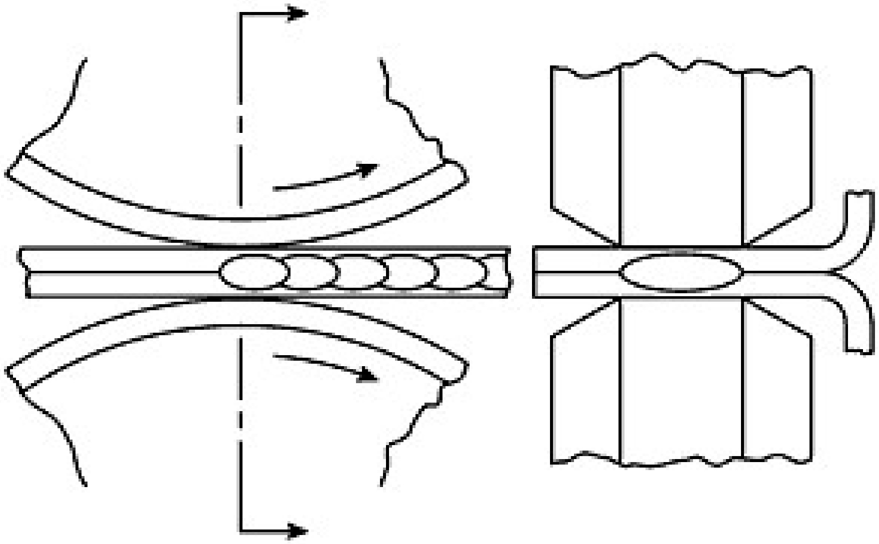
- The initial cost of equipment is high
- Skilled persons are needed for the maintenance of equipment and its controls
- In some materials, special surface preparation is required
- Bigger job thickness' cannot be welded

Applications

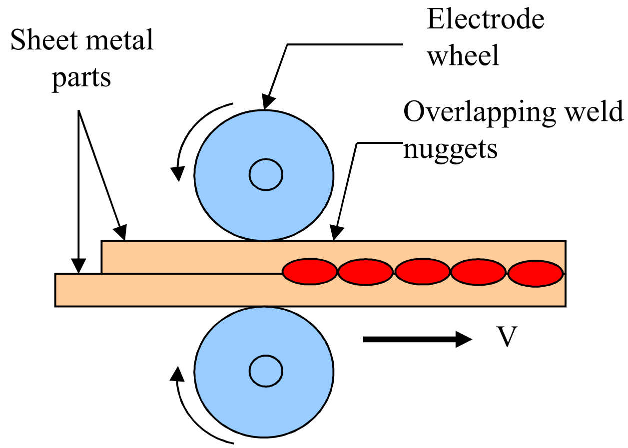
- Spot welding of two 12.5 mm thick steel plates has been done satisfactorily.
- Many assemblies of two or more sheet metal stampings that do not require gas tight joints can be more economically joined by spot welding than by mechanical methods
- The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers, bases or trays is another application of spot welding.
- Spot welding finds application in automobile and aircraft industries.

Resistance Seam Welding (RSEW)

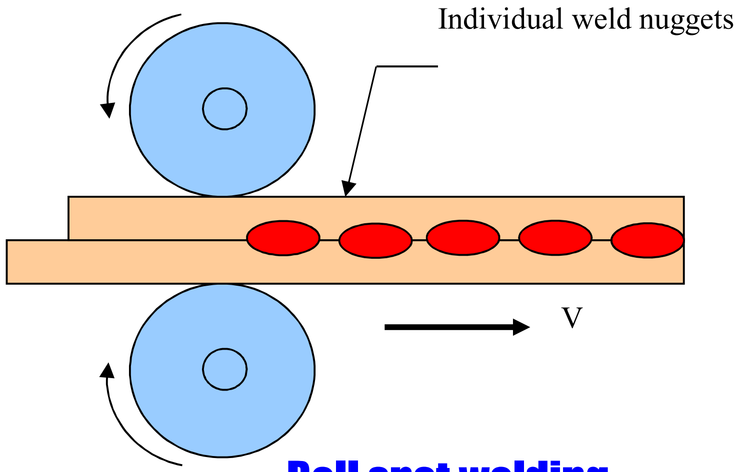
The seam-welding form of the resistance process is a series of overlapping welds. Two or more sheets of base metal are usually passed between electrode rollers, as shown in following Figure, which transmit the current and also the mechanical pressure required for producing a welded seam which is normally gas-tight or liquid-tight.



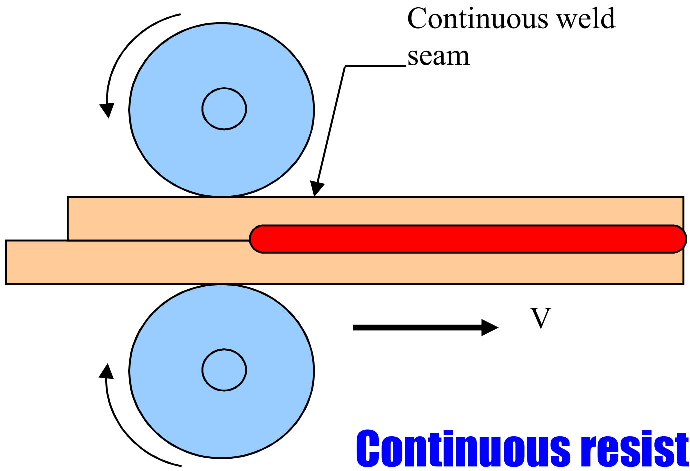
Different types of seams produced by electrode wheels



Conventional resistance seam welding



Roll spot welding



Continuous resistance seam

Advantages, Disadvantages and Applications

Advantages

- It can produce gas tight or liquid- tight joints
- Overlap can be less than for spot or projection welds
- A single seam weld or several parallel seams may be produced simultaneously

Disadvantages

- Welding can be done only along a straight or uniformly curved line
- It is difficult to weld thicknesses greater than 3mm
- A change in the design of electrode wheels is required to avoid obstructions along the path of the wheels during welding.

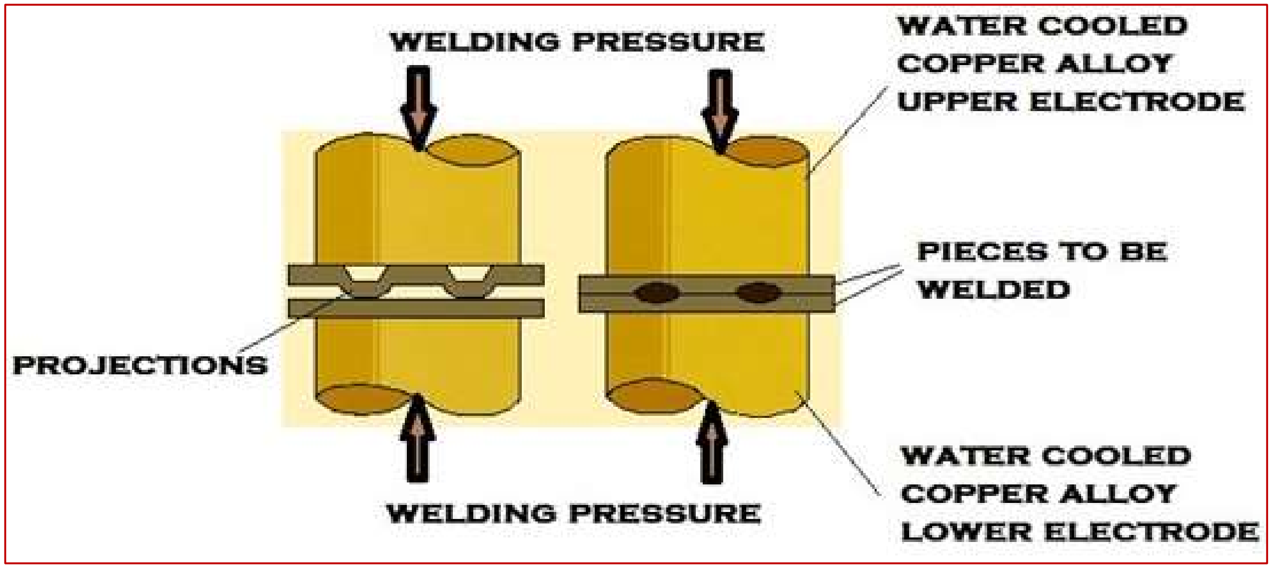
Applications

- Girth welds can be made in round, square or rectangular parts
- Except for copper and high copper alloys, most other metals of common industrial use can be seam welding.
- Besides lap welds, seam-welding can be used for making butt seam welds too.

Resistance Projection Welding (RPW)

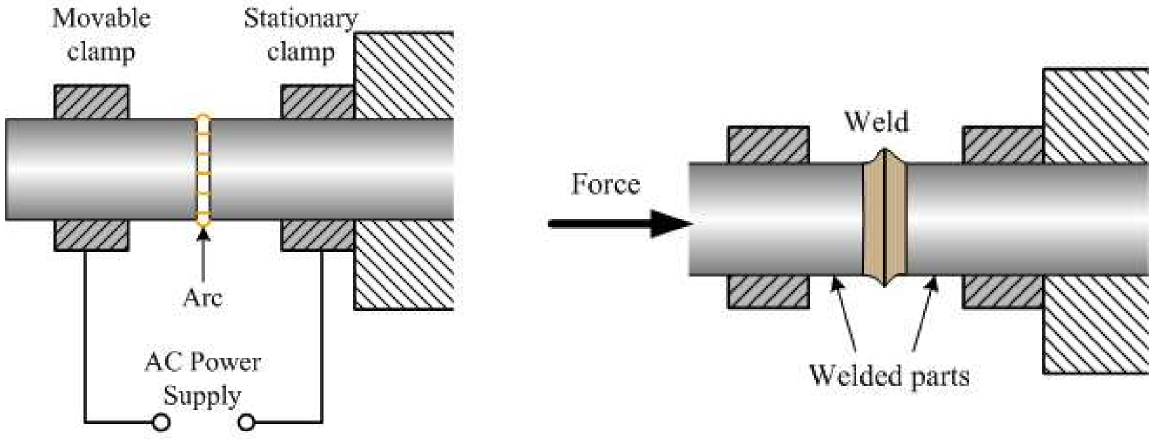
In resistance projection welding, small projections are formed on one or both pieces of the base metal to obtain contact at a point which localize the current flow and concentrate the heat. Under pressure, the heated and softened projections collapse and a weld is formed.

Projection on the upper component is pressed against the lower component by electrode force. The projection collapses and a fused weld nugget are formed with the application of current. This technique is of special value in mounting attachments to surfaces of which the back side is inaccessible to a welding operator.



Flash Welding (FW)

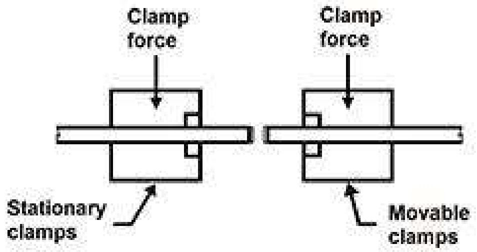
- Flash Welding (FW) is a resistance welding process which produces coalescence simultaneously over the entire area of abutting surfaces, by the heat obtained from resistance to electric current between the two surfaces, and by the application of pressure after heating is substantially completed.
- Flashing and upsetting are accompanied by expulsion of metal from the joint. During the welding operation there is an intense flashing arc and heating of the metal on the surface abutting each other. After a predetermined time the two pieces are forced together and coalescence occurs at the interface, current flow is possible because of the light contact between the two parts being flash welded.

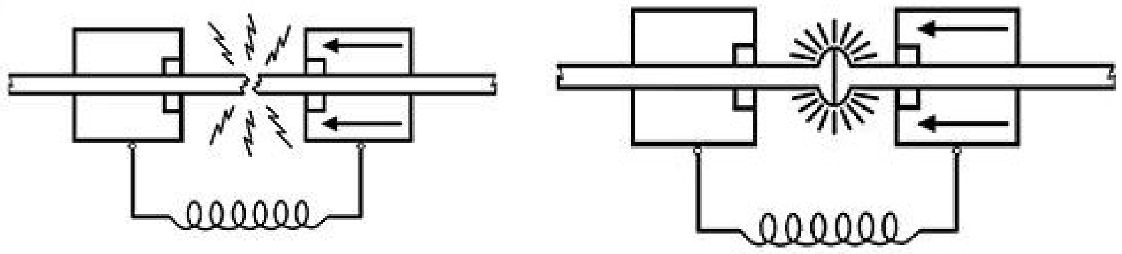


Percussion Welding (PEW)

Percussion welding is a resistance welding process which produces coalescence of the abutting members using heat from an arc produced by a rapid discharge of electrical energy. Pressure is applied progressively during or immediately following the electrical discharge.

This process is quite similar to flash welding and upset welding, but is limited to parts of the same geometry and cross section. It is more complex than the other two processes in that heat is obtained from an arc produced at the abutting surfaces by the very rapid discharge of stored electrical energy across a rapidly decreasing air gap. This is immediately followed by application of pressure to provide an impact bringing the two parts together in a progressive percussive manner. The advantage of the process is that there is an extremely shallow depth of heating and time cycle is very short. It is used only for parts with fairly small cross-sectional areas.

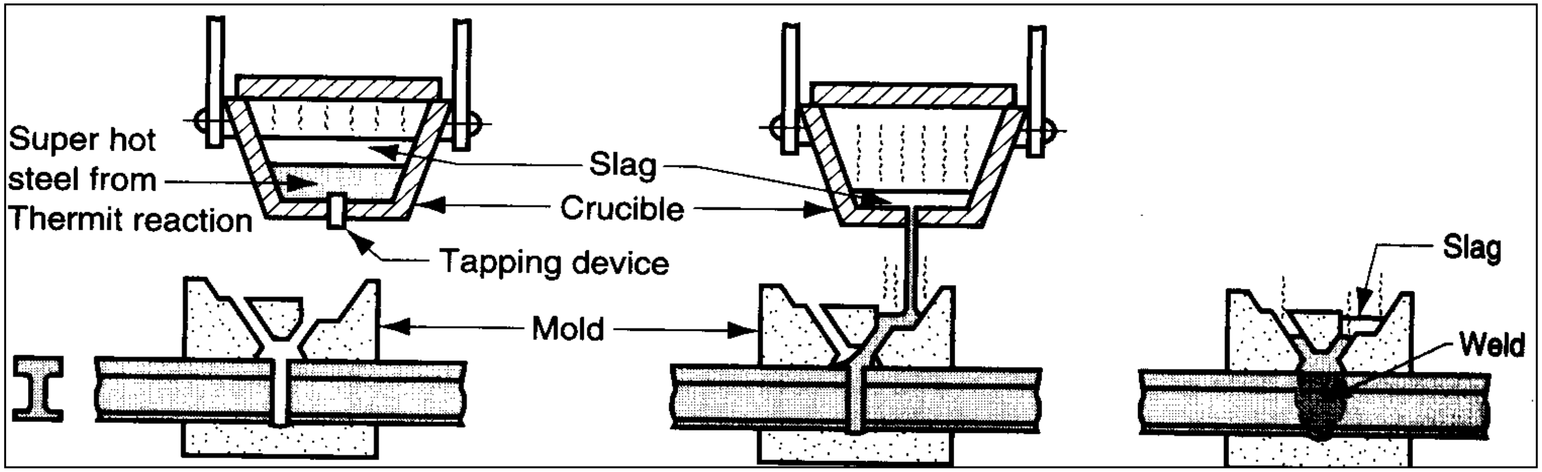




Thermit Welding (TW)

Thermit welding differs from other welding processes principally in that the heating is obtained from the thermit chemical reaction rather than from fire or electric current. A mixture of a metallic oxide and finely divided aluminum were ignited. The two materials react exothermically thereby converting the mixture into a superheated mass of the metal itself and a slag.

The superheated metal flows into a mold around the parts to be united and weld them into one homogeneous mass while the slag overflows on top of the mold. Thermit welding now finds only limited application, chiefly in the repair of large iron and steel castings, though it was the traditional method for joining rails on site.



Advantages, Disadvantages & Applications

Advantages

- The heat necessary for welding is obtained from a chemical reaction and thus no costly power-supply is required. Therefore broken parts (rails) can be welded on the site itself.

Disadvantages

- Thermit welding is applicable only to ferrous metal parts of heavy sections, i.e., mill housings and heavy rail sections.
- The process is uneconomical if used to weld cheap metals or light parts.

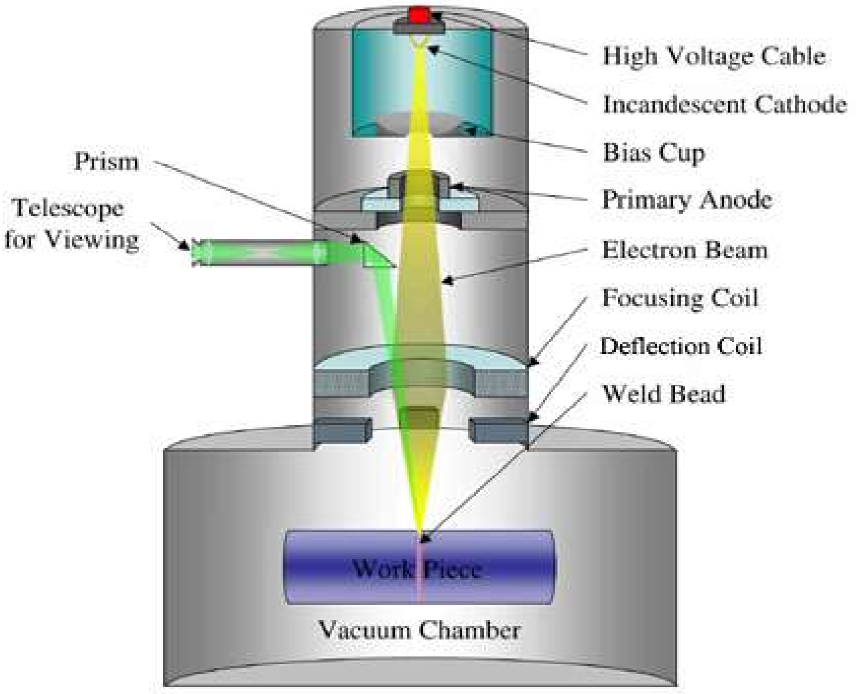
Applications

- For repairing fractured rails (railway tracks).
- For butt-welding pipes end to end.
- For welding large fractured crankshafts.
- For welding broken frames of machines
- For replacing broken teeth on large gears.
- For welding new necks to rolling mill rolls and pinions.
- For welding cables for electrical conductors.
- For end welding of reinforcing bars to be used in concrete (building) construction.)

Electron Beam Welding (EBW)

Electron beam welding is defined as a fusion welding process wherein coalescence is produced by the heat obtained from a concentrated beam composed primarily of high velocity electrons. As the high velocity electrons strike the surfaces to be joined, their kinetic energy changes to thermal energy thereby causing the workpiece metal to melt and fuse.

The electron beam is produced in a high vacuum environment by an electron gun, usually consisting of a tungsten or tantalum cathode, a grid or forming electrode and an anode. A stream of electrons is giving off from a tungsten filament heated to about 2200^{o}C. The electrons are gathered, accelerated to a high velocity and shaped into a beam by the potential difference between cathode and anode. The beam is collimated and focusing by passing through the field of an electro-magnetic focusing coil or magnetic lens. Beams typically are focused to about 0.25 to 1 mm diameter and have a power density of about 10 kW/mm^2, which is sufficient to melt and vaporize any metal.



Advantages, Disadvantages & Applications

Advantages

- Ability to make welds that are deeper, narrower and less tapered than arc welds with a total heat input much lower than in arc welding
- Superior control over penetration and other weld dimensions and properties
- High welding speeds are common: no filler metal is required; the process can be performed in all positions and preheating or post heating is generally unnecessary
- Clean and sound welds
- Energy conversion efficiency is high, about 65%

Disadvantages

- The equipment is expensive and high operating cost
- High cost of precision joint preparation and precision tooling
- Limitations of the vacuum chamber. Work size is limited by the size of the chamber
- Production rate and unit welding cost are adversely affected by the need to pump down the work chamber for each load.

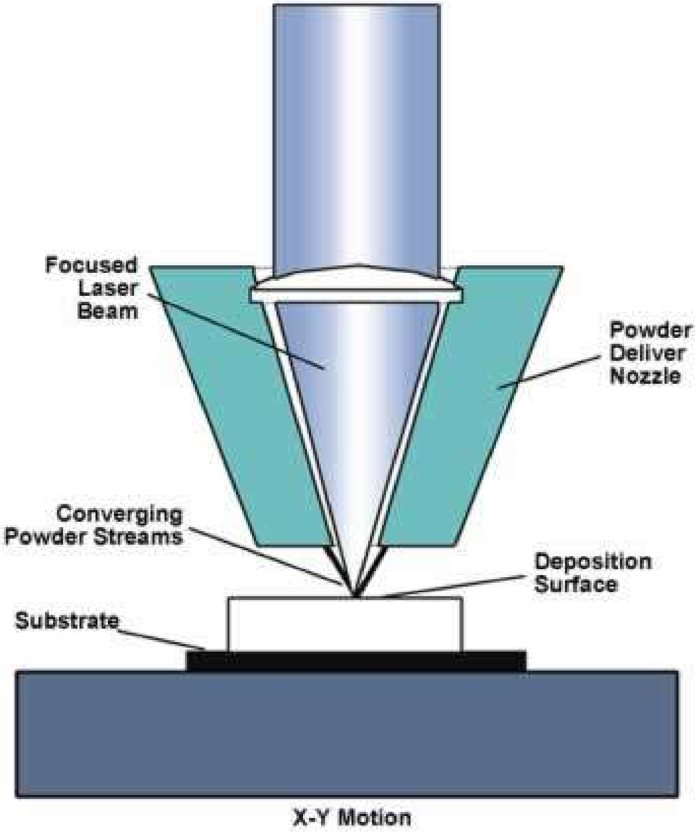
Applications

- Materials that are difficult to weld by other processes, such as zirconium, beryllium and tungsten can be welded successfully by this method but the weld configuration should be simple and preferably flat.
- Narrow weld can be obtained with remarkable penetrations
- The high power and heat concentrations can produce fusion zones with depth-to-width ratios of 25:1 with low total heat input, low distortion and a very narrow heat-affected zone
- Heat sensitive materials can be welded without damage to the base metal.

Laser Beam Welding (LBW)

The word **LASER** stands for Light Amplification by Stimulated Emission of Radiation. Laser beam welding is defined as a welding process wherein coalescence is produced by the heat obtained from the application of a concentrated coherent light beam impinging upon the surface to be joined.

The laser crystal (Ruby) is in the form of a cylinder, the ends being flat and parallel to a high degree of accuracy and silvered to give mirror-reflecting surfaces. There is a small aperture on the axis of the crystal, through the mirror at the output end. When the crystal is pumped with high-intensity white light from a xenon or krypton lamp, the Cr ions in the crystal get excited. The excited ions posses more energy and some of it are given as a red fluorescent light. This light is reflected backward and forward in the crystal between the two ends (mirrors), striking more Cr ions on the path. These ions affected by the collisions are each caused to emit their quota of red light. There is a cumulative effect of the increasing red light existing more and more Cr ions, until the number of collisions is high enough to cause a burst of red light through the small aperture in the mirror at the output end of the crystal. The beam produced is extremely narrow and can be focused to a pinpoint area by an optical lens.



Advantages, Disadvantages & Applications

Advantages

- Welds can be made inside transparent glass or plastic housings
- A wide variety of materials can be welded
- As no electrode is used, electrode contamination or high electric current effects are eliminated
- Unlike electron beam welding it operates in air, no vacuum is required
- Laser beam being highly concentrated and narrowly which produces narrow size of the HAZ
- It is possible to weld heat-treated alloys without affecting their heat-treated condition
- Because it is light, it is clean – no vaporized metal or electrodes dirty up the delicate assemblies.

Disadvantages

- The major drawback to laser beam welds is the slow welding speeds (25-250 mm/min) resulting from the pulse rates and puddle sizes at the fusion point
- Laser welding is limited to depths of approximately 1.5 mm and additional energy only tends to create gas voids and undercuts in the work
- Most industrial laser are of the CO_2 variety and consume considerable amounts of power
- Reflected or scattered laser beams can be quite dangerous to human eyes.

Applications

- Laser is a high energy light beam that can both weld and cut the metals
- For connecting leads on small electronic components and in IC in the electronic industry
- It is possible to weld wires without removing the polyurethane insulation. The laser simply evaporates the insulation and completes the weld with the internal wire.
- Laser beam is used for micro welding purposes. It is particularly suitable for the welding of miniaturized and microminiaturized components.

Defects in Welding

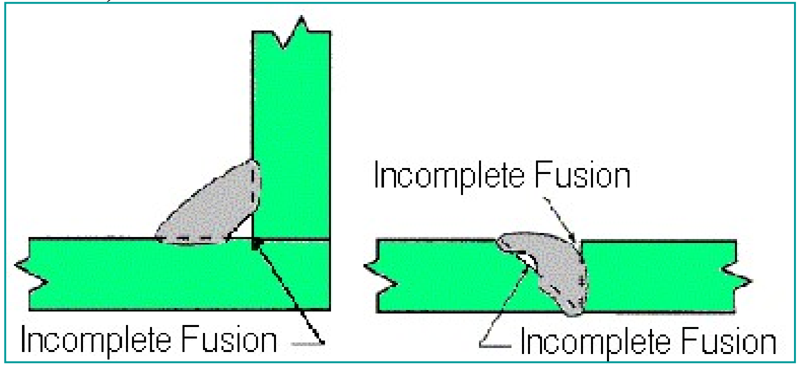
Defects during welding may be caused by the presence of impurities and gases at the liquification temperature, fast solidification of the weld metal, thermal shock and microstructural changes. **Common defects** in welding and their remedies are discussed below:

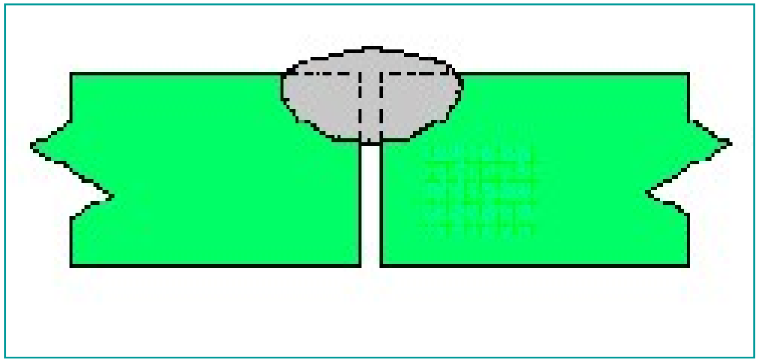
- Lack of Fusion and Lack of penetration
- Porosity and blow holes
- Slag inclusions
- Cracking
- Distortion
- Welding profile
- Residual stresses
- Surface damage

Any of these defects are potentially disastrous as they can all give rise to high stress intensities which may result in sudden unexpected failure below the design load or in the case of cyclic loading, failure after fewer load cycles than predicted.

Lack of Fusion and Lack of Penetration

- To achieve a good quality join it is essential that the fusion zone extends the full thickness of the sheets being joined. Thin sheet material can be joined with a single pass and a clean square edge will be a satisfactory basis for a join. However thicker material will normally need edges cut at a V angle and may need several passes to fill the V with weld metal. Where both sides are accessible one or more passes may be made along the reverse side to ensure the joint extends the full thickness of the metal.
- Lack of fusion results from too little heat input and / or too rapid traverse of the welding torch (gas or electric).





Porosity and Blow Holes

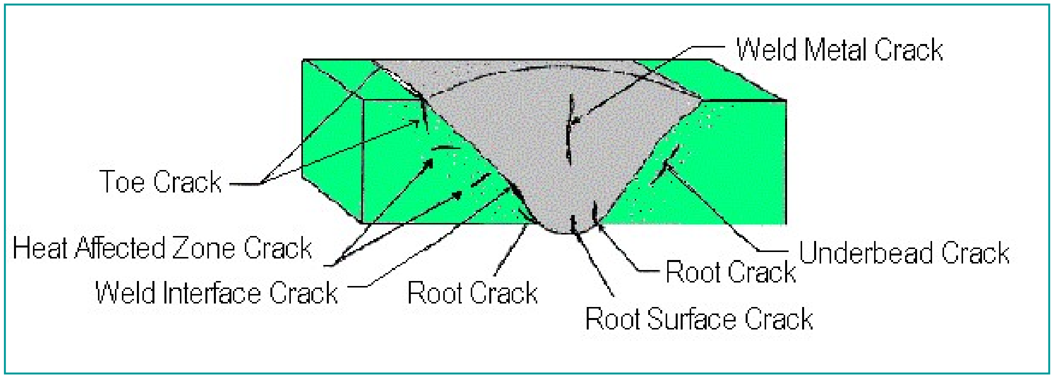
- This occurs when gases are trapped in the solidifying weld metal. These may arise from damp consumables or metal or, from dirt, particularly oil or grease, on the metal in the vicinity of the weld. This can be avoided by ensuring all consumables are stored in dry conditions and work is carefully cleaned and degreased prior to welding.

Slag Inclusions

- These can occur when several runs are made along a V join when joining thick plate using flux cored or flux coated rods and the slag covering a run is not totally removed after every run before the following run.

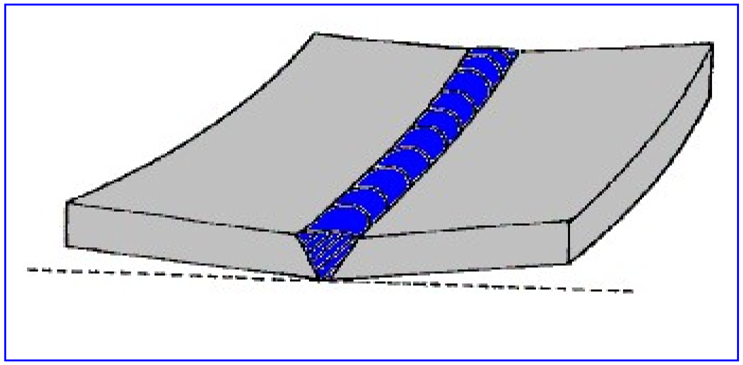
Cracking

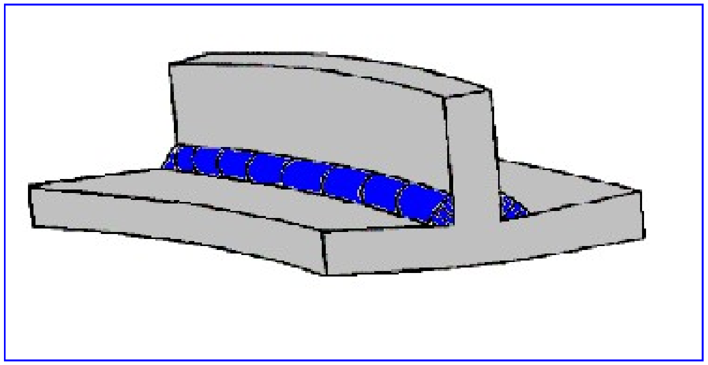
- This can occur due just to thermal shrinkage or due to a combination of strain accompanying phase change and thermal shrinkage. In the case of welded stiff frames, a combination of poor design and inappropriate procedure may result in high residual stresses and cracking. Where alloy steels or steels with a carbon content greater than about 0.2% are being welded, self cooling may be rapid enough to cause some (brittle) martensite to form. This will easily develop cracks.
- To prevent these problems a process of pre-heating in stages may be needed and after welding a slow controlled post cooling in stages will be required. This can greatly increase the cost of welded joins, but for high strength steels, such as those used in petrochemical plant and piping, there may well be no alternative.



Distortion

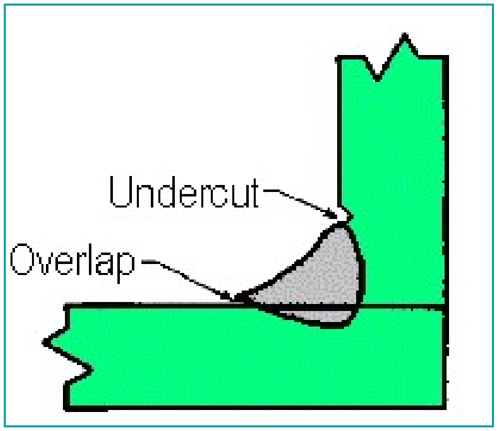
- While welding a job, base metal under the arc melts, base metal ahead gets preheated and the base metal portion already welded starts cooling. There is good amount of temperature difference at various points along the joint and thus at any instant certain areas of the base metal expand and others including weld bead contract. This phenomena lead to distortion. Distortion is the change in shape and difference between the positions of the two plates before welding and after welding. The various factors leading to distortion are:
  - More number of passes with small diameter electrodes
  - Slow arc travel speed
  - Type of joint. A V-joint needs more metal to be deposited to fill the groove as compared to a U- joint, thus leading to comparatively more distortion
  - High residual stresses in plates to be welded
  - Welding sequence being improper. Use of jigs and fixtures, clamps, presetting, wedging, and proper tacking may minimize distortion.

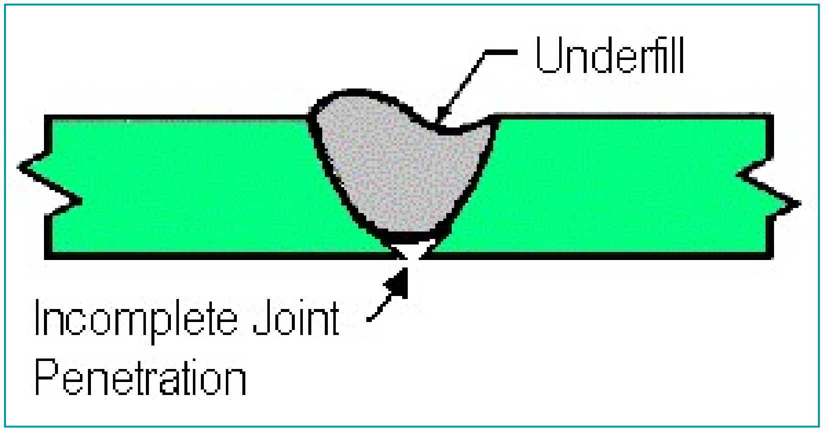




Welding Profile

- Weld profile is important not only because of its effects on the strength and appearance of the weld, but also because it can signal incomplete fusion or the presence of slag inclusions in multiple layer welds.
  - **Underfilling** results when the joint is not filled with the proper amount of weld metal.
  - **Undercutting** results from the melting away of the base metal and the consequent generation of the groove in the shape of a sharp recess or notch. If it is deep or sharp, an undercut can act as a stress raiser and can reduce the fatigue strength of the joint; in such cases, it may lead to premature failure.
  - **Overlapping** is the surface discontinuity usually caused by poor welding practice and by the selection of improper materials.





Residual Stresses

- Because of the localized heating and cooling during welding, expansion and contraction of the weld area causes residual stresses in the workpiece. Residual stresses can cause the following defects:
  - Distortion, warping and buckling of the welded parts
  - Stress-corrosion cracking
  - Further distortion, if a portion of the welded structure is subsequently removed (by machining or by sawing)
  - Reduced fatigue life.

Surface Damage

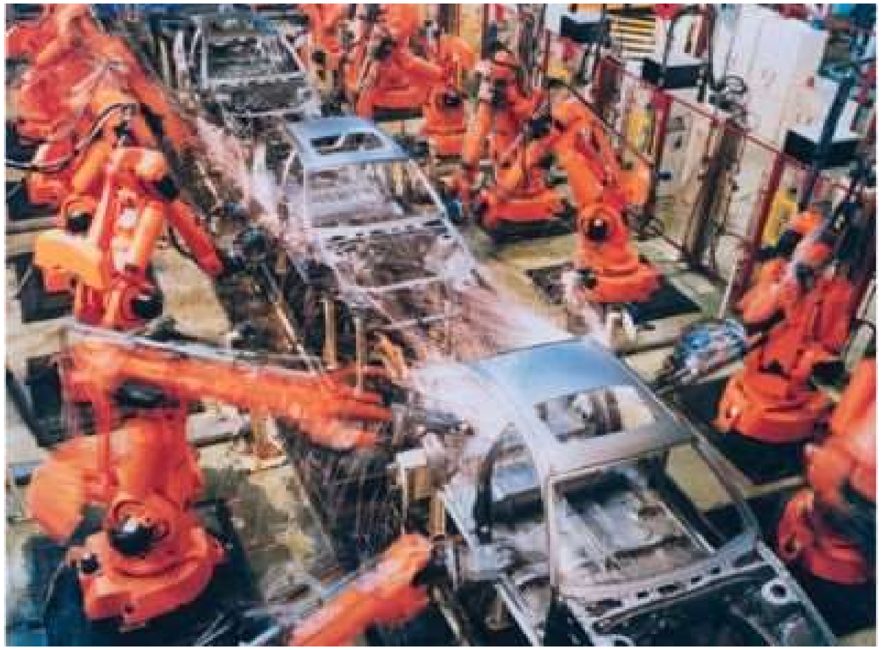
- Some of the metal may spatter during welding and be deposited as small droplets on adjacent surfaces. In arc welding processes, the electrode may inadvertently touch the parts being welded at places other than the weld zone (arc strikes). Such surface discontinuities may be objectionable for reasons of appearance or of subsequent use of the welded part.

Robotic Welding

- **Robot welding** is the use of mechanized programmable tools (robots), which completely automate a welding process by both performing the weld and handling the part. Processes such as gas metal arc welding, while often automated, are not necessarily equivalent to robot welding, since a human operator sometimes prepares the materials to be welded. Robot welding is commonly used for **Resistance Spot** welding and **Arc Welding** in high production applications, such as the **Automotive Industry**.

- Robot welding is a relatively new application of robotics, even though robots were first introduced into US industry during the 1960s. The use of robots in welding did not take off until the 1980s, when the automotive industry began using robots extensively for **Spot Welding**. Since then, both the number of robots used in industry and the number of their applications has grown greatly.

- Robot arc welding has begun growing quickly just recently, and already it commands about 20% of industrial robot applications. The major components of arc welding robots are the manipulator or the mechanical unit and the controller, which acts as the robot's "brain". The manipulator is what makes the robot move, and the design of these systems can be categorized into several common types, such as the SCARA robot and Cartesian coordinate robot, which use different coordinate systems to direct the arms of the machine.



Spot welding

Arc welding

Welding Automation with Robots

There are two basic categories of welding automation: semi-automatic and fully automatic

- **Semi-automatic welding** occurs when an operator manually loads the part(s) into the welding fixture. The torch/part motions and welding parameters are controlled by a weld controller to ensure a quality, repeatable weld. When the weld is completed, the operator removes the completed part and then the process starts over.
- **Fully automatic welding** utilizes a custom machine or succession of machines to load the workpiece, place the part or torch into position, effect the weld, supervise quality control, and then when the product is finished, unload it. If necessary, additional "part in place" and final product quality checks may be designed into the machine. The details of the specific operation designate whether a machine operator may or may not be necessary.

There are many factors that need to be considered when setting up a robotic welding facility. Some of the consideration for a robotic welding facility are listed below:

- Accuracy and repeatability
- Number of axes and Reliability
- Fixtures
- Programming
- Seam tracking systems
- Maintenance and Controls
- Weld monitors
- Arc welding equipment
- Positioners and Part transfer

Benefits of Automated Welding

Well-engineered welding systems include benefits that range from improved weld quality to decreased variable labor costs. The foremost advantages are:

- Improved Weld Quality: Mechanized welding improves weld integrity and repeatability.
- Increased Output/Volume: Production weld speeds are set by the machine at a reasonable percentage of maximum. With minimized part set up time, and higher weld speeds increased output will occur.
- Decreased Scrap/Rework: Automating the torch/part motions and part placement minimizes the error potential.
- Decreased Variable Labor Costs: Relying on human welders dramatically increases a manufacturer's labor costs. A Semi-automatic system will normally have at least twice the output of a skilled welder. A fully automatic system with sufficient stations can run at four times the pace of semi-automatic system or at eight times the pace of a skilled welder.