NEHRU COLLEGE OF ENGINEERING AND RESEARCH CENTRE
(NAAC Accredited)
(Approved by AICTE, Affiliated to APJ Abdul Kalam Technological University, Kerala)

DEPARTMENT OF MECHATRONICS ENGINEERING

COURSE MATERIALS

ME 220 MANUFACTURING TECHNOLOGY

VISION OF THE INSTITUTION
To mould true citizens who are millennium leaders and catalysts of change through excellence in education.
MISSION OF THE INSTITUTION
NCERC is committed to transform itself into a center of excellence in Learning and Research in Engineering and Frontier Technology and to impart quality education to mould technically competent citizens with moral integrity, social commitment and ethical values. We intend to facilitate our students to assimilate the latest technological know-how and to imbibe discipline, culture and spiritually, and to mould them in to technological giants, dedicated research scientists and intellectual leaders of the country who can spread the beams of light and happiness among the poor and the underprivileged.

ABOUT DEPARTMENT

- Established in: 2013
- Course offered: B.Tech Mechatronics Engineering
- Approved by AICTE New Delhi and Accredited by NAAC
- Affiliated to the University of Dr. A P J Abdul Kalam Technological University.

DEPARTMENT VISION

To develop professionally ethical and socially responsible Mechatronics engineers to serve the humanity through quality professional education.

DEPARTMENT MISSION

1) The department is committed to impart the right blend of knowledge and quality education to create professionally ethical and socially responsible graduates.

2) The department is committed to impart the awareness to meet the current challenges in technology.

3) Establish state-of-the-art laboratories to promote practical knowledge of mechatronics to meet the needs of the society

PROGRAMME EDUCATIONAL OBJECTIVES

I. Graduates shall have the ability to work in multidisciplinary environment with good professional and commitment.

II. Graduates shall have the ability to solve the complex engineering problems by applying electrical, mechanical, electronics and computer knowledge and engage in lifelong learning in their profession.

III. Graduates shall have the ability to lead and contribute in a team with entrepreneur skills, professional, social and ethical responsibilities.

IV. Graduates shall have ability to acquire scientific and engineering fundamentals necessary for higher studies and research.

PROGRAM OUTCOME (PO'S)

Engineering Graduates will be able to:

PO 1. Engineering knowledge: Apply the knowledge of mathematics, science, engineering fundamentals, and an engineering specialization to the solution of complex engineering problems.

PO 2. Problem analysis: Identify, formulate, review research literature, and analyze complex engineering problems reaching substantiated conclusions using first principles of mathematics, natural sciences, and engineering sciences.

PO 3. Design/development of solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO 4. Conduct investigations of complex problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions.

PO 5. Modern tool usage: Create, select, and apply appropriate techniques, resources, and modern engineering and IT tools including prediction and modeling to complex engineering activities with an understanding of the limitations.

PO 6. The engineer and society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO 7. Environment and sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO 8. Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

PO 9. Individual and team work: Function effectively as an individual, and as a member or leader in diverse teams, and in multidisciplinary settings.

PO 10. Communication: Communicate effectively on complex engineering activities with the engineering community and with society at large, such as, being able to comprehend and write effective reports and design documentation, make effective presentations, and give and receive clear instructions.

PO 11. Project management and finance: Demonstrate knowledge and understanding of the engineering and management principles and apply these to one’s own work, as a member and leader in a team, to manage projects and in multidisciplinary environments.

PO 12. Life-long learning: Recognize the need for, and have the preparation and ability to engage in independent and life-long learning in the broadest context of technological change.

PROGRAM SPECIFIC OUTCOME(PSO'S)

PSO 1: Design and develop Mechatronics systems to solve the complex engineering problem by integrating electronics, mechanical and control systems.

PSO 2: Apply the engineering knowledge to conduct investigations of complex engineering problem related to instrumentation, control, automation, robotics and provide solutions.

COURSE OUTCOME

After the completion of the course the student will be able to

COURSE OUTCOMES	
CO1	Understand about different techniques of casting
CO2	Acquire knowledge on different rolling processes and different rolled processes
CO3	Describe different forging methods, cautions adopted in die design
CO4	Identify various work and tool holding devices used in manufacturing
CO5	Understand bending, shearing, drawing processes of sheet metal
CO6	Interpret about welding metallurgy, weldability and to introduce various metal joining techniques

CO VS PO'S MAPPING

CO Vs PO														
SUBJECT														
COURSE COUTCOME	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12	PSO1	PSO2
C305.1	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305.2	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305.3	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305.4	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305.5	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305.6	3	-	3	-	-	-	-	-	-	-	-	3	3	3
C305	3	0	3	0	0	0	0	0	0	0	0	3	3	3
CO ATTAINMENT	3.00	0.00	3.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	3.00	3.00

Note: H-Highly correlated=3, M-Medium correlated=2, L-Less correlated=1

SYLLABUS

Course No.	Course Name	L-T-P-Credits	Year of Introduction
ME220	MANUFACTURING TECHNOLOGY	3-0-0-3	2016

Prerequisite: Nil

Course Objectives:-

1. To give an exposure to different techniques of casting and molds required.
2. To provide an exposure to different rolling processes and different rolled products
3. To familiarize with different forging methods, cautions to be adopted in die design.
4. To give an introduction to various work and tool holding devices used in manufacturing.
5. To introduce to the bending, shearing and drawing processes of sheet metal working and allied machines,
6. To give an understanding of welding metallurgy and weldability and to introduce various metal joining techniques.

SYLLABUS

Casting –patterns - Cores – Gating – Risering – Defects in Castings - Rolling –Defects in Rolled parts- forging – Coining – Heading – Piercing –Die Design– Extrusion Process– Extrusion Defects – Drawing Process -Principles of Location –Principles of Clamping – Types of Clamp -Sheet metal characteristics –Deep drawing –Spinning –Definition of Welding – Weldability – Solidification of Weld Metal – Heat Affected Zone – Welding Defects - Gas Welding -Arc Welding - Ultrasonic Welding – Friction Welding – Resistance Welding —
Brazing- Soldering.

Expected outcomes: At the end of the course the students will be able to

1. Acquire knowledge in various casting processes and technology related to them.
2. Understand the rolling passes required for getting required shapes of rolled products.
3. Discuss important aspects of forging techniques
4. Discuss sheet metal working processes and their applications to produce various shapes and products.
5. Acquire knowledge in various types of welding processes.

Text books:-

1. Amitabha Ghosh and Ashok Kumar Mallick, Manufacturing Science Affiliated East West Press Ltd, New Delhi, 2002
2. S.Kalpakjian and Steven R Schimid, Manufacturing Engineering and Technology, Pearson,2001

Reference books:-

1. RAO, Manufacturing Technology-Vol 2 3e, McGraw Hill Education India, 2013
2. RAO, Manutacturing Technology-Vol 1 4e, McGraw Hill Education India, 2013
3. Cyril Donaldson and George H LeCain, Tool Design,TMH
4. Handbook of Fixture Design – ASTME
5. Campbell J. S., Principles of Manufacturing Materials and Processes, Tata McGraw Hill, 1999
6. P R Beeley, Foundry Technology, Elsevier, 2001
7. Richard W. Heine, Carl R. Loper, Philip C. Rosenthal, Principles of Metal Casting,

QUESTION BANK

MODULE I

Q:NO:	QUESTIONS	CO	KL
1	State and explain various casting defects	CO1	K5
2	Discuss in detail about Slush casting	CO1	K3
3	Sketch the type of casting opt for wax molding?	CO2	K2
4	Elucidate about Die casting process with neat figures.	CO1	K3
5	Explain why gating system is used in casting process?	CO1	K1
6	State and explain various casting defects?	CO1	K2
7	Discuss in detail about Slush casting?	CO1	K5
8	Discuss in detail about design considerations based on various shapes while doing casting process	CO1	K2
9	Elucidate Pressure die-casting with neat figures?	CO1	K2
10	State the types of patterns and their materials	CO1	K4
11	State and explain various casting defects	CO1	K2
12	Explain the use of risers in casting	CO1	K2
13	Describe the term core? Briefly explain the different types of cores	CO1	

MODULE II

1	Discuss the difference between Hot rolling and cold rolling process?	CO2	K2
2	Describe the ring rolling process?	CO2	K4
3	With neat sketch explain about various types of rolling mills?	CO2	K2

4	Describe the thread rolling process?	CO2	K5
5	With neat sketch, mechanics of flat rolling with neat sketch?	CO2	K5
6	Industries are using rolling process to make " I " beams. Explain in detail ?	CO1	K3
7	What are the common defects in rolled plates?	CO2	K5
8	Why rolling is more important than casting in terms of strength?	CO2	K4
MODULE III			
1	Explain forging? State its advantages and limitations?	CO1	K3
2	Discuss in detail about Impression die forging?	CO1	K3
3	Sketch and explain various die design features?	CO2	K2
4	Differentiate between open and closed die forging, Explain the classification of forging (10M)	CO1	K3
5	With neat sketch, explain the different types of forging methods (10M)	CO2	K5
6	State and explain the forge welding techniques?	CO3	K3
7	Discuss in detail about various defects in forged parts?	CO3	K2
8	Describe the term Forgeability?	CO3	K5
9	Elucidate about precision forging with neat sketch (10M)	CO3	K5
10	With neat sketch, explain any one type of forging hammers(10M)	CO3	K2
MODULE IV			

1	Discuss the difference between swing and hinge clamps?	CO4	K2
2	Describe the principles of clamping?	CO4	K1
3	Explain the use of bridge clamp?	CO4	K2
4	Describe the clamping devices and state the principles of clamping?	CO4	K3
5	Describe the vaccum clamping in detail?	CO4	K1
6	Briefly explain the 3-2-1 principle of locating?	CO4	K2
7	With neat sketch, explain bridge clamping? Do you prefer bridge clamp for holding workpiece (10M)	CO4	K3

MODULE V

1	What do you mean by the term Bendability?	CO5	K4
2	Write notes on Shear spinning process.	CO5	K2
3	Write notes on rubber forming process.	CO5	K3
4	What is Bending? Write short notes on Bend allowance and Bend Deduction	CO5	K2
5	What is spring back effect? How can we avoid spring back?	CO5	K3
6	Briefly explain a note on Deep drawing process?	CO5	K2
7	What are the main factors that decide the weldability?	CO5	K2
8	Briefly explain the various welding defects during welding process?	CO5	K3

MODULE VI

1	What is Gas welding? Explain any one type of welding?	CO6	K4
2	Briefly explain about the use of fluxes during welding process	CO6	K2

3	Write notes on rubber forming process.	CO6	K3
4	With neat sketch explain about SMAW?	CO6	K2
5	What is ultrasonic welding? Explain its advantages?	CO6	K3
6	Briefly explain a note on Friction welding?	CO6	K2
7	What are the main factors that decide the quality of welds?	CO6	K2
8	Briefly explain the stud welding?	CO6	K3

APPENDIX 1

CONTENT BEYOND THE SYLLABUS

S:NO;	**TOPIC**
1	CNC MACHINE INTRODUCTION
2	CNC MACHINE CONSTRUCTION
3	WORKING OF CNC
4	ADVANTAGES, DIS ADVANTAGES AND APPLICATIONS OF CNC

MODULE I
CASTING

Manufacture of a machine part by heating a metal or alloy above its melting point and pouring the liquid metal/alloy in a cavity approximately of same shape and size as the machine part is called casting. After the liquid metal cools and solidifies, it acquires the shape and size of the cavity and resembles the finished product required. The term casting also applied to the part that is made by this process. It is one of the oldest shaping processes, dating back 6,000 years .The department of the workshop, where castings are made is called foundry.

So the following steps are involved in producing a cast part:

1. Preparing the mould.
2. Preparing the molten metal.
3. Introducing the molten metal into the mould.
4. Solidifying the metal.
5. Removing the piece.

Casting processes are most often selected over other manufacturing methods for the following reasons (Advantages of casting):

- Casting can produce complex shapes and can incorporate internal cavities or hollow sections.
- Very large parts can be produced in one piece.
- Casting can utilize materials that are difficult or uneconomical to process by other means.
- The casting process can be economically competitive with other manufacturing processes.

CLASSIFICATION OF CASTINGPROCESSES

Casting processes can be classified based on the mould material, method of producing the mould ,and the pressure on the molten metal during filling.

1. Expendable mould casting
2. Permanent mould casting
3. Special processes

1. Expendable mould casting

a) Permanent pattern
    I. Water and clay bond
        i. Green sand moulding
        ii. Skin dry sand moulding
        iii. Dry sand moulding
        iv. Core sand moulding
        v. Floor and pit moulding
        vi. Loam moulding
        vii. High pressure moulding

    II. Resin bond
        i. Shell moulding
        ii. Hot box
        iii. Cold box
    III. Plaster bond
    IV. Silicate bond
        i. Co_2 Process
        ii. Ceramic moulding
        iii. Shaw process
    V. No bond
        i. Vacuum “v” process
  b) Expendable pattern
    I. Investment (wax) casting
    II. Full mould (lost foam)casting

2. Permanent mould casting

  a) Low pressure
  b) Pressure die
    I. Hot chamber
    II. Cold chamber
  c) Gravity die
    I. Permanent core
    II. Expendable core
    III. Slush casting
  d) Centrifugal
    I. True centrifugal
    II. Semi-centrifugal
    III. Cnetrifuging
  e) Vacuum

3. Special processes

  a) Squeeze casting
  b) Continuous casting
  c) Chilled casting

PATTERN

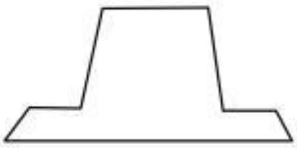
A pattern is a model or the replica of the object (to be casted). It is embedded in molding sand and suitable ramming of molding sand around the pattern is made. The pattern is then withdrawn for generating cavity (known as mold) in molding sand. Thus it is a mould forming tool. Pattern can be said as a model or the replica of the object to be cast except for the various allowances a pattern exactly resembles the casting to be made.

TYPES OF PATTERN

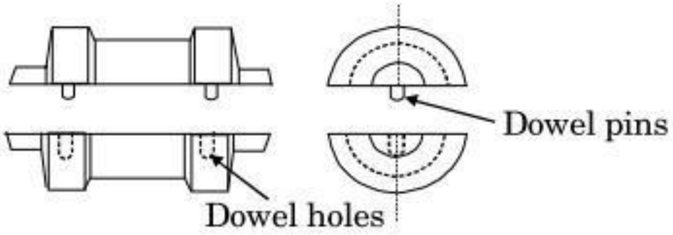
1. One piece or solid pattern
2. Two piece or split pattern
3. Cope and drag pattern
4. Three-piece or multi- piece pattern
5. Loose piece pattern
6. Match plate pattern
7. Follow board pattern
8. Gated pattern
9. Sweep pattern
10. Skeleton pattern
11. Segmental or part pattern

1.One piece or solid pattern

Solid pattern is made of single piece without joints, partings lines or loose pieces. It is the simplest form of the pattern.



Single piece pattern



Two -piece pattern

2. Two piece or split pattern

When solid pattern is difficult for withdrawal from the mold cavity, then solid pattern is splited in two parts. Split pattern is made in two pieces which are joined at the parting line by means of dowel pins. The splitting at the parting line is done to facilitate the withdrawal of the pattern.

3. Cope and drag pattern

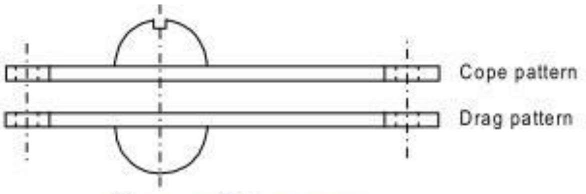
In this case, cope and drag part of the mould are prepared separately. This is done when the complete mould is too heavy to be handled by one operator. The pattern is made up of two halves, which are mounted on different plates.

4. Three-piece or multi- piece pattern

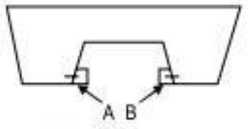
Some patterns are of complicated kind in shape and hence cannot be made in one or two pieces because of difficulty in withdrawing the pattern. Therefore these patterns are made in either three pieces or in multi- pieces. Multi molding flasks are needed to make mold from these patterns.

5. Loose piece pattern

Loose piece pattern is used when pattern is difficult for withdrawal from the mould. Loose pieces are provided on the pattern and they are the part of pattern. The main pattern is removed first leaving the loose piece portion of the pattern in the mould. Finally the loose piece is withdrawal separately leaving the intricate mould



Cope and drag pattern



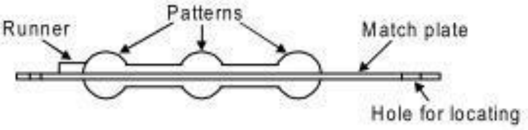
Loose piece pattern

6. Match plate pattern

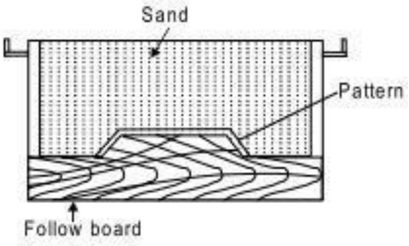
This pattern is made in two halves and is on mounted on the opposite sides of a wooden or metallic plate, known as match plate. The gates and runners are also attached to the plate. This pattern is used in machine molding.

7. Follow board pattern

When the use of solid or split patterns becomes difficult, a contour corresponding to the exact shape of one half of the pattern is made in a wooden board, which is called a follow board and it acts as a molding board for the first molding operation as shown in Fig.



Match plate pattern



Follow board pattern

8. Gated pattern

In the mass production of casings, multi cavity moulds are used. Such moulds are formed by joining a number of patterns and gates and providing a common runner for the molten metal, as shown in Fig. These patterns are made of metals, and metallic pieces to form gates and runners are attached to the pattern.

9. Sweep pattern

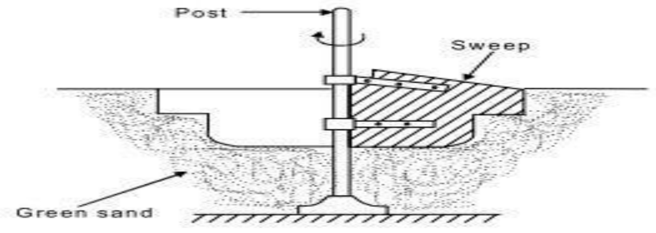
Sweep patterns are used for forming large circular moulds of symmetric kind by revolving a sweep attached to a spindle as shown in Fig. Actually a sweep is a template of wood or metal and is attached to the spindle at one edge and the other edge has a contour depending upon the desired shape of the mould. The pivot end is attached to a stake of metal in the center of the mould.

10. Skeleton pattern

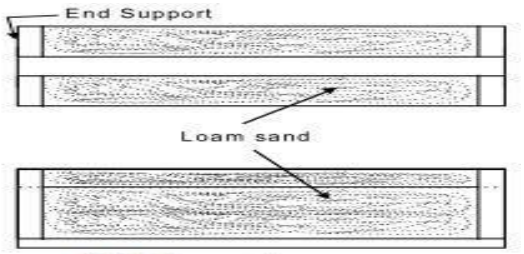
When only a small number of large and heavy castings are to be made, it is not economical to make a solid pattern. In such cases, however, a skeleton pattern may be used. This is a ribbed construction of wood which forms an outline of the pattern to be made. This frame work is filled with loam sand and rammed. The surplus sand is removed by strickle board. For round shapes, the pattern is made in two halves which are joined with glue or by means of screws etc. A typical skeleton pattern is shown in Fig

11. Segmental or part pattern

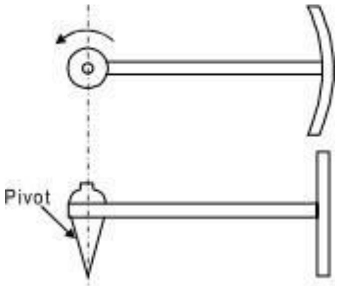
Patterns of this type are generally used for circular castings, for example wheel rim, gear blank etc. Such patterns are sections of a pattern so arranged as to form a complete mould by being moved to form each section of the mould. The movement of segmental pattern is guided by the use of a central pivot. A segment pattern for a wheel rim is shown inFig.



Sweep pattern



Skeleton pattern



Segmental pattern

PATTERN ALLOWANCES

In order for a pattern to be successfully employed in producing a casting having the desired dimensions, it must not be an exact replica of the part to be cast. A number of allowances must be made on the dimensions of the pattern:

1. Shrinkage Allowance

In practice it is found that all common cast metals shrink a significant amount when they are cooled from the molten state. The total contraction in volume is divided into the following parts:

- *Liquid contraction,* i.e. the contraction during the period in which the temperature of the liquid metal or alloy falls from the pouring temperature to the liquidus temperature.
- Contraction on cooling from the liquidus to the solidus temperature, i.e. *solidification contraction.*
- Contraction that results there after until the temperature reaches the room temperature. This is known as *solid contraction*.

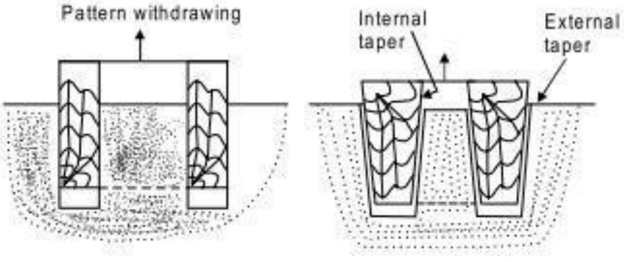
The first two of the above are taken care of by proper *gating and risering*. Only the last one, i.e. the solid contraction is taken care by the pattern makers by giving a positive shrinkage allowance. This contraction allowance is different for different metals. The contraction allowances for different metals and alloys such as Cast Iron 10 mm/mt.. Brass 16 mm/mt, Aluminium Alloys. 15 mm/mt., Steel 21 mm/mt., Lead 24 mm/mt. In fact, there is a special rule known as the *pattern marks contraction rule* in which the shrinkage of the casting metals is added. It is similar in shape as that of a common rule but is slightly bigger than the latter depending upon the metal for which it is intended.

2. Machining Allowance

It is a positive allowance given to compensate for the amount of material that is lost in machining or finishing the casting. If this allowance is not given, the casting will become undersize after machining. The amount of this allowance depends on the size of casting, methods of machining and the degree of finish. In general, however, the value varies from 3 mm. to 18 mm.

3. Draft or Taper Allowance

Taper allowance is also a positive allowance and is given on all the vertical surfaces of pattern so that its withdrawal becomes easier. The normal amount of taper on the external surfaces varies from 10 mm to 20 mm/mt. On interior holes and recesses which are smaller in size, the taper should be around 60 mm/mt. These values are greatly affected by the size of the pattern and the molding method. In machine molding its, value varies from 10 mm to 50 mm/mt.



Draft or taper allowance

4. Rapping or Shake Allowance

Before withdrawing the pattern it is rapped and thereby the size of the mould cavity increases. Actually by rapping, the external sections move outwards increasing the size and internal sections move inwards decreasing the size. This movement may be insignificant in the case of small and medium size castings, but it is significant in the case of large castings. This allowance is kept negative and hence the pattern is made slightly smaller in dimensions 0.5-1.0 mm.

5. Distortion Allowance

This allowance is applied to the castings which have the tendency to distort during cooling due to thermal stresses developed. For example a casting in the form of U shape will contract at the closed end on cooling, while the open end will remain fixed in position. Therefore, to avoid the distortion, the legs of U pattern must converge slightly so that the sides will remain parallel after cooling.

6. Mold wall Movement Allowance

Mold wall movement in sand moulds occurs as a result of heat and static pressure on the surface layer of sand at the mold metal interface. In ferrous castings, it is also due to expansion due to graphitisation. This enlargement in the mold cavity depends upon the mold density and mould composition. This effect becomes more pronounced with increase in moisture content and temperature.

Pattern colour coding

Many mistakes may be eliminated by indicating the functions of various parts of the pattern with proper colours:

a) A loose piece may get lost and unless the pattern is marked to indicate the seat of the loose piece ,it is quite possible that the casting will be made from the incomplete pattern.
b) With properly marked core prints, the moulder is constantly reminded that cores must be set in the mould before it is closed.
c) Patterns with stop offs should be marked to remind the moulder to fill the mould cavity made by stop off.
d) If a moulder knows what surfaces are to be machined, he will, if possible mould the pattern in a position to produce a surface more nearly free of impurities.

A common colour scheme is given below :

1. Surface as cast : Black
2. Machined surface : Red
3. Core prints and seats : Yellow
4. Loose pieces : Yellow/Red diagonal stripes
5. Stop off : Yellow/Black diagonal stripes

CONSTITUENTS OF MOULDING SANDS

The main constituents of molding sand involve *silica sand, binder, moisture content* and *additives*.

Silica sand

Silica sand in form of granular quarts is the main constituent of molding sand having enough refractoriness which can impart strength, stability and permeability to molding and core sand. But along with silica small amounts of iron oxide, alumina, lime stone, magnesia, soda and potash are present as impurities. The chemical composition of silica sand gives an idea of the impurities like lime, magnesia, alkalis etc. present.

Binder

In general, the binders can be either inorganic or organic substance. The inorganic group includes clay sodium silicate and port land cement etc. In foundry shop, the clay acts as binder which may be Kaolonite, Ball Clay, Fire Clay, Limonite, Fuller’s earth and Bentonite. Binders included in the organic group are dextrin, molasses, cereal binders, linseed oil and resins like phenol formaldehyde, urea formaldehyde etc. Organic binders are mostly used for core making.

Among all the above binders, the bentonite variety of clay is the most common. However, this clay alone cannot develop bonds among sand grins without the presence of moisture in molding sand and core sand.

Moisture

The amount of moisture content in the molding sand varies generally between 2 to 8 percent. This amount is added to the mixture of clay and silica sand for developing bonds. This is the amount of water required to fill the pores between the particles of clay without separating them. This amount of water is held rigidly by the clay and is mainly responsible for developing the strength in the sand. The effect of clay and water decreases permeability with increasing clay and moisture content. The green compressive strength first increases with the increase in clay content, but after a certain value, it starts decreasing. For increasing the molding sand characteristics some other additional materials besides basic constituents are added which are known as additives.

Additives

Additives are the materials generally added to the molding and core sand mixture to develop some special property in the sand. Some common used additives for enhancing the properties of molding and core sands are discussed as under.

Coal dust

Coal dust is added mainly for producing a reducing atmosphere during casting. This reducing atmosphere results in any oxygen in the poles becoming chemically bound so that it cannot oxidize the metal. It is usually added in the molding sands for making molds for production of grey iron and malleable cast iron castings.

Corn flour

It belongs to the starch family of carbohydrates and is used to increase the collapsibility of the molding and core sand. It is completely volatilized by heat in the mould, thereby leaving space between the sand grains. This allows free movement of sand grains, which finally gives rise to mould wall movement and decreases the mold expansion and hence defects in castings. Corn sand if added to molding sand and core sand improves significantly strength of the mold and core.

Dextrin

Dextrin belongs to starch family of carbohydrates that behaves also in a manner similar to that of the corn flour. It increases dry strength of the molds.

Sea coal

Sea coal is the fine powdered bituminous coal which positions its place among the pores of the silica sand grains in molding sand and core sand. When heated, it changes to coke which fills the pores and is unaffected by water: Because to this, the sand grains become restricted and cannot move into a dense packing pattern. Thus, sea coal reduces the mould wall movement and the permeability in mold and core sand and hence makes the mold and core surface clean and smooth.

Pitch

It is distilled form of soft coal. It can be added from 0.02 % to 2% in mold and core sand. It enhances hot strengths, surface finish on mold surfaces and behaves exactly in a manner similar to that of sea coal.

Wood flour

This is a fibrous material mixed with a granular material like sand; its relatively long thin fibers prevent the sand grains from making contact with one another. It can be added from 0.05 % to 2% in mold and core sand. It volatilizes when heated, thus allowing the sand grains room to expand. It will increase mould wall movement and decrease expansion defects. It also increases collapsibility of both of mold and core.

Silica flour

It is called as pulverized silica and it can be easily added up to 3% which increases the hot strength and finish on the surfaces of the molds and cores. It also reduces metal penetration in the walls of the molds and cores.

KINDS OF MOULDING SAND

Molding sands can also be classified according to their use into number of varieties which are described below.

Green sand

Green sand is also known as tempered or natural sand which is a just prepared mixture of silica sand with 18 to 30 percent clay, having moisture content from 6 to 8%. The clay and water furnish the bond for green sand. It is fine, soft, light, and porous. Green sand is damp, when squeezed in the hand and it retains the shape and the impression to give to it under pressure. Molds prepared by this sand are not requiring backing and hence are known as green sand molds. This sand is easily available and it possesses low cost. It is commonly employed for production of ferrous and non-ferrous castings.

Dry sand

Green sand that has been dried or baked in suitable oven after the making mold and cores,is called dry sand. It possesses more strength, rigidity and thermal stability. It is mainlysuitable for larger castings. Mold prepared in this sand are known as dry sand molds.

Loam sand

Loam is mixture of sand and clay with water to a thin plastic paste. Loam sand possesses high clay as much as 30-50% and 18% water. Patterns are not used for loam molding and shape is given to mold by sweeps. This is particularly employed for loam molding used for large grey iron castings.

Facing sand

Facing sand is just prepared and forms the face of the mould. It is directly next to the surfaceof the pattern and it comes into contact molten metal when the mould is poured. Initialcoating around the pattern and hence for mold surface is given by this sand. This sand issubjected severest conditions and must possess, therefore, high strength refractoriness. It ismade of silica sand and clay, without the use of used sand. Different forms of carbon are usedto prevent the metal burning into the sand. A facing sand mixture for green sand of cast ironmay consist of 25% fresh and specially prepared and 5% sea coal. They are sometimes mixedwith 6-15 times as much fine molding sand to make facings. The layer of facing sand in a moldusually ranges from 22-28 mm. From 10 to 15% of the whole amount of molding sand is thefacing sand.

Backing sand

Backing sand or floor sand is used to back up the facing sand and is used to fill the wholevolume of the molding flask. Used molding sand is mainly employed for this purpose. Thebacking sand is sometimes called black sand because that old, repeatedly used molding sandis black in color due to addition of coal dust and burning on coming in contact with the moltenmetal.

System sand

In mechanized foundries where machine molding is employed. A so called system sand is usedto fill the whole molding flask. In mechanical sand preparation and handling units, no facingsand is used. The used sand is cleaned and re-activated by the addition of water and specialadditives. This is known as system sand. Since the whole mold is made of this system sand,the properties such as strength, permeability and refractoriness of the molding sand must behigher than those of backing sand.

Parting sand

Parting sand without binder and moisture is used to keep the green sand not to stick to the pattern and also to allow the sand on the parting surface the cope and drag to separate without clinging. This is clean clay-free silica sand which serves the same purpose as parting dust.

Core sand

Core sand is used for making cores and it is sometimes also known as oil sand. This is highlyrich silica sand mixed with oil binders such as core oil which composed of linseed oil, resin, light mineral oil and other bindmaterials. Pitch or flours and water may also be used in largecores for the sake of economy.

PROPERTIES OF MOULDING SAND

Refractoriness

Refractoriness is defined as the ability of molding sand to withstand high temperatureswithout breaking down or fusing thus facilitating to get sound casting. It is a highly important characteristic of molding sands. Refractoriness can only be increased to a limited extent.Molding sand with poor refractoriness may burn on to the casting surface and no smooth casting surface can be obtained. The degree of refractoriness depends on the SiO2 i.e. quartzcontent, and the shape and grain size of the particle. The higher the SiO2 content and therougher the grain volumetric composition the higher is the refractoriness of the molding sand and core sand. Refractoriness is measured by the sinter point of the sand rather than its melting point.

Permeability

It is also termed as porosity of the molding sand in order to allow the escape of any air, gasesor moisture present or generated in the mould when the molten metal is poured into it. Allthese gaseous generated during pouring and solidification process must escape otherwise thecasting becomes defective. Permeability is a function of grain size, grain shape, and moistureand clay contents in the molding sand. The extent of ramming of the sand directly affects thepermeability of the mould. Permeability of mold can be further increased by venting usingvent rods

Cohesiveness

It is property of molding sand by virtue which the sand grain particles interact and attract each other within the molding sand. Thus, the binding capability of the molding sand gets enhanced to increase the green, dry and hot strength property of molding and core sand.

Green strength

The green sand after water has been mixed into it, must have sufficient strength and toughness to permit the making and handling of the mould. For this, the sand grains must be adhesive, i.e. they must be capable of attaching themselves to another body and. therefore, and sand grains having high adhesiveness will cling to the sides of the molding box. Also, thesand grains must have the property known as cohesiveness i.e. ability of the sand grains to stickto one another. By virtue of this property, the pattern can be taken out from the mould without breaking the mould and also the erosion of mould wall surfaces does not occur during the flow of molten metal. The green strength also depends upon the grain shape and size, amount and type of clay and the moisture content.

Dry strength

As soon as the molten metal is poured into the mould, the moisture in the sand layer adjacent to the hot metal gets evaporated and this dry sand layer must have sufficient strength to its shape in order to avoid erosion of mould wall during the flow of molten metal. The dry strength also prevents the enlargement of mould cavity cause by the metallostatic pressure of the liquid metal.

Flowability or plasticity

It is the ability of the sand to get compacted and behave like a fluid. It will flow uniformly to all portions of pattern when rammed and distribute the ramming pressure evenly all around in all directions. Generally sand particles resist moving around corners or projections.In general, flowability increases with decrease in green strength, an, decrease in grain size. The flowability also varies with moisture and clay content.

Adhesiveness

It is property of molding sand to get stick or adhere with foreign material such sticking of molding sand with inner wall of molding box

Collapsibility

After the molten metal in the mould gets solidified, the sand mould must be collapsible so that free contraction of the metal occurs and this would naturally avoid the tearing or cracking of the contracting metal. In absence of this property the contraction of the metal is hindered by the mold and thus results in tears and cracks in the casting. This property is highly desired in cores.

SAND TESTING

Molding sand and core sand depend upon shape, size composition and distribution of sand grains, amount of clay, moisture and additives. The increase in demand for good surface finish and higher accuracy in castings necessitates certainty in the quality of mold and core sands. Sand testing often allows the use of less expensive local sands. It also ensures reliable sand mixing and enables a utilization of the inherent properties of molding sand. Sand testing on delivery will immediately detect any variation from the standard quality, and adjustment of the sand mixture to specific requirements so that the casting defects can be minimized. It allows the choice of sand mixtures to give a desired surface finish. Thus sand testing is one of the dominating factors in foundry and pays for itself by obtaining lower per unit cost andincreased production resulting from sound castings. Generally the following tests are performed to judge the molding and casting characteristics of foundry sands:

1. Moisture content Test 2. Clay content Test3. Chemical composition of sand

4. Grain shape and surface texture of sand. 5. Grain size distribution of sand

6. Specific surface of sand grains 7. Water absorption capacity of sand
8. Refractoriness of sand 9. Strength Test 10. Permeability Test 11. Flowability Test

12. Shatter index Test13. Mould hardness Test.
Some of the important sand tests are :
Moisture Content Test

The moisture content of the molding sand mixture may determined by drying a weighed amount of 20 to 50 grams of molding sand to a constant temperature up to 100°C in a oven for about one hour. It is then cooled to a room temperature and then reweighing the molding sand. The moisture content in molding sand is thus evaporated. The loss in weight of molding sand due to loss of moisture, gives the amount of moisture which can be expressed as apercentage of the original sand sample. The percentage of moisture content in the molding sand can also be determined in fact more speedily by an instrument known as a speedy moisture teller. This instrument is based on the principle that when water and calcium carbide react, they form acetylene gas which can be measured and this will be directly proportional to the moisture content. This instrument is provided with a pressure gauge calibrated to read directly the percentage of moisture present in the molding sand. Some moisture testing instruments are based on principle that the electrical conductivity of sand varies with moisture content in it.

Clay Content Test

The amount of clay is determined by carrying out the clay content test in which clay in molding sand of 50 grams is defined as particles which when suspended in water, fail to settle at the rate of one inch per min. Clay consists of particles less than 20 micron, per 0.0008 inch in dia.

Grain Fineness Test

For carry out grain fineness test a sample of dry silica sand weighing 50 gms free from clay is placed on a top most sieve bearing U.S. series equivalent number 6. A set of eleven sieveshaving U.S. Bureau of standard meshes 6, 12, 20, 30, 40, 50, 70, 100, 140, 200 and 270 are mounted on a mechanical shaker . The series are placed in order of fineness from top to bottom. The free silica sand sample is shaked in a mechanical shaker for about 15minutes. After this weight of sand retained in each sieve is obtained sand and the retained sand in each sieve is multiplied by 2 which gives % of weight retained by each sieve. The same is further multiplied by a multiplying factor and total product is obtained. It is then divided by total % sand retained by different sieves which will give G.F.N.

Refractoriness Test

The refractoriness of the molding sand is judged by heating the American Foundry Society (A.F.S) standard sand specimen to very high temperatures ranges depending upon the type of sand. The heated sand test pieces are cooled to room temperature and examined under a microscope for surface characteristics or by scratching it with a steel needle. If the silica sand grains remain sharply defined and easily give way to the needle. Sintering has not yet set in. In the actual experiment the sand specimen in a porcelain boat is p1aced into an electric furnace. It is usual practice to start the test from l000°C and raise the temperature in steps of 100°C to 1300°C and in steps of 50° above 1300°C till sintering of the silica sand grains takes place. At each temperature level, it is kept for at least three minutes and then taken out from the oven for examination under a microscope for evaluating surface characteristics or byscratching it with a steel needle.

Strength Test

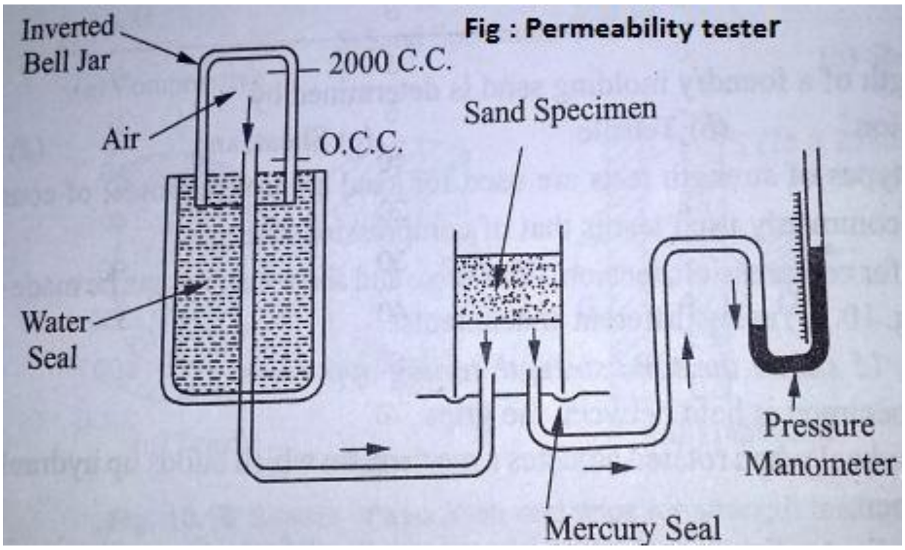
The strength of a foundary moulding sand is determined by a) compression b) tension c) shear and d) transverse test. The most commonly used test is that of compression strength. Specimen for compression, tension, transverse and shear testings can be made on the sand specimen tester using different attachments. The compression test is as follows:

1. The specimen is held between the grips.
2. Hand wheel when rotated actuates a mechanism which builds up hydraulic pressure on the specimen.
3. Dial indicator fitted on the tester measures the deformation occurring in the specimen.
4. There are two indicators (manaometers). One is meant for use when testing low strength sands and other for relatively high strength core sands.
5. Each indicator has three scales- one for reading compressive strengths and the remaining two for recording tensile (or transverse) and shear strength respectively.

Permeability Test

Permeability is that property of molding sand which permits the escape of steam and other gases generated in the mould during hot metal pouring. Since permeability is the property of rammed sand, a standard sized sand specimen is first rammed by a specimen rammer and it is then used in permeability tester. Permeability of the sand specimen prepared is determined by passing a given volume of air through the sand. A permeability tester consists of

1. An inverted bell jar, which floats in a water seal and can permit 2000cc of air to flow
2. Specimen tube, to hold the sample specimen
3. A manometer to read the air pressure



Sand permeability can be determined by two methods 1. Standard method 2.Rapid (shop) method

Standard method : 2000cc of air held in the inverted bell jar is forced to pass through the sand specimen. A situation comes when the air entering the specimen equals the air escaped through the specimen to the atmosphere. This gives a stabilized pressure reading (P) on the manometer and the same can be read on the vertical scale. Simultaneously, using a stop watch the time (T) required for 2000cc of air to pass through the sand specimen is also recorded. As the next step, permeability number can be determined by the following relation

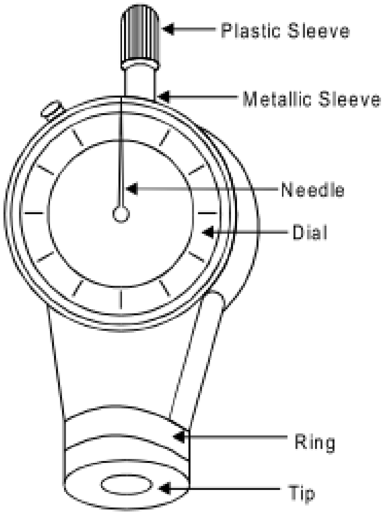
$$\text{Permeability number} = \frac{V.H}{A.P.T}$$

where V = volume of the air passed through the specimen =2000cc, H = height of the specimen = 5.08cm,

A= area of the specimen =20.268cm^2, T =time (in minutes) taken by the 2000cc of air to pass through the sand specimen, P= air pressure (gm/cm^2) recorded by the manometer.

Mould Hardness Test

This test is performed by a mold hardness tester. The working of the tester is based on the principle of Brinell hardness testing machine. In an A.F.S. standard hardness tester a half inch diameter steel hemi-spherical ball is loaded with a spring load of 980 gm. This ball is made to penetrate into the mold sand or core sand surface. The penetrationof the ball point into the mould surface is indicated on a dial in thousands of an inch. The dial is calibrated to read the hardness directly i.e. a mould surface which offers no resistance to the steel ball would have zero hardness value and a mould which is more rigid and is capable of completely preventing the steel ball from penetrating would have a hardness value of 100. The dial gauge of the hardness tester may provide direct readings.



Mould Hardness Tester

Molding processes

Green sand can be molded by employing a variety of processes, including some that are carried out both by hand and with molding machines.

1. Flask molding.

Flask molding is the most widely used process in both hand- and machine-molding practices. Fig. illustrates the procedure for simple hand-molding using a single (loose) pattern. First, the lower half of the pattern is placed on a molding board and surrounded by the drag. The drag is then filled with sand (using a shovel) and rammed very firmly. Ventilation holes are made using a steel wire, but these should not reach the pattern. The drag is turned upside down to bring the parting plane up so that it can be dusted. Next, the other half of the pattern is placed in position to match the lower half, and the cope is located around it, with the eyes of the cope fitted to the pins of the drag. Sand is shoveled into the cope and rammed firmly, after using a sprue pin to provide for the feeding passage.Ventilation holes are made in the cope part of the mold in the same way they were made in the other half. The pouring basin is cut around the head of the sprue pin using a trowel, and the sprue pin is pulled out of the cope. The cope is then carefully lifted off the drag and turned so that the parting plane is upward. The two halves of the pattern are removed from both the cope and the drag. The runner and/or gate are cut from the mold cavity to the sprue in the drag part of the mold. Then, any damages are repaired by slightly wetting the location and using a slick. The cope is then carefully placed on the drag to assemble the two halves of themold. Finally, the cope and the drag are fastened together by means of shackles orbolts to prevent the pressure created by the molten metal (after pouring) from separating them.

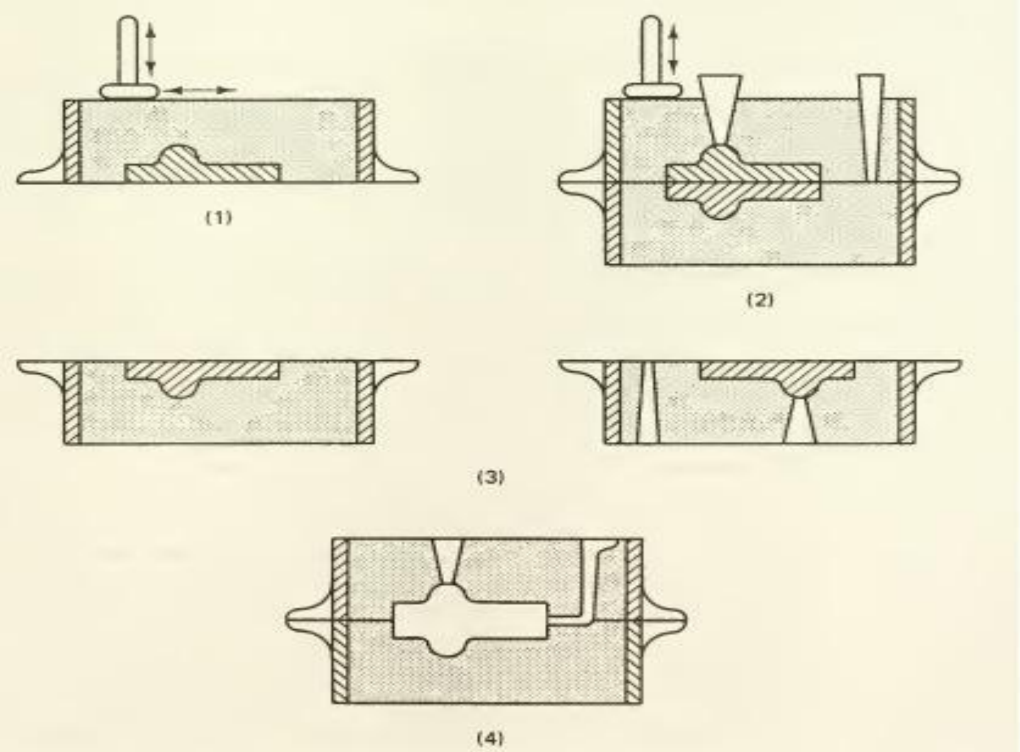


Fig . Flask moulding

2. Stack molding

Stack molding is best suited for producing a large number of small,light castings while using a limited amount of floor space in the foundry. As can be seen in Fig, there are two types of stack molding: *upright*and *stepped*. In upright stack molding, 10 to 12 flask sections are stacked up. They all have a common sprue that is employed in feeding all cavities. The drag cavity is always molded in the upper surface of the flask section, whereas the cope cavity is molded in the lower surface. In stepped stack molding, each section has its own sprue and is, therefore, offset from the one under it to provide for the pouring basin.In this case, each mold is cast separately.

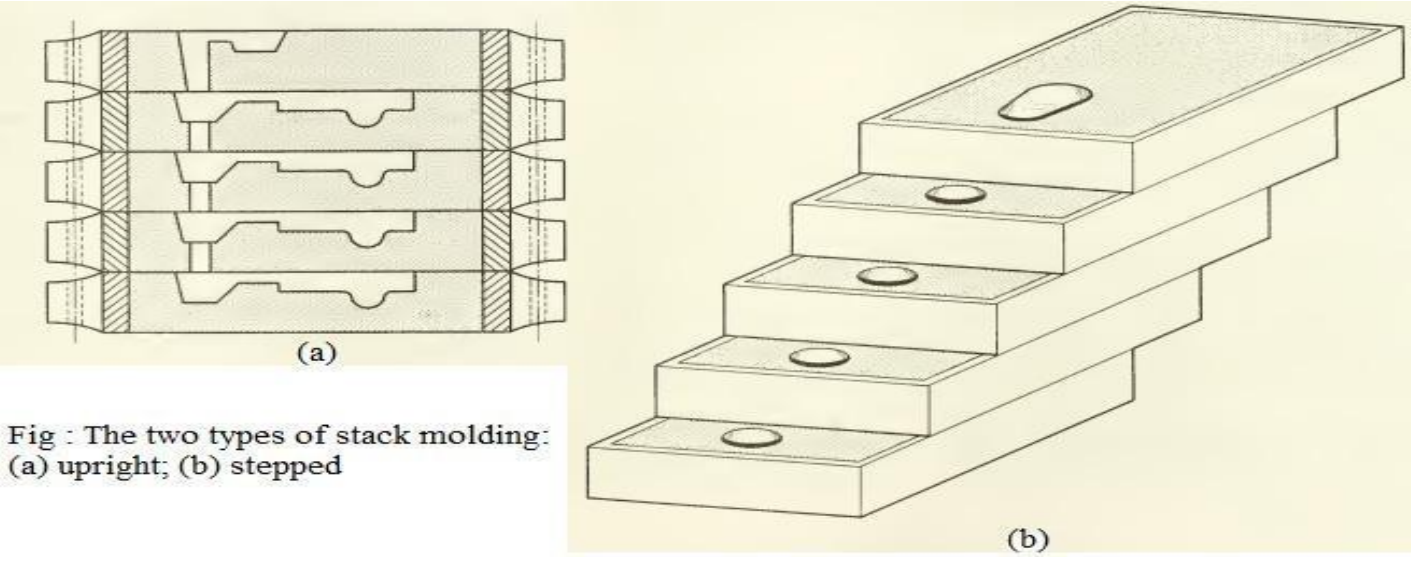


Fig : The two types of stack molding:
(a) upright; (b) stepped

3. Sweep molding. Sweep molding is used to form the surfaces of the mold cavitywhen a large-size casting must be produced without the time and expenses involved in making a pattern. A sweep that can be rotated around an axis is used for producing a surface of revolution, contrary to a drawing sweep, which is pushed axially while being guided by a frame to produce a surface having a constant section along its length .

4. Pit molding : Pit molding is usually employed for producing a single piece of a largecasting when it would be difficult to handle patterns of that size in flasks. Molding is done in specially prepared pits in the ground of the foundry. The bottom of the pit is often covered with a layer of coke that is 2 to 3 inches (50 to 75 mm) thick.Then, a layer of sand is rammed onto the coke to act as a "bed" for the mold. Vent pipes connect the coke layer to the ground surface. Molding is carried out as usual, and molds are almost always dried before pouring the molten metal. This drying is achieved by means of a portable mold drier. A cope that is also dried is then placed on the pit, and a suitable weight or a group of weights are located on the cope to prevent it from floating when the molten metal is poured.

Molding machines

The employment of molding machines results in an increase inthe production rate, a marked increase in productivity, and a higher and more consistent quality of molds. The function of these machines is to pack the sand onto the pattern and draw the pattern out from the mold. There are several types of molding machines, each with a different way of packing the sand to form the mold. The main types include *squeezers*, *joltmachines*, and*sandslingers*. There are also some machines, such as *jolt-squeeze machines*, that employ a combination of the workingprinciples of two of the main types.

1. Squeezers. The pattern plate is clamped on the machine table, and a flask is put into position. A sand frame is placed on the flask, and both are then filled withsand from a hopper. Next, the machine table travels upward to squeeze the sand between the pattern plate and a stationary head. The squeeze head enters into the sand frame and compacts the sand so that it is level with the edge of the flask.

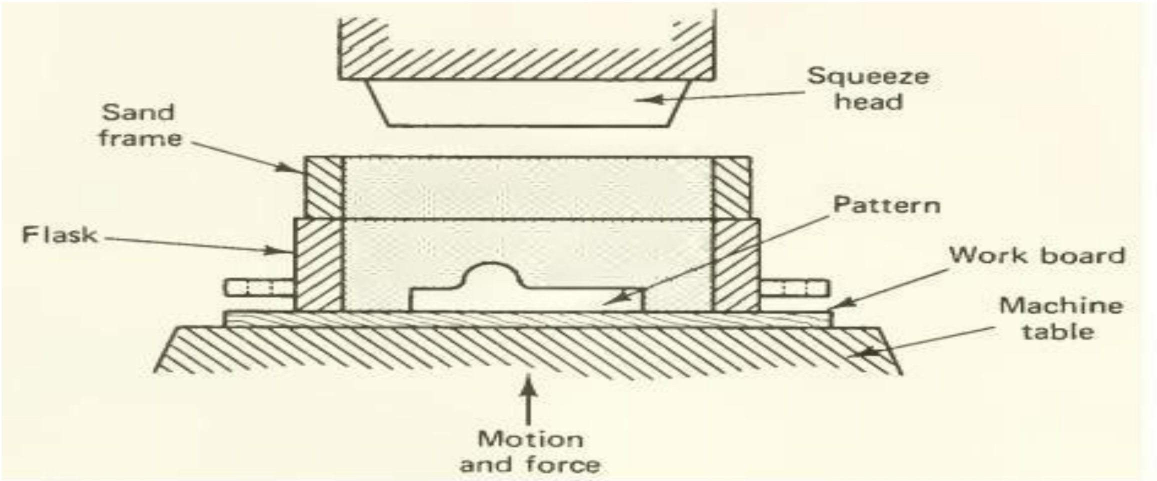
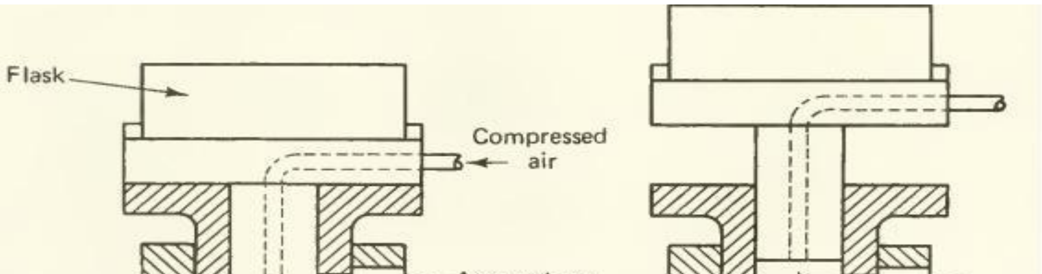


Fig . Squeezer

2. Jolt machines : Compressed air is admitted through the hose to apressure cylinder to lift the plunger (and the flask, which is full of sand) up to a certain height, where the side hole is uncovered to exhaust the compressed air. The plunger then falls down and strikes the stationary guiding cylinder. The shock wave resulting from each of the successive impacts contributes to packi



3. Sandslingers. This type of machine is employedin molding sand in flasks of any size, whether for individual or mass production of molds. Sandslingers are characterized by their high output, which amounts to 2500 cubic feet (more than 60 cubic meters) per hour. As in fig. , molding sand is fed into a housing containing an impeller that rotates rapidly around a horizontal axis. Sand particles are picked up by the rotating blades and thrown at a high speed through an opening onto the pattern, which is located in the flask.

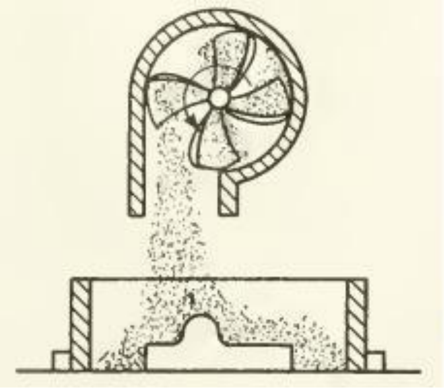


Fig. Sandslinger

Sand conditioning.

The molding sand, whether new or used, must be conditioned before being used. When used sand is to be recycled, lumps should be crushed and then metal granules or small parts removed (a magnetic field is employed in a ferrous foundry). Next, sand (new or recycled) and all other molding constituents must be screened in shakers, rotary screens, or vibrating screens. Molding materials are thenthoroughly mixed in order to obtain a completely homogeneous green sand mixture.The more uniform the distribution, the better the molding properties (like permeability and green strength) of the sand mixture will be.

Mixing is carried out in either continuous-screw mixers or vertical-wheel mullers.The mixers mix the molding materials by means of two large screws or worm gears; the mullers are usually used for batch-type mixing. A sand muller consists primarily of a pan in which two wheels rotate about their ownhorizontal axis as well as about a stationary vertical shaft. Centrifugal mullers are also in use, especially for high production rates.

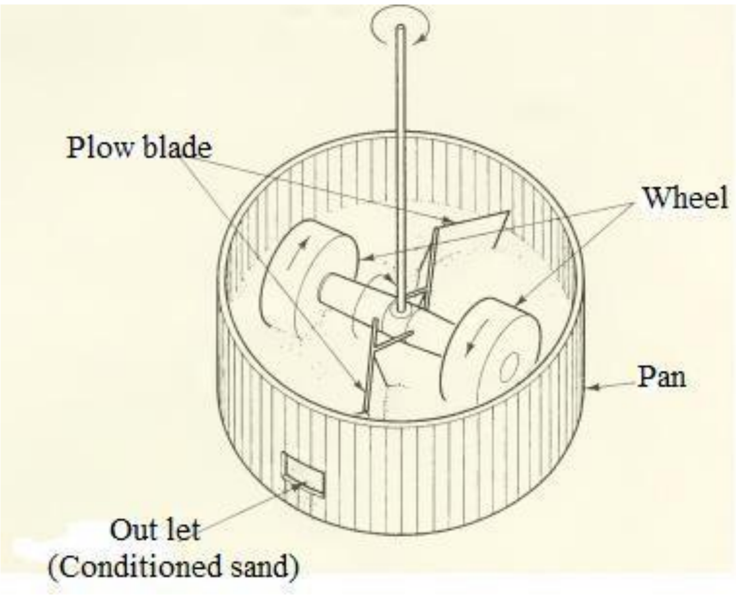


Fig . a muller for sand conditioning

GATING SYSTEM

When molten metal is poured into a mold, the gating system conveys the material and delivers it to all sections of the mold cavity.The speed or rate of metal movement is important as well as the amount of cooling that occurs while it is flowing. Slow filling and high loss of heat can result in casting defects. Rapid rates of filling, on the other hand, can produce erosion of the gating system and mold cavity, and might result in the entrapment of mold material in the final casting.

Elements of the gating system

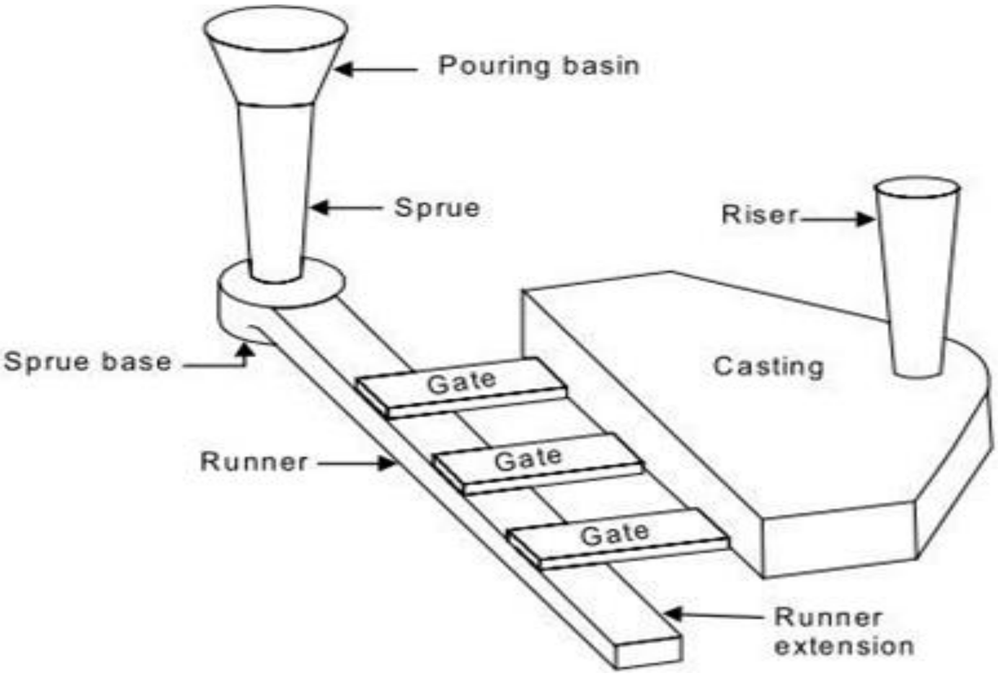


Fig . Gating system

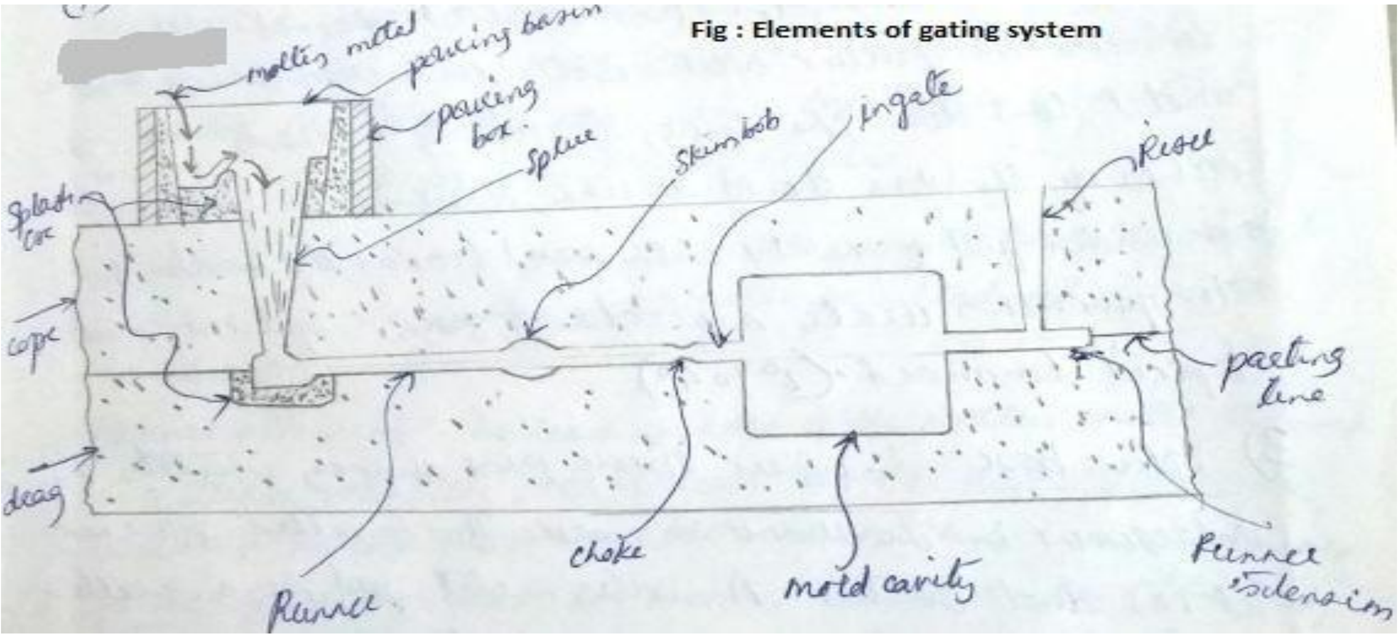


Fig : Elements of gating system

1. Pouring basin

It is a reservoir at the top of the sprue that receives the stream of molten metal poured from the ladle. The basin is filled quickly at the start of the pour and it should remain full of moten metal during pouring. Thus , dross consisting of oxides and slags which float , may be kept from entering the sprue. If the depth of metal in the cup is insufficient , a funnel is likely to form above the sprue entrance, through which air and slag may get in to the sprue and then into the mould cavity. The depth of pouring basin is a function of sprue entrance diameter. The pouring basin is designed to reduce turbulence. Experience has shown that the liquid metal depth above the sprue entrance should be 2.5 times the sprue entrance distance diameter to prevent the formation of a vortex.

2. Sprue or down sprue or downrunner

From the pouring basin , the molten metal is transported down into the mould cavity by means of sprue. It is a vertical channel that connects the pouring basin with runners and gates .As the metal flows down the sprue ,its velocity increases .Hence the section of the sprue should decrease ,otherwise the sprue will not remain full of metal and with metal leaving the walls of the sprue.This creates aspiration of gases. Therefore sprue is made tapered downward ($2^0 – 4^0$).

Strainer : A ceramic strainer in the sprue removes the dross.

3. Sprue base

Where sprue joins runner , usually an enlargement is made in the runner. This is called sprue base , it has dual function. A molten metal pool is an excellent device for preventing excessive sand erosion where the molten metal impinges on the runner at the sprue base. Also there is a sudden slowing of flow which dissipates kinetic energy and helps to drop out inclusions ,scums etc that may have been washed with the molten metal.

Splash core : It is a piece of ceramic or baked sand core insertion in the mould directly beneath the sprue.Its function is to prevent erosion of the mould sand where the molten metal strikes it at the base of the sprue.

4. Runner

It is commonly the horizontal channel that carry the molten metal from the sprue into the mold cavity or connect the sprue to the gate. The runners and ingates must be designed to withstand the metal impact and reduce the metal velocity sufficiently so that the shape of the mould cavity is not compromised.

Runner extension: The leading edge of the molten metal flowing in a stream follows the path of least resistance and continues to build up kinetic energy until it reaches the end of the runner. If the extension is used ,the kinetic energy may be absorbed ,thus causing a smoother flow of metal in the runners and into the mould cavity.

Choke: The part of the gating system which most restricts or regulates the rate of pouring is the choke.It possesses smallest cross-section area.

Skim – bob :It is an enlargement along the runner ,whose function is to trap heavier and lighter impurities such as dross and eroded sand.

5. Gates or ingates

Gates are the channels which connect runner to the mould cavity and through which incoming metal directly enters the mould cavity.

6. Risers or feeder head

Risers are reservoirs of molten metal that feed the metal in the casting properly as it solidifies .The riser thus provides the feed metal which flows from the riser to the casting to make up for the shrinkage which takes place in casting metal as it changes from liquid to solid.

RISER DESIGN

Requirements of a riser

1. To be effective, a riser must be the last part of the casting to solidify, such that all the shrinkages that are likely to occur should be in the riser.
2. The volume of the riser must be sufficient to compensate for metal shrinkage within the casting.
3. The fluidity of the metal inside the riser must be maintained so that the metal can flow from if and penetrate to the last contraction of the cavity.

Riser location

Before the shape and size of the riser is determined, its location must be specified. Any casting no matter how complex can be subdivided into several geometrical shapes ,consisting of two heavier section joined by a thinner section. A riser should be located close to each heavier section.

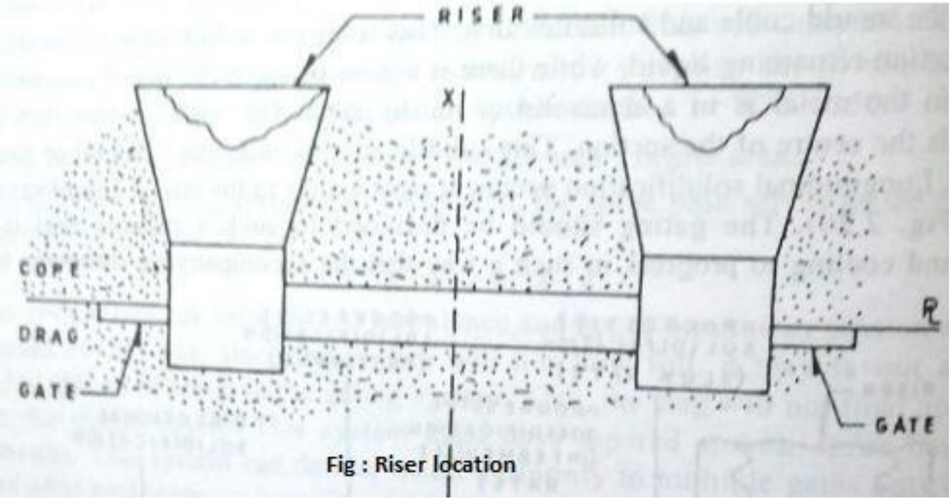
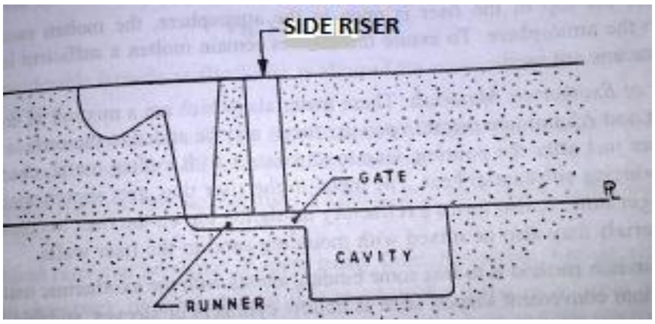
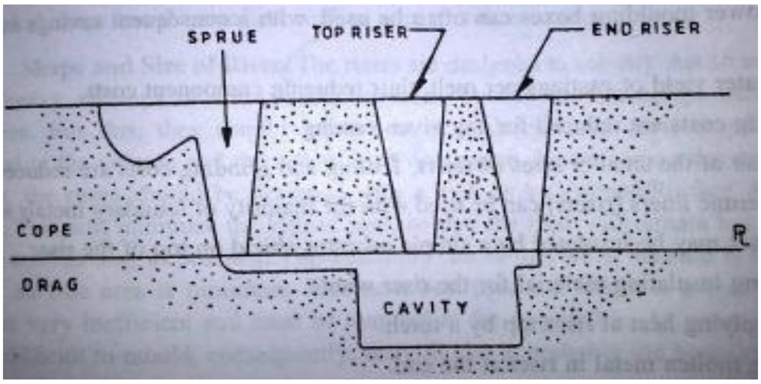


Fig : Riser location

Types of risers

Depending upon its location the riser can be described as “*top-riser or side-riser*”. If the riser is located between the runners and casting it is known as *side riser*. It is also called a “*live or hot riser*” since it is filled last and containing the hottest metal. If the riser must be placed at the top of the casting or at the end of the mould cavity, then it is called as “top riser or dead or cold riser”. Also a riser may be *open or blind*. Open risers are open to atmosphere at the top surface of the mould. Blind riser is a riser that does not break to the top of the cope and is entirely surrounded by moulding sand.





Shape and size of riser

The risers as designed to solidify last so as to feed enough metal to heavy sections of the casting to make up for the shrinkage before and during solidification. For this,they should loose heat at a slower rate. The risers should be assigned with a high volume to surface area ratio (V/A), for a given size. This will minimize the loss of heat. This can be met if the riser is spherical. The next best shape is of cylinder.

The riser size depends primarily on the metal poured. The riser should be tall enough so that any shrinkage cavity in riser (pipe formation) does not penetrate into the castings. In general ,

Height of cylindrical riser = 1.5 x diameter of riser.
Two main methods for riser size determination are ;

1. Chvorinov’s rule

It tells us that solidification time is a function of the volume of a casting and its surface area.

Solidification time, $t = C\left(\frac{V}{A}\right)^n$

Where V = volume of casting , A = surface area of casting ,

C is a constant that reflects (a) the mold material,(b) the metal properties (including latent heat), and (c) thetemperature.The parameter n has a value between 1.5 and 2, but usually is taken as 2. Thus, a large solid sphere will solidify and cool to ambient temperature at a much slower rate than will a smaller solid sphere.

For proper riser design, the time for the riser to solidify, calculated chvorinov’s rule , must be more than the solidification time for the casting. i.e,

$$\left(\frac{V}{Æ}\right)_{riser} > \left(\frac{V}{Æ}\right)_{casting}$$

In practice, $\left(\frac{V}{Æ}\right)_{riser} = 1.05 \text{ to } 1.075\left(\frac{V}{Æ}\right)_{casting}$

Sincevolume and surface area of casting are known $\left(\frac{V}{Æ}\right)_{casting}$ can be determined. Assuming height to diameter ratio for the cylindrical riser, the riser size can be determined.

2. Caine’s formula

Caine’s method was based on an experimentally determined hyperbolic relationship between relative volumes and relative freezing rates of riser and casting to produce castings free from shrinkage cavities.

Freezing ratio or relative freezing time , $X = \frac{\left(\frac{A}{V}\right)_{casting}}{\left(\frac{A}{V}\right)_{riser}}$

volume ratio, $Y = \frac{\text{Volume of riser}}{\text{Volume of casting}}$

The caine’s formula is given as ,

$$X = \frac{a}{F-b} + c$$

Where a = freezing characteristics constant

b = liquid–solid solidification contraction,

c = relative freezing rate of riser and casting

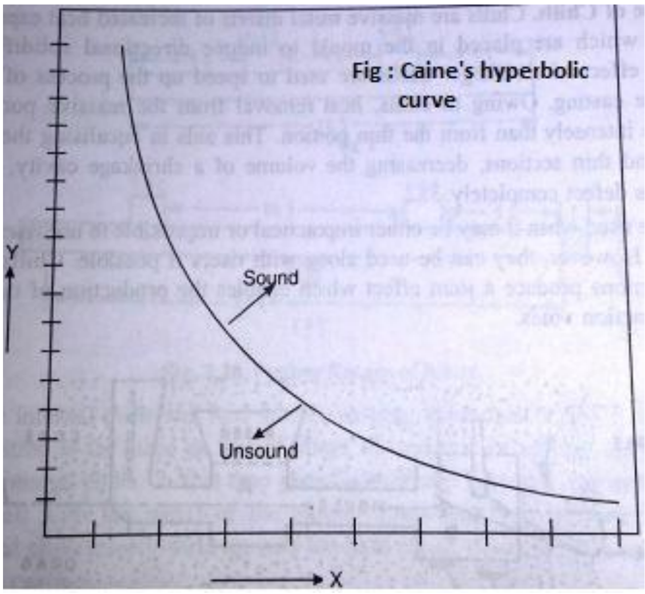


Fig : Caine's hyperbolic curve

Such curves for different cast metals are available in handbooks. To find the riser size for a given casting , the riser diameter and height are assumed . Then knowing the values of a,b and c , the values of X AND Y are calculated. These values of X&Y are plotted on the hyperbolic curve figure. If the value of X&Y met above the curve , the assumed risers size is satisfactory. Otherwise a new assumption is made.

GATING DESIGN

Most modern studies of gating systems have been based upon consideration of two laws of fluid dynamics. The first of these, the Equation of Continuity, states that the volume rate of flow is constant throughout a system and is expressed by

$$Q = A_1V_1 = A_2V_2$$

where Q = volume rate of flow, A = cross-sectional area of flow passage, V = linear velocity of flow

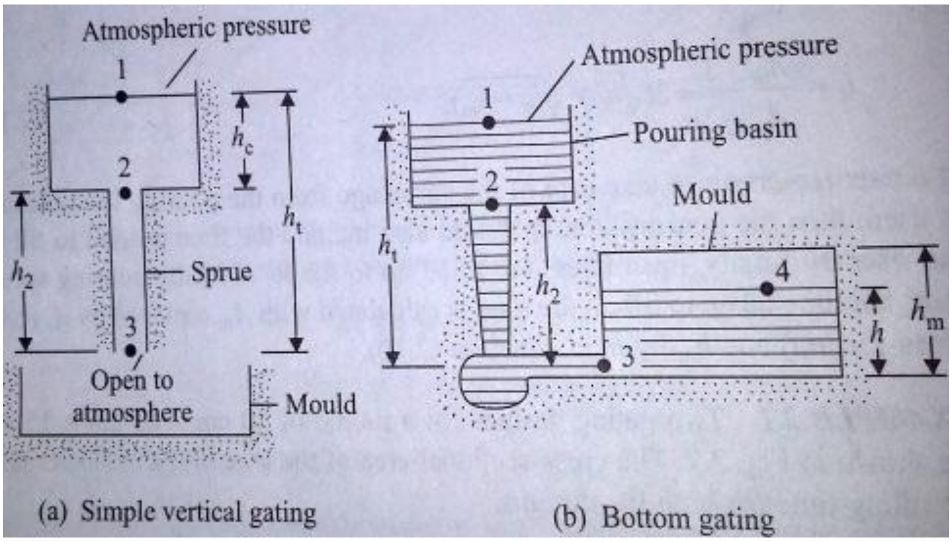
The linear velocity of flow in a system is related to other factors in Bernoulli's Theorem, which states that the total energy of unit weight offluid is constant throughout a system:

$2+$ —

where V = linear velocity of flow,h = height above the datum plane,P = pressure,ρ = density. Gating designs can be classified into three categories;

(i) Vertical gating (ii)Bottom gating (iii) Horizontal gating

In vertical gating , the liquid metal is poured vertically to fill the mould with atmospheric pressure at the base. In bottom gating , the liquid metal is filled in the mould from bottom to top ,thus avoiding splashing and oxidation associated with vertical gating. In horizontal gating , additional horizontal portions are introduced for better distribution of metal with minimum turbulence.



(a) Simple vertical gating (b) Bottom gating

Simple calculations based on principles of fluid mechanics can lead to an estimate of the time taken to fill the mould. Consider vertical gating system (fig1). Apply Bernoulli's equation between points 1 and 3. It is assumed that the pressure at points 1 and 3 are equal and that level at point 1 is maintained constant. Thus velocity at 1 is zero. Moreover, the frictional losses are neglected. Beroulli's equation between point 1 and 3 ,

Where V_3 velocity of liquid metal at the gate , subsequently referred to as V_g. So , time taken to fill up the mould (t_f) is obtained as ,

$t_f = \frac{V}{Æ_g V_3}$, Where A_g and V are the cross sectional area of the gate and volume of the mould respectively.

In bottom gating (fig 2) apply Bernoulli's equation between points 1 and 3 ,

$\frac{V_1^2}{2g} + h_1 + P_1 \quad \frac{V_3^2}{2g} \quad 3 + \frac{}{qg} \quad + h \quad P3$

$\frac{}{qg} =$

[$V_1 = 0$, $h_3 = 0$, $h_1 = h_t$]

We get , $_t \frac{}{q}$ gh = $P3$ N

$$v^2$$

$$+\frac{3}{2} \qquad \text{-----(1)}$$

ρ_m is the density of the molten metal , and P_3 is the gauge pressure at state 3 and h_t is assumed to be constant.

Furthur applying Bernoulli's equation between points 3 and 4 , with assumption that v_g is very small and all kinetic energy at station 3 is lost after the liquid metal enters the mould , we can write

$$\frac{P_3}{q_N} = gh \text{ -------------(2)}$$

From equation 1 and 2 , the velocity of the liquid metal at the gate we obtain is ,

$$v_g = v_3 = ƒ\overline{2g(h_t - h)} \text{ -------------------- (3)}$$

Equation 3 gives the velocity of a jet discharging against a static head h,making the effective head as

(h_t – h). Now, for instant shown, let the metal level in the mould move up through a height dh in a time interval dt; A_m and A_g be the cross sectional areas of the mould and the gate respectively. Then,

$A_m dh = A_g V_g dt$--------------------(4)

Using equations 3 and 4, we get

$$\frac{1}{ƒ2g}\,\frac{dh}{ƒh_t - h} = \frac{Æg}{ÆN}\,dt \text{ ------------- (5)}$$

At t = 0 , h = 0

t=t_f (filling time), h =h_m

Integrating equation (5) between the limits , we have ,

$$\frac{1}{ƒ2g}\int_0^{h_0}\frac{dh}{ƒh_t - h} = \frac{Æg}{ÆN}\int_0^{t_f} dt$$

$$\text{Or} \quad t_f = \frac{ÆN}{Æg}\,\frac{1}{ƒ2g}\,2(ƒ□t - \overline{ƒ□t - □N}) \text{ -------------------------- (6)}$$

GATING RATIO

It is used to describe the relative cross sectional area of components of a gating system. gating ratio ;
a : b : c

where a = cross-sectional area of sprue (or down runner) , b = total cross-sectional area of runners, c = total cross-sectional area of in gates.
Generally the ratio is 1:3:3

Depending upon different gating ratio , gating systems are classified as

- ***Pressurised system (High ratio)***
- **Unpressurised system (Low ratio)**

Pressurised gating system

- Total cross sectional area decreases toward the mould cavity
- Back pressure is maintained by the restriction in metal flow
- Flow of liquid (volume) is almost equal from all gates
- Back pressure helps in reducing the aspiration as the sprue always run full
- Because of restriction the metal flows at high velocity leading to more turbulence and chance of erosion (metal enter the mould producing a jet effect)

Unpressurised gating system

- Total cross sectional area increases towards the mould cavity
- Restriction only at the bottom of the sprue
- Flow of liquid (volume) is different from all gates
- Aspiration in gating system as the system never runs full
- Less turbulence

Heat transfer

The resistances to heat flow from the interior of the casting are:

1. The liquid. 2. The solidified metal.

3. The metal/mould interface. 4. The mould.

5. The surroundings of the mould.

In nearly all cases resistance (I) is negligible. The turbulent flow during pouring and mixing quickly transport heat and so smooth out temperature gradients. In many instances. resistance (5) is also negligible in practice.

Heat flow at different locations in the system is a complex phenomenon and depends on several factors relating to the material cast and the mold and process parameters. For instance, in casting thin sections, the metal flow rates must be high enough to avoid premature chilling and solidification. On the other hand, the flow rate must not be so high as to cause excessive turbulence-with its detrimental effects on the casting process.

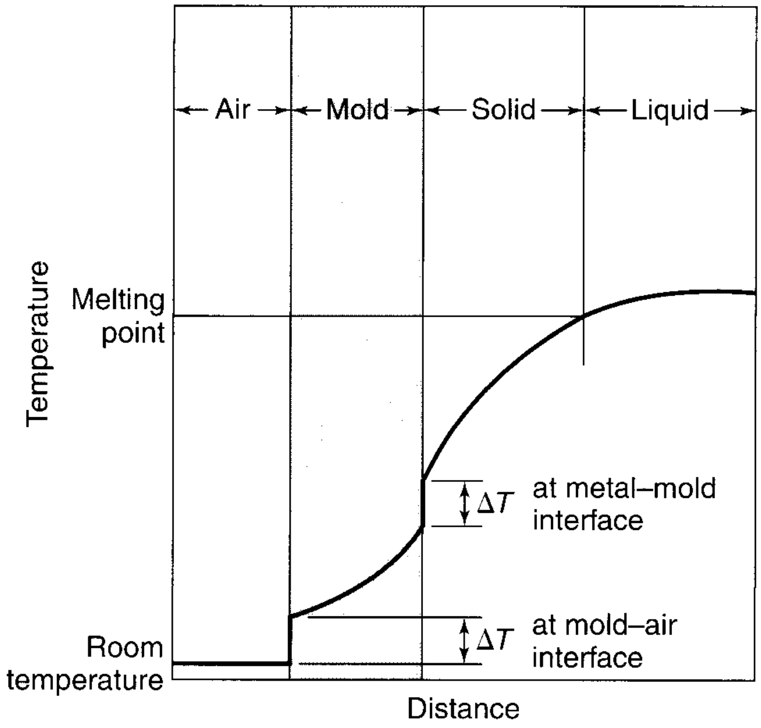


Fig . Temperature distribution at the interface of the mold wall and the liquid metal during the solidification of metals in casting

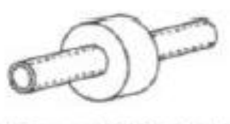
The temperature drop at the air-mold and mold-metal interfaces is caused by the presence of boundary layers and imperfect contact at these interfaces. The shape of the curve depends on the thermal properties of the molten metal and the mold.

EXPENDABLE-MOLD, PERMANENT-PATTERN CASTING PROCESSES

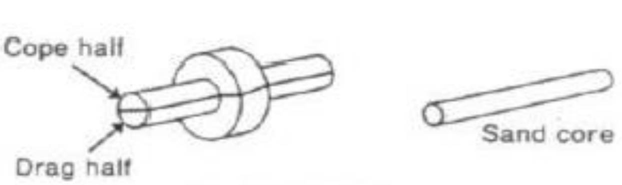
Sand, shell mold, plaster mold, ceramic mold

Sand casting

As the name implies sand is used as the mould material. The process has the advantages of low capital investment, design flexibility and large alloy selection. The major steps involved when sand casting a pipe with an integral flange are illustrated in Fig. A split wooden or metal master *pattern* is made of the shape to be cast. One half of the pattern is positioned on a bottom board and surrounded by the *drag* (bottom) half of the moulding *flask* (step 1). Aparting compound (step 2), such as talc, is sprinkled over the pattern to facilitate separation of the pattern from the mould prior to pouring the liquid metal. Often a fine sand is placed against the pattern and then a coarser sand mixture is used to fill the rest of the drag. A fine sand provides a relatively good surface finish on the cast part. The sand is packed tightly to ensure that the shape of the pattern is retained and excess sand removed. The drag is inverted and the top half, or *cope*, of the mould prepared in the same manner as the drag (step 3).

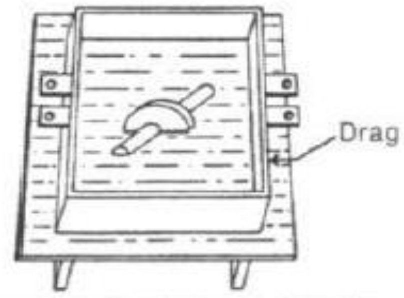


Desired shape of finished casting



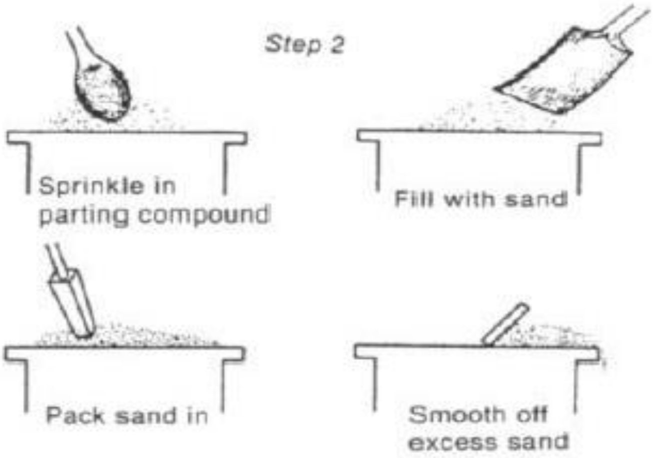
Wooden pattern

Step 1

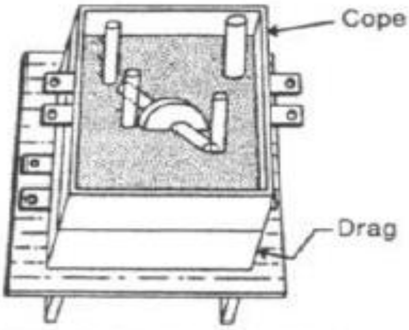


Drag half of pattern is placed in drag half of flask

Step 2

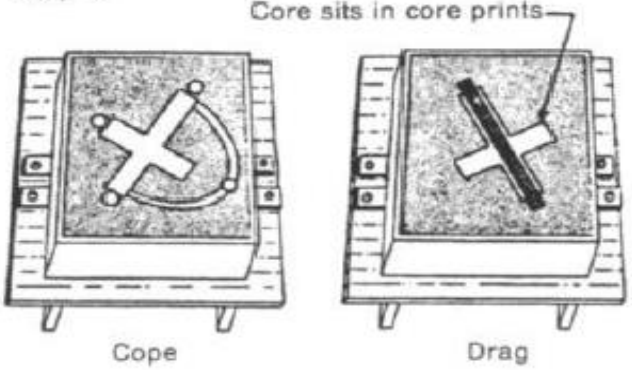


Step 3



Invert drag and place cope half of pattern; position sprue and riser sticks

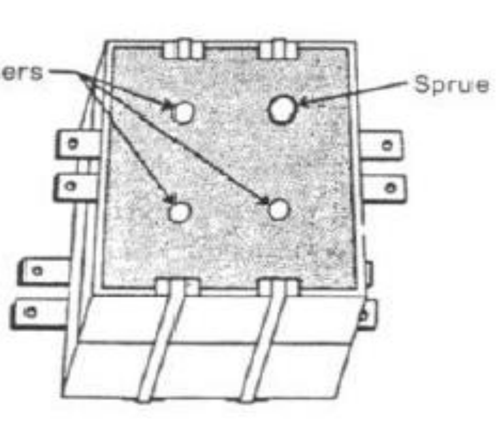
Step 4

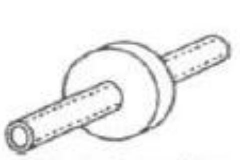


Separate the cope and drag; remove pattern, riser sticks and sprue plug; make gating system

Step 5

Clamp flask together and pour metal





Finished casting after trimming

A feeding system for delivery of the molten metal is formed in the cope. This typically consists of a *pouring basin*, *a sprue* (vertical metal transfer channel), *runners*(horizontal transfer channels) and *ingates* connecting the runners to the mould cavity. The feeding

system can be made part of the pattern or can be carved into the split mould after the pattern has been removed. In addition to the feeding system, *riser* cavities are designed into strategic positions, as shown in Fig. These serve as reservoirs of molten metal which are fed into the casting as it cools to compensate for solidification shrinkage.

The cope and drag are separated and the pattern removed (step 4). A *core* of sand mixed with resin or ceramic is placed in the mould to form the hollow of the pipe. The strength of the core must be higher than the rest of the mould to prevent damage from the inrush of molten metal. The cope and drag are reassembled (step 5) and clamped together, ready for receipt of the metal. The metal is poured from a small ladle intothe sprue, flows into the mould cavity and solidifies. Once solidification is complete the mould is broken and the cast part removed, all sand cleaned off and the riser and feeding system are cut away.

Shell Molding

the basic steps shell moulding are described below and illustrated in Fig.

1. The individual grains of fine silica sand are first precoated with a thin layer of thermosetting phenolic resin and heat-sensitive liquid catalyst. This material is then dumped, blown, or shot onto a metal pattern (usually some form of cast iron) that has been preheated to a temperature between 230° and 315°C (450° and 600°F). Duringa period of sustained contact, heat from the pattern partially cures (polymerizes and crosslinks) a layer of material. This forms a strong, solid-bonded region adjacent to the pattern. The actual thickness of cured material depends on the pattern temperature and the time of contact but typically ranges between 10 and 20mm(0.4 to 0.8 in.).

2. The pattern and sand mixture are then inverted, allowing the excess (uncured) sand to drop free. Only the layer of partially cured material remains adhered to the pattern.

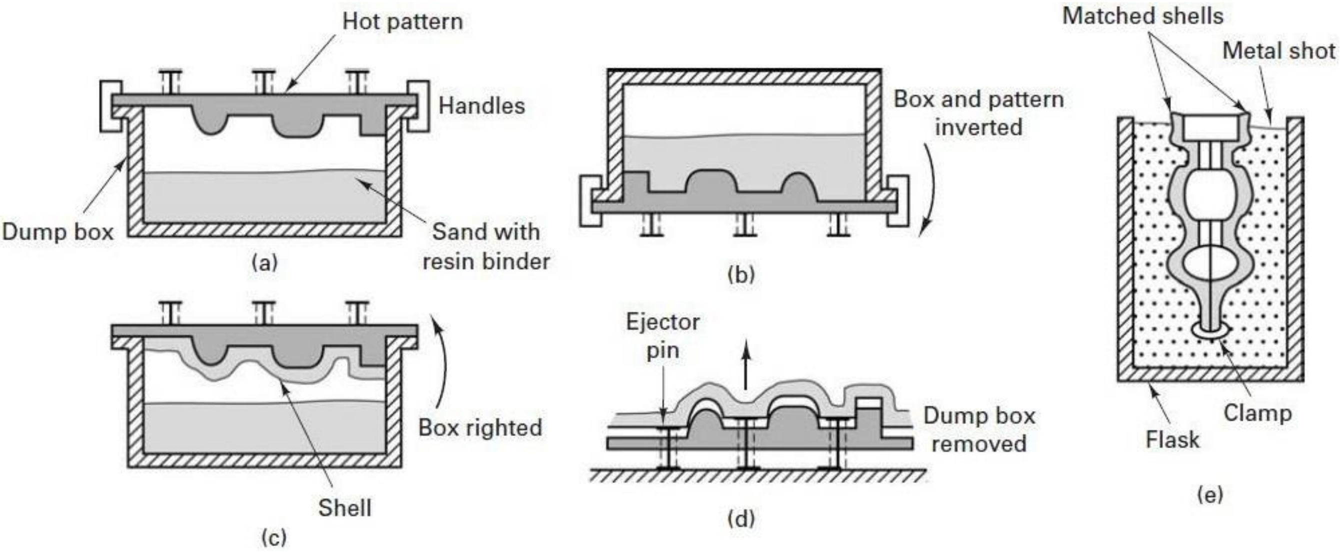
3. The pattern with adhering shell is then placed in an oven, where additional heating completes the curing process.

4. The hardened shell, with tensile strength between 2.4–3.1 MPa, is then stripped from the pattern.

5. Two or more shells are then clamped or glued together with a thermoset adhesive to produce a mold, which may be poured immediately or stored almost indefinitely.

6. To provide extra support during the pour, shell molds are often placed in a pouring jacket and surrounded with metal shot, sand, or gravel.

Advantages : excellent dimensional accuracy ,smooth casting surface ,Cleaning, machining, and other finishing costs can be significantly reduced



Plaster-mold Casting

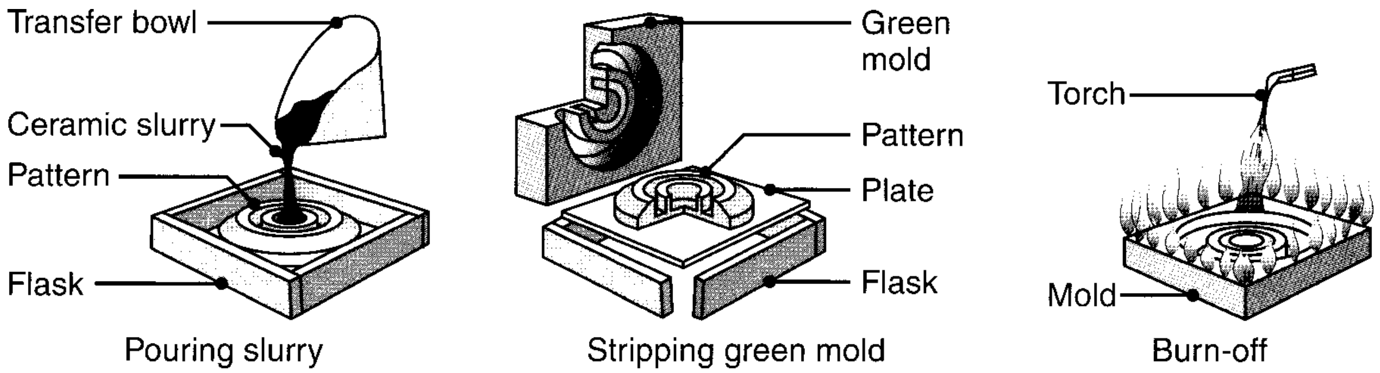
In the plaster-molding process, the mold is made of plaster of paris (gypsum or calcium sulfate) with the addition of tale and silica flour to improve strength and to control the time required for the plaster to set. These components are mixed with water, and the resulting slurry is poured over the pattern. After the plaster sets (usually within 15 minutes), it is removed, and the mold is dried at a temperature range of 120° to 260°C. Higher drying temperatures may be used, depending on the type of plaster. The mold halves are assembled to form the mold cavity and are preheated to about 120°C. The molten metal is then poured into the mold.

Because plaster molds have very low permeability, gases evolved during solidification of the metal cannot escape. Consequently, the molten metal is poured eitherin a vacuum or under pressure. Mold permeability can be increased substantially by the Antioch process, in which the molds are dehydrated in an autoclat/e (pressurizedoven) for 6 to 12 hours and then rehydrated in air for 14 hours. Another method of increasing the permeability of the mold is to use foamed plaster containing trappedair bubbles.

Ceramic-mold Casting

The ceramic-mold casting process (also called cope-and-drag investment casting) is similar to the plaster-mold process, except that it uses refractory mold materials suitable for high-temperature applications. The slurry is a mixture of fine-grained zircon ($ZrSiO_4$), aluminum oxide, and fused silica, which are mixed with bonding agents and poured over the pattern(Fig. 11.10), which has been placed in a flask.

The pattern may be made of wood or metal. After setting, the molds (ceramic facings) are removed, dried, ignited to burn off volatile matter, and baked. The molds are clamped firmly and used as all-ceramic molds. In the Shaw process, the ceramic facings are backed by fireclay (which resists high temperatures) to give strength to the mold. The facings then are assembled into a complete mold, ready to be poured



Pouring slurry 1. Stripping green mold 2. Burn-off 3.

Expendable-mold, Expendable-pattern Casting Processes

Evaporative-pattern Casting (Lost-foam Process)

The evaporative-pattern casting process uses a polystyrene pattern, which evaporates upon contact with molten metal to form a cavity for the casting; this process is also known as *lost-foam casting* and falls under the trade name *full-mold process*. It has become one of the more important casting processes for ferrous and non ferrous metals, particularly for the automotive industry.

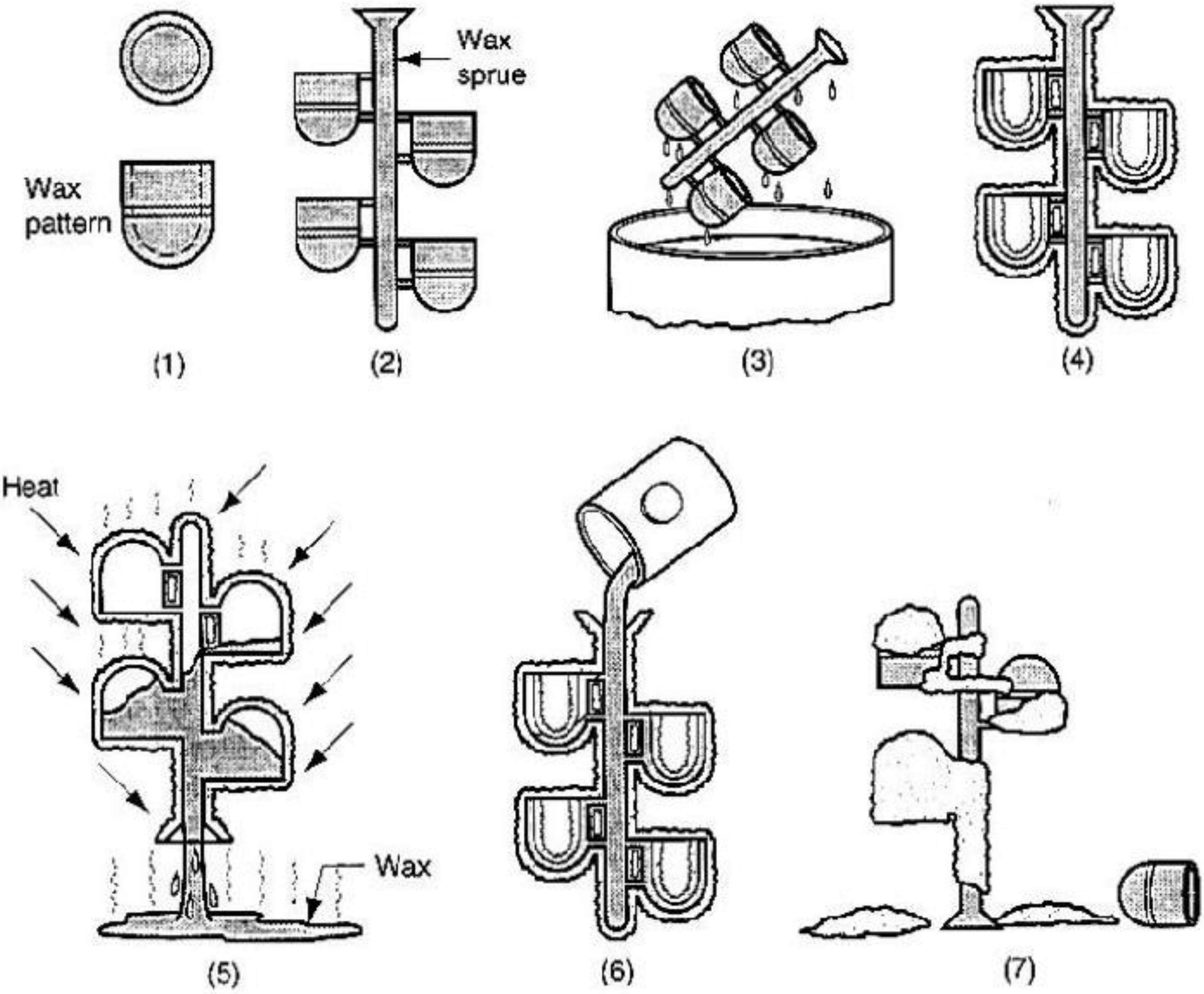
In this process, polystyrene beads containing 5 to 8% pentane (a volatile hydrocarbon)are placed in a preheated die that is usually made of aluminum. The polystyrene expands and takes the shape of the die cavity. Additional heat is applied to fuse and bond the beads together. The die is then cooled and opened, and the polystyrene pattern is removed.

The pattern is coated with a water-based refractory slurry, dried, and placed in a flask. The flask is then filled with loose, fine sand, which surrounds and supports the pattern and may be dried or mixed with bonding agents to give it additional strength. The sand is compacted periodically, without removing the polystyrene pattern; then the molten metal is poured into the mold. The molten metal vaporizes the pattern and fills the mold cavity, completely replacing the space previously occupied by the polystyrene. Any degradation products from the polystyrene are vented into the surrounding sand.

Advantages over other casting methods:

- The process is relatively simple because there are no parting lines, cores, or riser systems. Hence, it has design flexibility.
- Inexpensive flasks are satisfactory for the process.
- Polystyrene is inexpensive and can be processed easily into patterns having complex shapes, various sizes, and fine surface detail.
- The casting requires minimal finishing and cleaning operations.
- The process can be automated and is economical for long production runs. However, major factors are the cost to produce the die used for expanding the polystyrene beads to make the pattern and the need for two sets of tooling.

Investment Casting



Steps : 1) Wax patterns are produced (2) Several patterns are attached to a sprue to form a pattern tree (3) The pattern tree is coated with a thin layer of refractory material.(4)The full mould is formed by covering the coated tree with sufficient refractory material to make it rigid. (5) The mold is held in an inverted position and heated to melt the wax and permit it to drip out of the cavity.(6) The mold is preheated to a high temperature , which ensures that all contaminants are eliminated from the mold; it also permit the liquid metal to flow more easily into the detailed cavity; the molten metal is poured; it solidifies ,and (7) The mold is broken away from the finished casting. Parts are separated from the sprue.

Permanent-mold Casting Processes

In permanent-mold casting (also called hard-mold casting), two halves of a mold are made from materials with high resistance to erosion and thermal fatigue, such as cast-iron, steel, bronze, graphite, or refractory metal alloys. Typical parts made are automobile pistons, cylinder heads, connecting rods, gear blanks for appliances, and kitchenware.

In order to increase the life of permanent molds, the surfaces of the mold cavity usually are coated with a refractory slurry (such as sodium silicate and clay) or sprayed with graphite every few castings. These coatings also serve as parting agent sand as thermal barriers, thus controlling the rate of cooling of the casting. Mechanical ejectors (such as pins located in various parts of the mold) may be required for the removal of complex castings; ejectors usually leave small round impressions.

The molds are clamped together by mechanical means and heated to about150° to 200°C to facilitate metal flow and reduce thermal damage to the dies due to high-temperature gradients. Molten metal is then poured through the gating system. After solidification, the molds are opened and the casting is removed. The mold often incorporates special cooling features, such as a means of pumping cooling water through the channels located in the mold and the use of cooling fins. Although the permanent-mold casting operation can be performed manually, it is often automated for large production runs. The process is used mostly for aluminum, magnesium, and copper alloys, as well as for gray iron, because of their generally lower melting points, although steels also can be cast using graphite or heat-resistant metal molds. Permanent-mold casting produces castings with a good surface finish, close dimensional tolerances, uniform and good mechanical properties, and at high production rates.

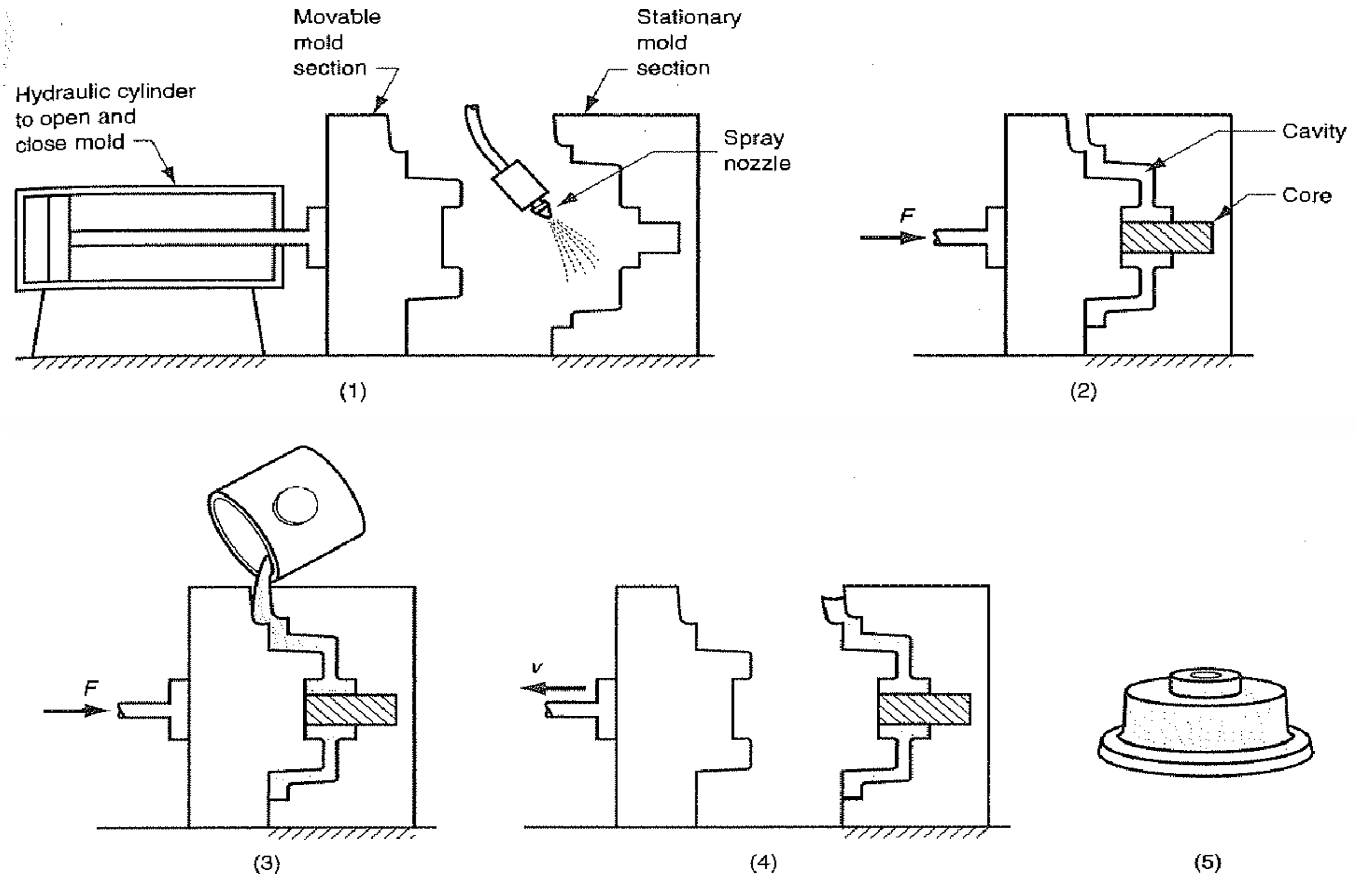


Fig : Steps in permanent mould casting (1) mold is prehested and coated (2) cores (if used) are inserted , mold is closed (3) molten metal is poured into the mold (4) mold is opened (5) finished part.

Vacuum Casting(or countergrazvity lowpressure(CL) process)

In the vacuum-casting process, a mixture of fine sand and urethane is molded over metal dies and cured with amine vapor. The mold is then held with a robot arm and immersed partially into molten metal held in an induction furnace. The metal may be melted in air (CLA process) or in a vacuum (CLV process). The vacuum reduces the air pressure inside the mold to about two-thirds of atmospheric pressure, thus drawing the molten metal into the mold cavities through a gate in the bottom of the mold. The metal in the furnace is usually at a temperature of 55°C above the liquid temperature of the alloy. Consequently, it begins to solidify within a very short time. After the mold is filled, it is withdrawn from the molten metal.

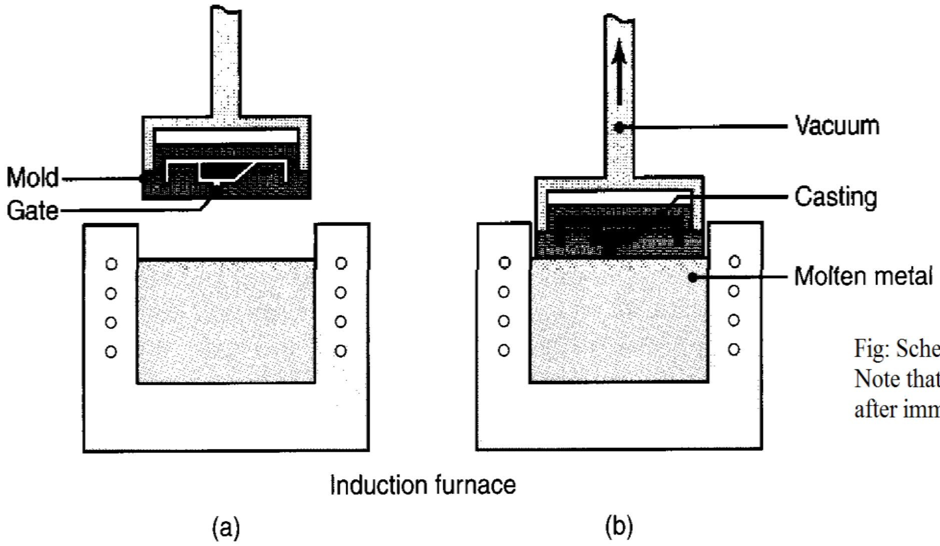


Fig: Schematic illustration of the vacuum-casting process. Note that the mold has a bottom gate. (a) Before and (b) after immersion of the mold into the molten metal.

Slush Casting

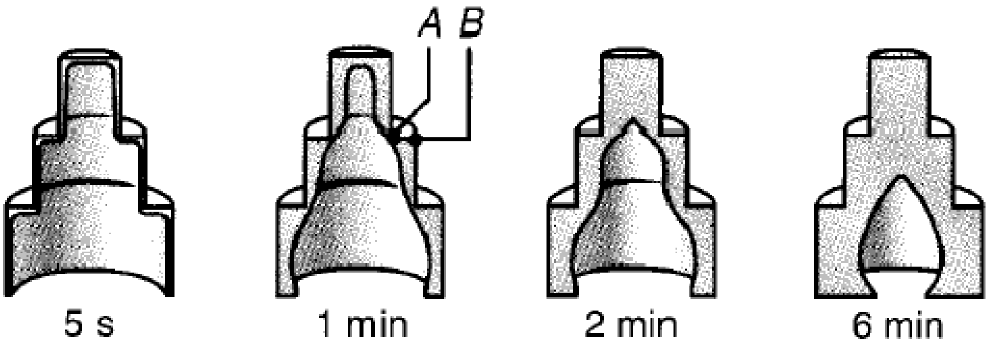


Fig: Solidified skin on a steel casting. The remaining molten metal is poured out at the times indicated in the figure. Hollow ornamental and decorative objects are made by a process called slush casting, which is based on this principle.

Hollow castings with thin walls can be made by permanent-mold casting using the principle illustrated in the above figure: a process called slush casting. This process is suitable for small production runs and generally is used for making ornamental and decorative objects (such as lamp bases and stems) and toys from low-melting- point metals such as zinc, tin, and lead alloys.

The molten metal is poured into the metal mold. After the desired thickness of solidified skin is obtained, the mold is inverted (or slung) and the remaining liquid metal is poured out. The mold halves then are opened and the casting is removed. This operation is similar to making hollow chocolate shapes, eggs, and other confectionaries.

Pressure Casting

In the two permanent-mold processes described previously, the molten metal flows into the mold cavity by gravity. In pressure casting (also called pressure pouring or low-pressure casting), the molten metal is forced upward by gas pressure into a graphite or metal mold. The pressure is maintained until the metal has solidified completely in the mold. The molten metal also may be forced upward by a vacuum, which also removes dissolved gases and produces a casting with lower porosity. Pressure casting generally is used for high-quality castings, such as steel railroad-car wheels, although these wheels also may be cast in sand molds or semi permanent molds made of graphite and sand.

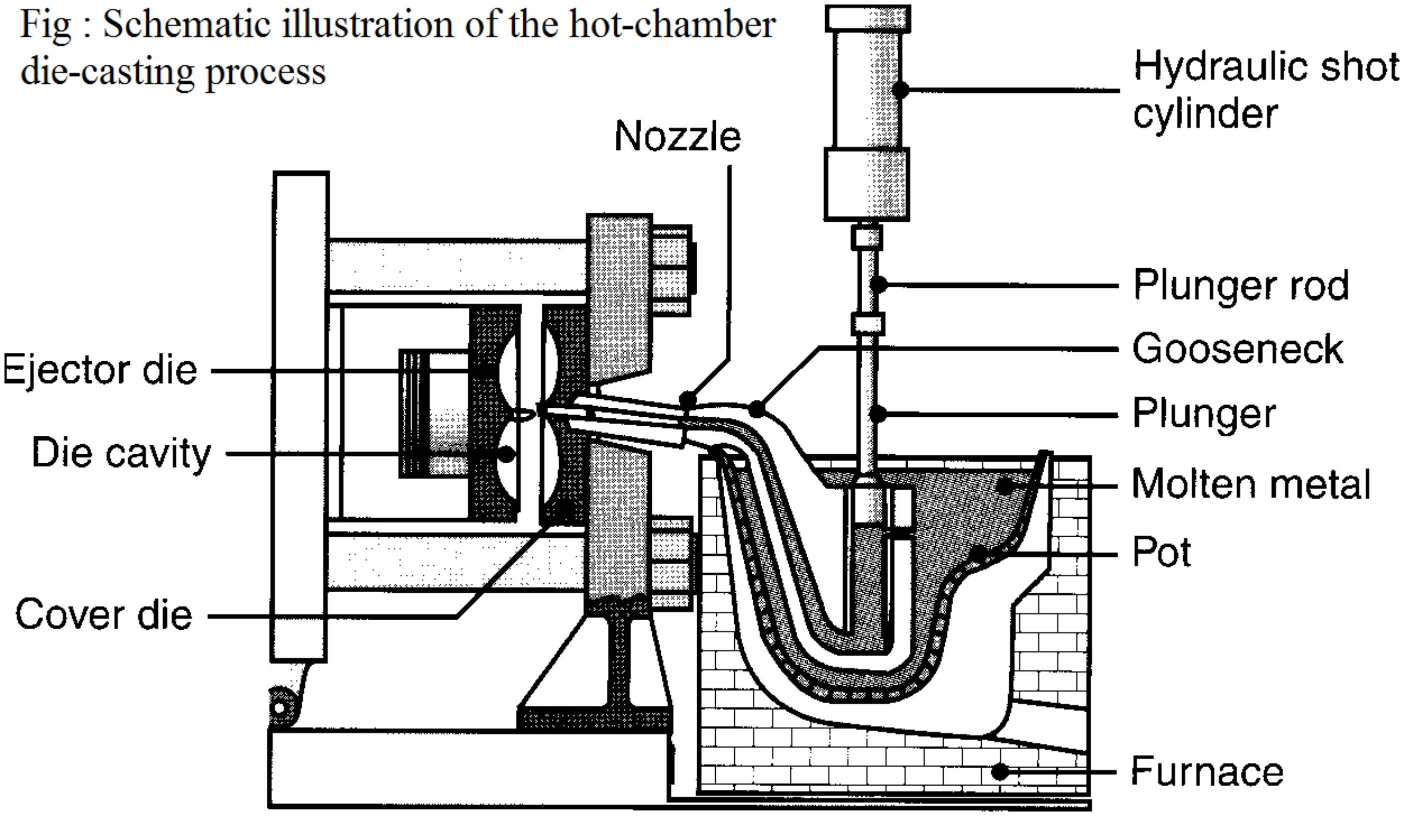
Die Casting

Typical parts made by die casting are housings, business-machine and appliance components, hand-tool components, and toys. The weight of most castings ranges from less than 90 g to about 25 kg. Equipment costs, particularly the cost of dies, are somewhat high, but labor costs are generally low, because the process is semi- or fully automated. Die casting is economical for large production runs.

In the die-casting process, molten metal is forced into the die cavity at pressures ranging from 0.7 to 700 MPa. There are two basic types of die-casting machines :hot- chamber and cold-chamber machines.

The hot-chamber process involves the use of a piston, which forcesa certain volume of metal into the die cavity through a gooseneck and nozzle. Pressures range up to 35 MPa, with an average of about 15 MPa. The metal is held under pressure until it solidifies in the die. To improve die life and to aid in rapid metal cooling (thereby reducing cycle time) dies usually are cooled by circulating water or oil through various passageways in the die block. Low-melting-point alloys (such as zinc, magnesium, tin, and lead) commonly are cast using this process. Cycle times usually range from 200 to 300 shots (individual injections) per hour for zinc, although very small components, such as zipper teeth, can be cast at rates of 18,000 shots per hour.

Fig : Schematic illustration of the hot-chamber die-casting process



In the cold-chamber process, molten metal is poured into the injection cylinder (shot chamber). The chamber is not heated-hence the term cold chamber. The metal is forced into the die cavity at pressures usually ranging from 20to 70 MPa, although they may be as high as 150 MPa.

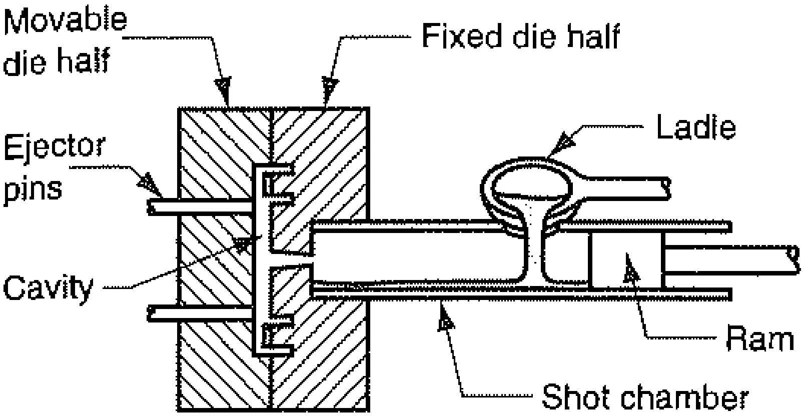


Fig:Schematic illustration of cold chamber process

Centrifugal Casting

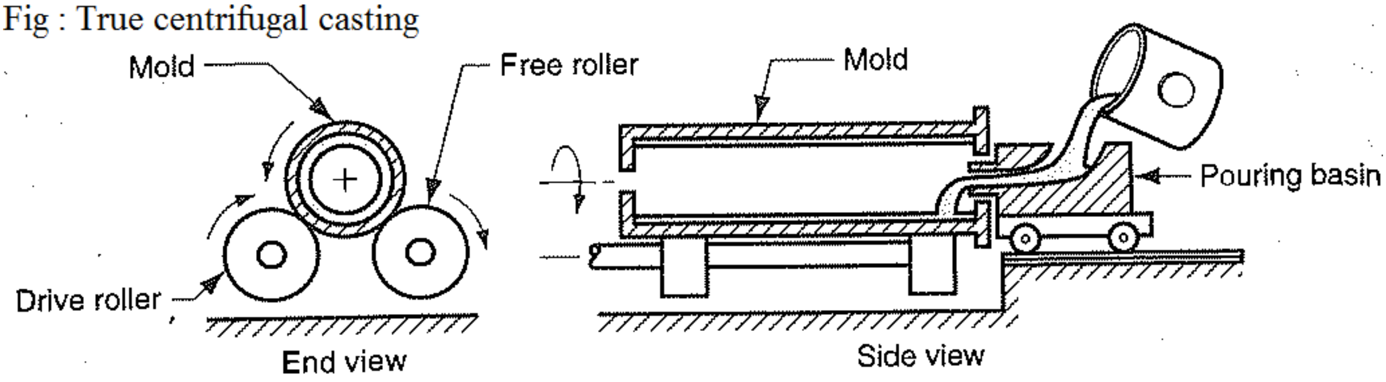
There are three types of centrifugal casting: true centrifugal casting, semi centrifugal casting, and centrifuging.

True Centrifugal Casting.

In true centrifugal casting, hollow cylindrical parts (suchas pipes, gun barrels, bushings, engine-cylinder liners, bearing rings with or without flanges, and street lampposts) are produced by the technique shown in Fig. In this process, molten metal is poured into a rotating mold. The axis of rotation is usually horizontal, but can be vertical for short work pieces. Molds are made of steel, iron, or graphite and may be coated with a refractory lining to increase mold life. The mold surfaces can be shaped so that pipes with various external designs can be cast. The inner surface of the casting remains cylindrical, because the molten metal is distributed uniformly by the centrifugal forces. However, because of density differences, lighter elements (such as dross, impurities, and pieces of the refractory lining) tend to collect on the inner surface of the casting. Consequently, the properties of the casting can vary throughout its thickness.

Cylindrical parts ranging from 13 mm to 3 m in diameter and 16 m long can be cast centrifugally with wall thicknesses ranging from 6 to 125 mm. The pressure generated by the centrifugal force is high (as much as 150 g); such high pressure is necessary for casting thick-walled parts. Castings with good quality, dimensional accuracy, and external surface detail are produced by this process.

Fig : True centrifugal casting



Semicentrifugal Casting

This method is used to cast parts with rotational symmetry, such as a wheel with spokes. Density of metal in the final casting is greater in the outer sections than at the centre of rotation. The process is often used on parts in which the centre of the casting is machined away , thus eliminating the portion of the casting where quality is lowest.

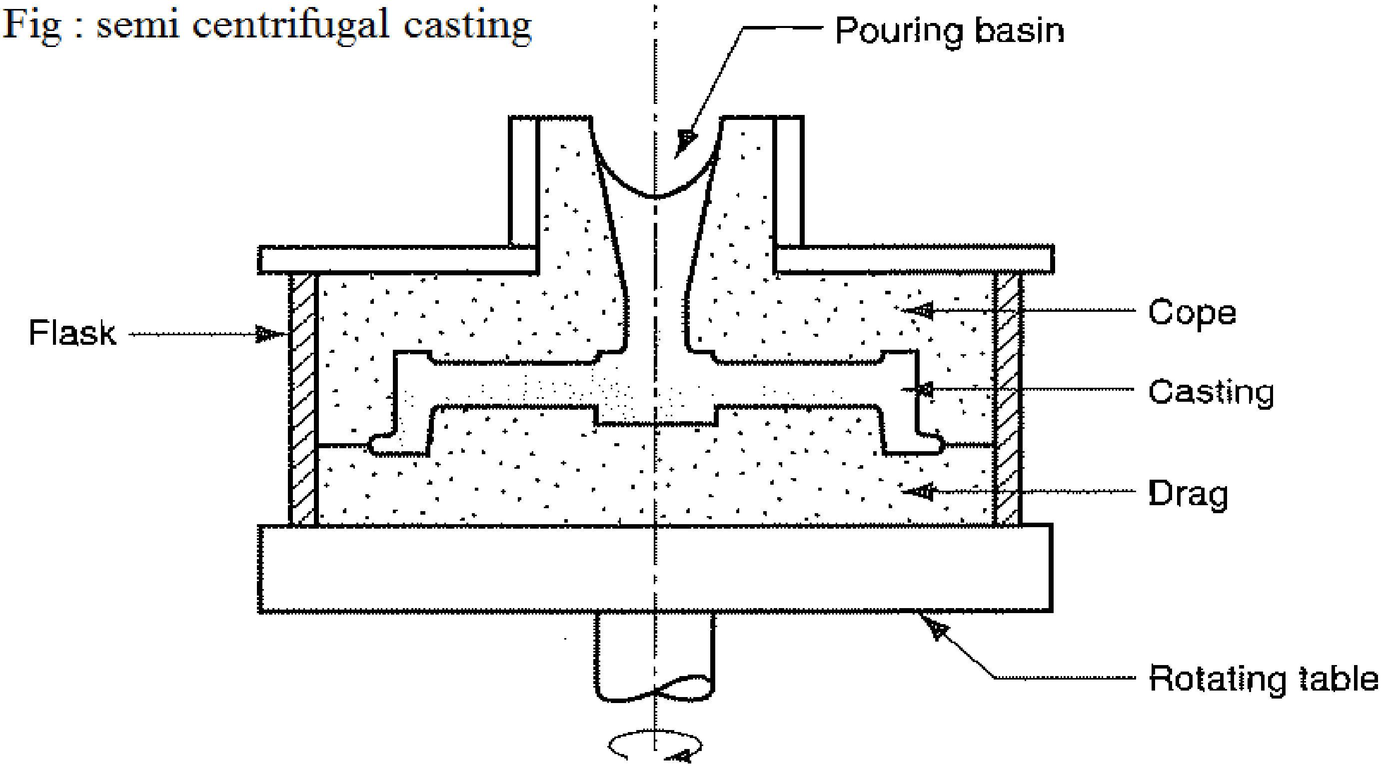


Fig : semi centrifugal casting

Centrifuging

In centrifuging (also called centrifuge casting), mold cavities of any shape are placed at a certain distance from the axis of rotation. The molten metal is poured from the center and is forced into the mold by centrifugal forces. The properties of the castings can vary by distance from the axis of rotation, as in true centrifugal casting. The process is used for smaller parts ,and radial symmetry of the part is not a requirement as it is for the other two centrifugal casting methods.

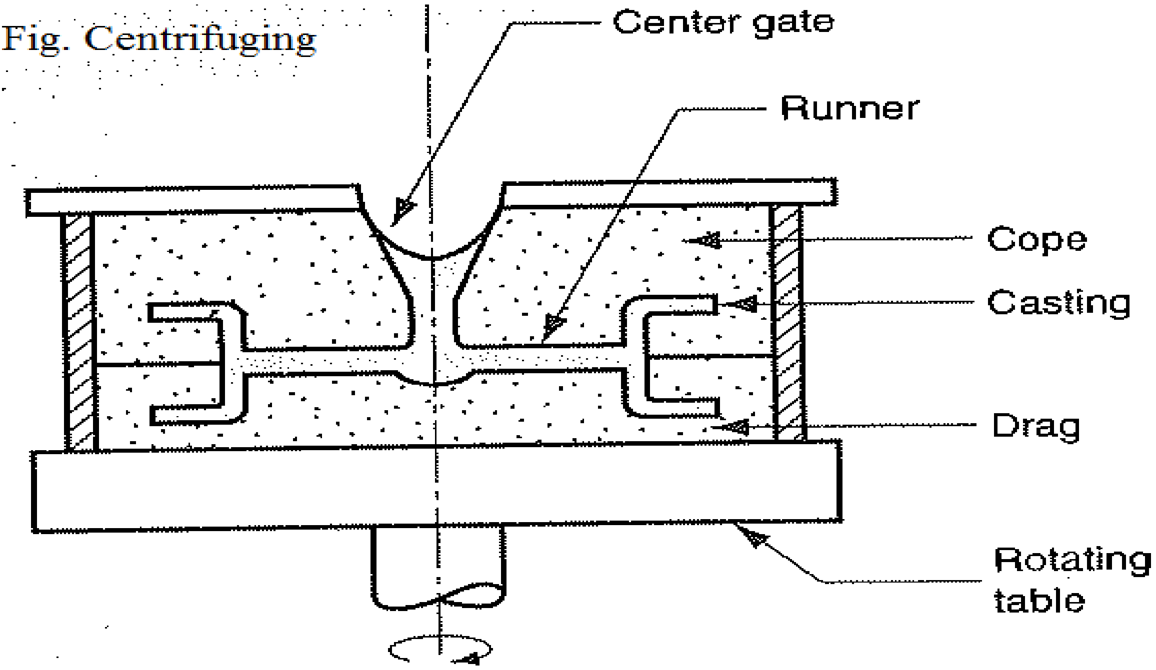


Fig. Centrifuging

Squeeze Casting and Semisolid-metal Forming

Squeeze Casting

In the *squeeze casting* process, molten metal is introduced into the die cavity of a metal mold, using large gate areas and slow metal velocities to avoid turbulence. When the cavity has filled, high pressure (20 to 175 MPa) is then applied and maintained during the subsequent solidification. The pressure applied keeps the entrapped gases in solution, and the contact under high pressure at the die-metal interface promotes rapid heat transfer, thus resulting in a fine microstructure with good mechanical properties.

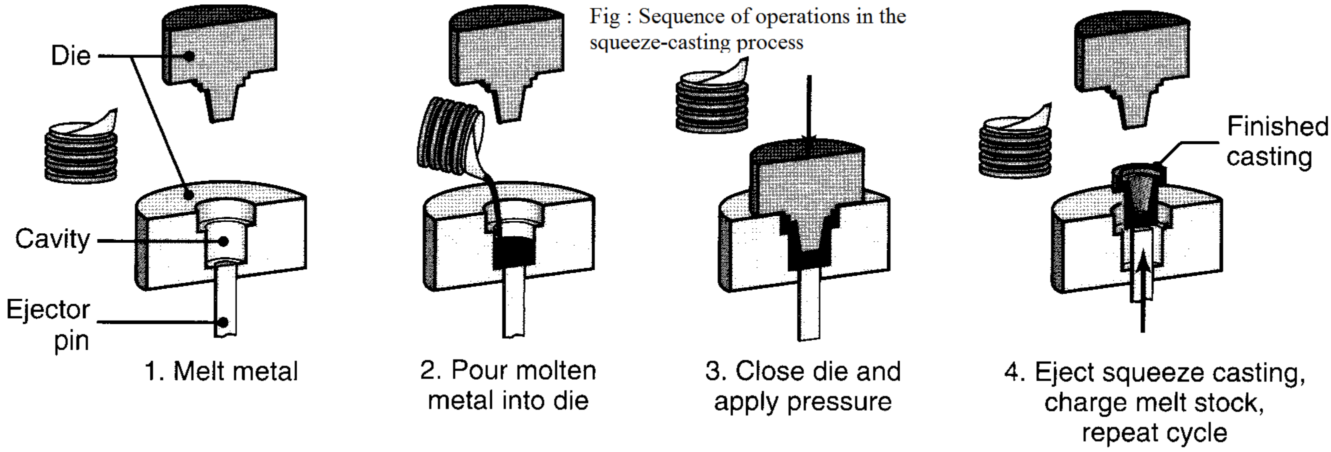


Fig : Sequence of operations in the squeeze-casting process

Semisolid-metal Forming

For most alloy compositions, there is a range of temperatures where liquid and solid coexist, and several techniques have been developed to produce shapes from this *semisolid* material.

In the *rheo casting* process, molten metal is cooled to the semisolid state with constant stirring. The stirring or shearing action breaks up the dendrites, producing slurry of rounded particles of solid in a liquid melt. This slurry, with about a 30%solid content, can be readily shaped by high-pressure injection into metal dies. Because the slurry contains no superheat and is already partially solidified, it freezes quickly.

In the *thixo casting* variation, there is no handling of molten metal. The material is first subjected to special processing (stirring during solidification as in rheo casting)to produce solid blocks or bars with a non dendritic structure. When reheated to the semisolid condition, the *thixotropic material* can be handled like a solid but flows like a liquid when agitated or squeezed. (thixotropic behavior of alloys is that the viscosity decreases when the liquid metal is agitated)The solid material is then cut to prescribed length, reheated to a semisolid state where the material is about 40% liquid and 60% solid, mechanically transferred to the shot chamber of a cold-chamber die- casting machine, and injected under pressure.

Defects in casting

Defects in casting occurs due to defects in the following :

1. Design of pattern and casting
2. Moulding sand and design of mould and core
3. Metal composition
4. Gating and risering
5. Melting and pouring

Various defects in casting are,

1. Blow: It is a fairly large well rounded cavity produced by the gases which displace the molten metal at the cope surface of casting. Blows usually occur on a convex casting surface and can be avoided by having a proper venting and an adequate permeability.

2 . Scar : It is a shallow blow , usually found on a flat casting surface .

3. Blister : This is a scar covered by thin layer of a metal

4. Gas holes : These refer to the entrapped gas bubbles having a nearly spherical shape , and occur when an excessive amount of gases is dissolved in the liquid metal.

5. Pin holes : These are nothing but tiny blow holes and occur either at or just below the casting surface. Normally these are found in large numbers and are almost uniformly distributed in the entire casting surface.

6. Porosity : It indicates very small holes uniformly dispersed trhoughout a casting.It arises when there is a decrease in gas solubility during solidification.

7. Drop : It is an irregularly shaped projection on the cope surface of a casting . This is caused by dropping of sand from the cope or other overhanging projectin into the mould. Adequate strength of sand and use of gaggers can help in avoiding drop.

8. Inclusion : It refers to a non metallic particle in the metal matrix, It becomes highly desirable when segregated.

9. Dross : Lighter impurities appearing on the top surface of a casting is called dross. It can be taken care of at the pouring stage by using items such as a strainer and skim bob.

10. Dirt : Sand particles dropping out of the cope gets embedded on the top surface of a casting. When removed these leave small , angular holes , known as dirt.

11. Wash : A low projection on the drag surface of a casting commencing near the gate is called wash.This is caused by the erosion of sand due to the high velocity of liquid metal in the bottom gating.

12. Buckle : It refers to a long , fairly shallow , broad , vee shaped depression occurring in the surface od a flat casting of a high temperature metal. At high temperature , an expansion of thin layer of sand at the mould face takes place before the liquid metal at the mould face solidifies. As this expansion is obstructed by the flak , the mould face tends to bulge out forming the vee shape. A proper amount of volatile additive is essential for overcoming this defect.

13. Scab : This refers to rough thn layer of a metal protruding above the casting surface ,on top of a thin layer of sand.
14. Rat tail : A long , shallow angular depression normally found in a thin casting. The reason for its formation is same as that of buckle. The reason for its formation is the same as that for a buckle. Here, instead of the expanding sand upheaving , the compressed layer fails by one layer , gliding over the other.
15. Penetration : If the mold surface is too soft and porous , the liquid metal may flow between the sand particles up to a distance , into the mould. This causes rough ,porous projections and this defect is called penetration.
16. Swell : This defect is found on the vertical surfaces of a casting if the molding sand is deformed by the hydrostatic pressure caused by the high moisture content in the sand.

17. Misrun : Many a time , the liquid metal may , due to insufficient superheat , start freezing before reaching the farthest point of the mould cavity. This defect is called as misrun.

18. Cold shut : For a casting with two gates at its two sides , the misrun may show up at the centre of the casting. When this happens , the defect is called cold shut.

19. Hot tear : A crack that develops in a casting due to high residual stresses is called a hot tear.

20. Shrinkage cavity : An improper riser may give rise to a defect called shrinkage cavity.

21. Shift : A misalignment between two halves of a mold or of a core may give rise to a defective casting. Accordingly this defect is called a mold shift or core shift.

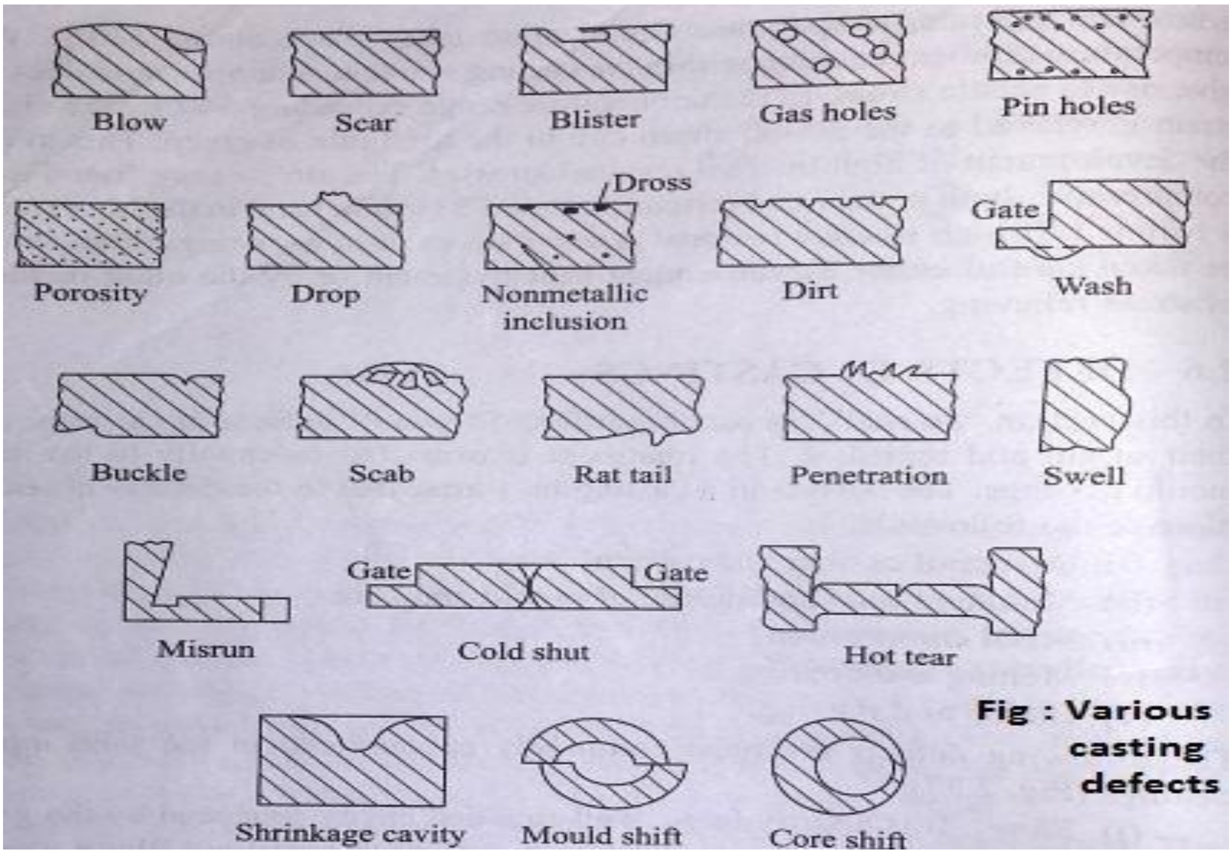


Fig : Various casting defects

Non destructive testing

In nondestructive testing, the product is examined in a manner that retains its usefulness for future service. Tests can be performed on parts during or after manufacture, or even on parts that are already in service.

1. Visual Inspection

Probably the simplest and most widely used nondestructive testing method is *visual inspection*.
The human eye is a very discerning instrument and, with training, the brain can readily interpret the signals. Optical aids such as mirrors, magnifying glasses, and microscopes can expand the capabilities of this system.

2. Liquid penetrant test

Liquid penetrant testing, also called *dye penetrant inspection*, is an effective method of detecting surface defects in metals and other nonporous materials. The piece to be tested is first subjected to a thorough cleaning and is dried prior to the test.Then a penetrant, a liquid material capable of wetting the entire surface and being drawn into fine openings, is applied to the surface of the work piece by dipping, spraying, or brushing. Sufficient time is given for capillary action to draw the penetrant into any surface discontinuities, and the excess penetrant liquid is then removed by wiping, water wash, or solvent. The surface is then coated with a thin film of developer, an absorbent material capable of drawing traces of penetrant from the defects back onto the surface. Brightly colored dyes or fluorescent materials that glow under ultraviolet light are generally added to the penetrant to make these traces more visible, and the developer is often selected to provide a contrasting background.

Preheating zone starts from the upper end of the melting zone and continues up to the bottom level of the charging door. This zone contains a number of alternate layers of coke bed, flux and metal charge. The main objective of this zone is to preheat the charges from room temperature to about 1090°C before entering the metal charge to the melting zone. The preheating takes place in this zone due to the upward movement of hot gases. During the preheating process, the metal charge in solid form picks up some sulphur content in this zone.

6. Stack

The empty portion of cupola above the preheating zone is called as stack. It provides the passage to hot gases to go to atmosphere from the cupola furnace.

Operation

A bed of molding sand is first rammed on the bottom to a thickness of about 6 inches (150 mm) or more. A bed of coke about 40 inches (1.0 m) thick is next placed on the sand. The coke is then ignited, and air is blown at a lower- than-normal rate. Next, the charge is fed into the cupola through the charging door. Many factors, such as the charge composition, affect the final structure of the gray cast iron obtained. Nevertheless, it can generally be stated that the charge is composed of 25 percent pig iron, 50 percent gray cast-iron scrap, 10 percent steel scrap, 12 percent coke as fuel, and 3 percent limestone as flux. These constituents form alternate layers of coke, limestone, and metal. Sometimes, ferromanganese briquettes and inoculants are added to the charge to control and improve the structure of the cast iron produced. Coke is the fuel used to heat the furnace. Forced air is introduced through openings near the bottom of the shell for combustion of the coke. The flux is a basic compound such as lime stones that react with coke ash and other impurities to form slag. The slag serves to cover the melt, protecting if from reaction with the environment inside the cupola and reducing heat loss. As the mixture is heated and melting of the iron takes place , the furnace is tapped periodically to provide liquid metal for the pour.

General Design Considerations for Castings

There are two types of design issues in casting: (a) geometric features, tolerances, etc., that should be incorporated into the part and (b) mold features that are needed to produce the desired casting. Robust design of castings usually involves the following steps:

I. Design the part so that the shape is cast easily. A number of important design considerations are given in this chapter to assist in such efforts.

2. Select a casting process and a material suitable for the part, size, required production volume, mechanical properties, and so on. Often, steps 1 and 2 in this list have to be specified simultaneously and can be a demanding design challenge.

3. Locate the parting line of the mold in the part.

4. Locate and design the gates to allow uniform feeding of the mold cavity with molten metal.

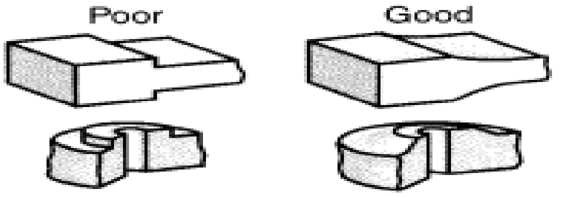
5. Select an appropriate runner geometry for the system.

6. Locate mold features, such as sprue, screens, and risers, as appropriate.

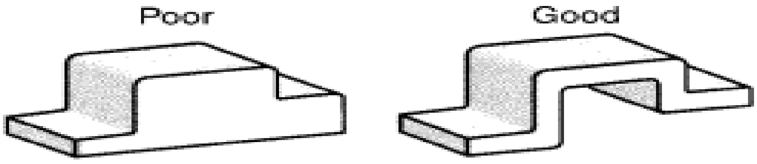
7. Make sure proper controls and good practices are in place.

Design of Cast Parts. The following considerations are important in designing castings, as outlined in Fig.

Corners, angles, and section thickness. Sharp corners, angles, and fillets should be avoided as much as possible, because they act as stress raisers and may cause cracking and tearing of the metal (as well as of the dies) during solidification. Fillet radii should be selected to reduce stress concentrations and to ensure proper liquid-metal flow during pouring.



Use radii or fillets to avoid corners and provide uniform cross-section.



Wall sections should be uniform.

Section changes in castings should be blended smoothly into each other. The location of the largest circle that can be inscribed in a particular region is critical so far as shrinkage cavities are concerned (Figs.a and b). Because the cooling rate in regions with larger circles is lower, these regions are called hot spots. They can develop shrinkage cavities and porosity (Figs.c and d). Cavities at hot spots can be eliminated by using small cores. Although they produce cored holes in the casting (Fig.e), these holes do not affect its strength significantly. It is important to maintain (as much as possible) uniform cross sections and wall thicknesses throughout the casting to avoid or minimize shrinkage cavities. Although they increase the cost of production, metal paddings or chills in the mold can eliminate or minimize hot spots (Fig .f)

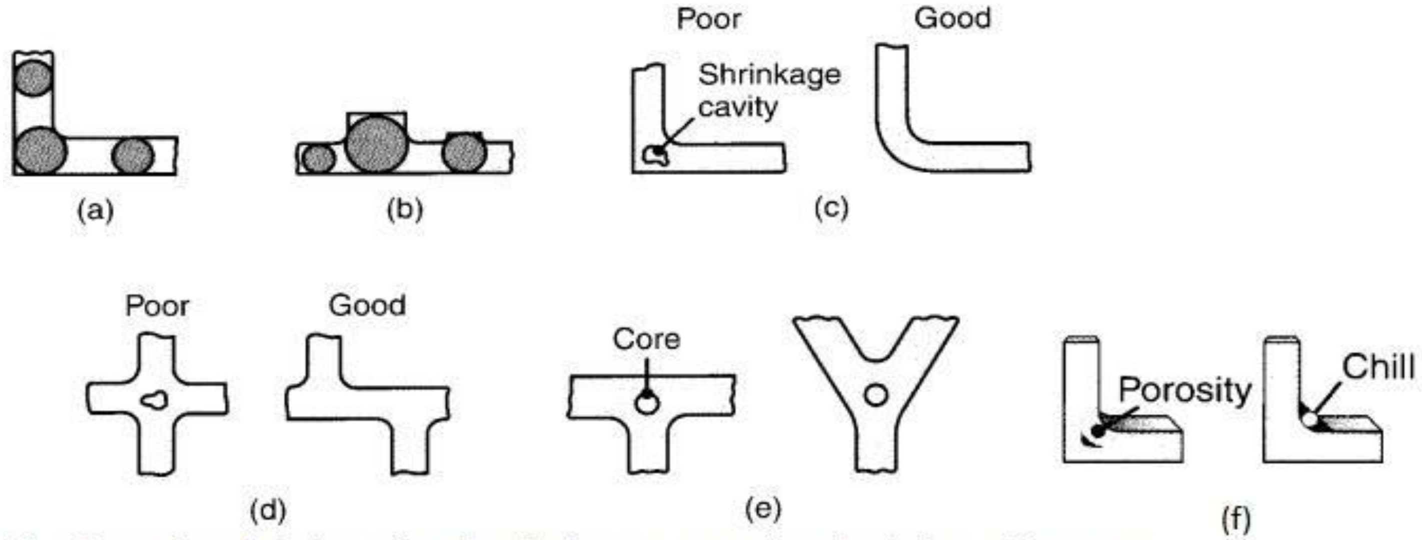


Fig : Examples of designs showing the importance of maintaining uniform cross sections in castings to avoid hot spots and shrinkage cavities.

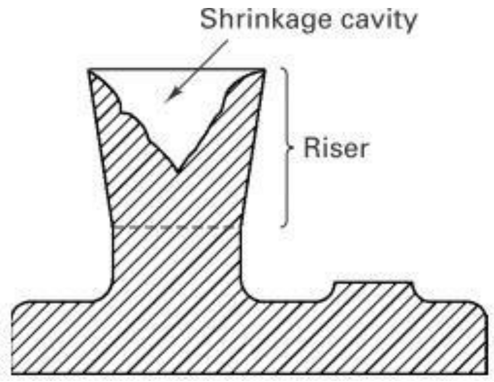


Fig : Attached risers can move the shrinkage cavity external to the actual casting

Flat areas : Large flat areas (plane surfaces) should be avoided, since they may Warp during cooling because of temperature gradients, or they develop poor surface finish because of an uneven flow of metal during pouring. One of the common techniques for avoiding either of these problems is to break up flat surfaces with staggered ribs and serrations.

Shrinkage : To avoid cracking of the casting during cooling, there should be allowances for shrinkage during solidification. In castings with intersecting ribs, the tensile stresses can be reduced by staggering the ribs or by changing the intersection geometry. Allowances for shrinkage, known as patternmaker's shrinkage allowances, usually range from about 10 to 20 mm/m.

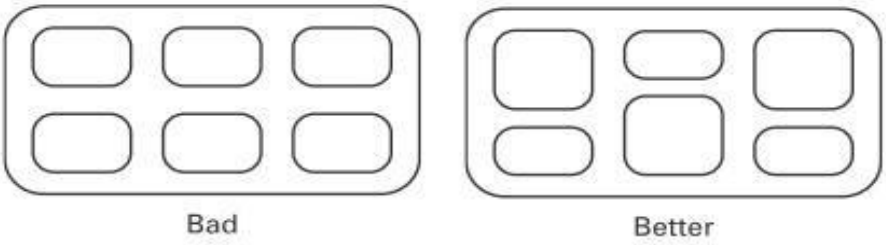
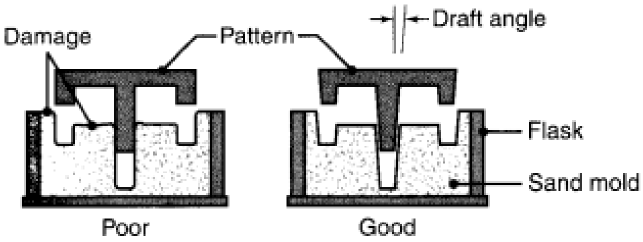


Fig : Using staggered ribs to prevent cracking during cooling

Draft : A small draft (taper) typically is provided in sand-mold patterns to enable removal of the pattern without damaging the mold (see Fig). Drafts generally range from 5 to 15 mm/m. Depending on the quality of the pattern, draft angles usually range from 0.5 ° to 2°.



Locating the Parting Line: A part should be oriented in a mold so that the large portion of the casting is relatively low and the height of the casting is minimized. Part orientation also determines the distribution of porosity. For example, in casting aluminum, hydrogen is soluble in liquid metal, but is not soluble as the aluminum solidifies. Thus, hydrogen bubbles can form during the casting of aluminum, float upwards due to buoyancy, and cause a higher porosity in the top parts of castings. Therefore, critical surfaces should be oriented so that they face downwards.

Avoid the causes of hot tears : Hot tears are casting defects caused by tensile stresses as a result of restraining a part of the casting. Figa and b shows locations where hot tears can occur and a recommended design that would eliminate their formation.

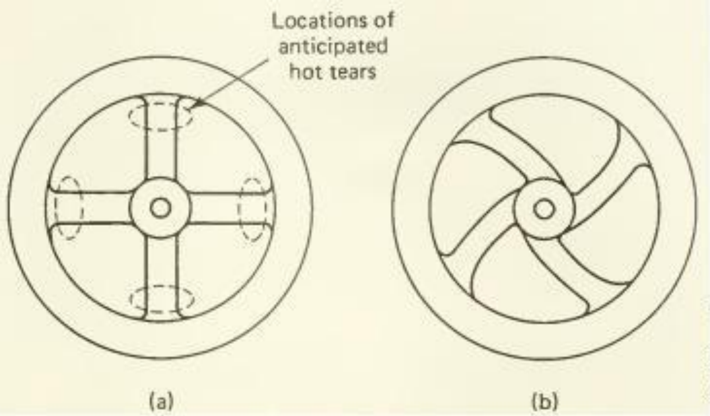


Fig : Hot tears: (a) a casting design that promotes hot tears; (b) recommended design to eliminate hot tears

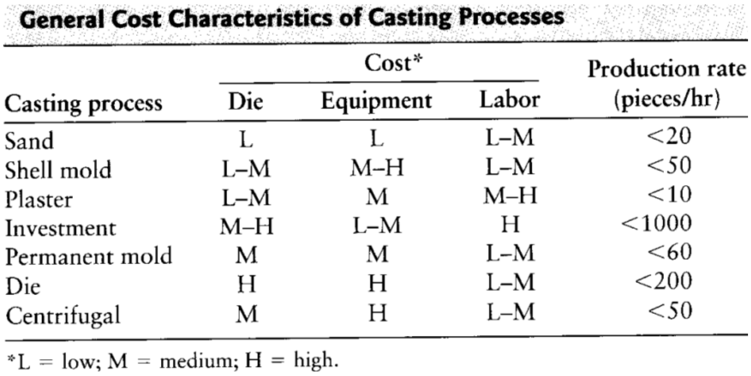
Casting Yield

Casting yield provides a direct measure of the relative success of individual casting methods in promoting metal economy.

$$\text{Casting yield} = \frac{\text{Weight of finished casting}}{\text{Weight of casting including gating and risering}} \times 100\ \%$$

Economics of Casting

As is the case with all manufacturing processes, the cost of each cast part (unit cost) depends on several factors, including materials, equipment, and labor. Some require more labor than others, some require expensive dies and machinery, and some require a great deal of time to produce the castings.



General Cost Characteristics of Casting Processes

Casting process	Cost*			Production rate (pieces/hr)
	Die	Equipment	Labor	
Sand	L	L	L–M	<20
Shell mold	L–M	M–H	L–M	<50
Plaster	L–M	M	M–H	<10
Investment	M–H	L–M	H	<1000
Permanent mold	M	M	L–M	<60
Die	H	H	L–M	<200
Centrifugal	M	H	L–M	<50

*L = low; M = medium; H = high.

Pouring Practice

Some type of pouring device, or ladle, is usually required to transfer the metal from the melting furnace to the molds. The primary considerations for this operation are (1) to maintain the metal at the proper temperature for pouring and (2) to ensure that only high-quality metal is introduced into the molds. The specific type of pouring ladle is determined largely by the size and number of castings to be poured. In small foundries, a handheld, shank- type ladle is used for manual pouring. In larger foundries, either bottom-pour or teapot-type ladles are used.

Cleaning and Finishing

After solidification and removal from the mold, most castings require some additional cleaning and finishing. Specific operations may include all or several of the following:

1. Removing cores 2. Removing gates and risers 3. Removing fins, flash, and rough spots from the surface 4. Cleaning the surface 5. Repairing any defects

Sand cores can usually be removed by mechanical shaking. At times, however, they must be removed by chemically dissolving the core binder. On small castings, sprues, gates, and risers can sometimes be knocked off. For larger castings, a cutting operation is usually required. Most nonferrous metals and cast irons can be cut with an abrasive cutoff wheel, power hacksaw, or band saw. Steel castings frequently require an oxy- acetylene torch. Plasma arc cutting can also be used.

After the gates and risers have been removed, small castings are often tumbled in barrels to remove fins, flash, and sand that may have adhered to the surface. Metal shot or abrasive material is often added to the barrel to aid in the cleaning. Extremely large castings usually require manual finishing, using pneumatic chisels, portable grinders, and manually directed blast hoses.

grinders, and manually directed blast hoses.

MODULE 2

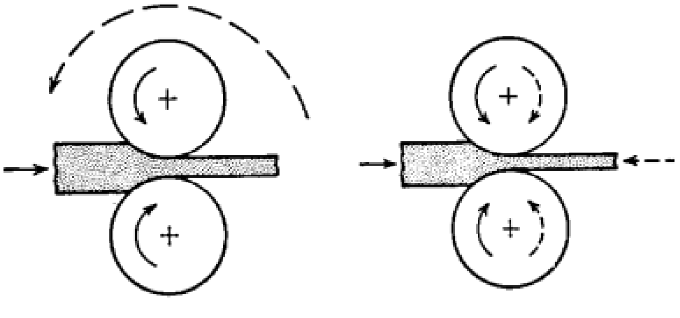
ROLLING

Rolling is the process of reducing the thickness or changing the cross section of a long work piece by compressive forces applied through a set of rolls. Rolling accounts for about 90% of all metals produced by metalworking.

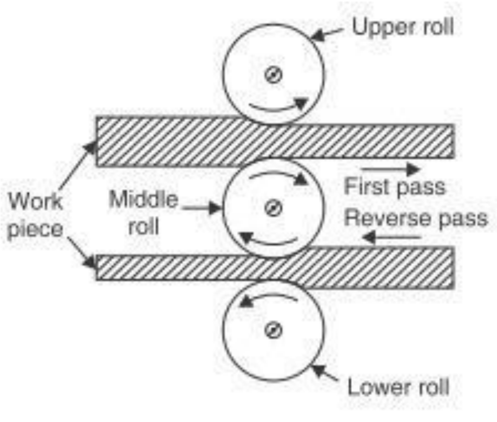
Rolling mills

A rolling mill consists of rolls , bearings , a housing for containing these parts , and a drive for applying power to the rolls and controlling their speed. Different types of rolling mills are described below in brief:

(i) Two high mills: It comprises of two heavy rolls placed one over the other. The vertical gap between the rolls is adjustable. The rolls rotate in opposite directions and are driven by powerful electrical motors. Usually the direction of rotation of rolls cannot be altered, thus the work has to be fed into rolls from one direction only. If rolling entails more than one 'pass' in the same set of rolls, the material will have to be brought back to the same side after the first pass is over. Since transporting material (which is in red hot condition) from one side to another is difficult and time consuming (material may cool in the meantime), a ''two high reversing mill'' has been developed in which the direction of rotation of rolls can be changed. This facilitates rolling of material by passing it through back and forth passes.


(a) (b)

(ii) Three high mills: It consists of three rolls positioned directly over one another as shown. The direction of rotation of the first and second rolls are opposite as in the case of two high mill. The direction of rotation of second and third rolls are again opposite to each other.



(b) A three high rolling mill

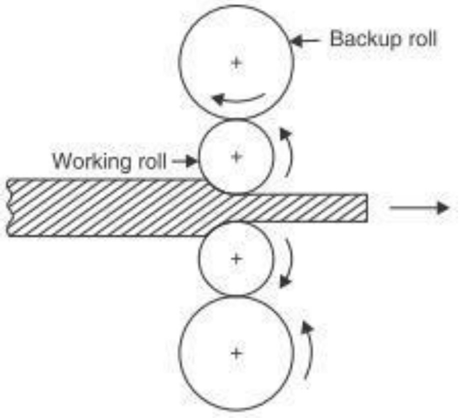
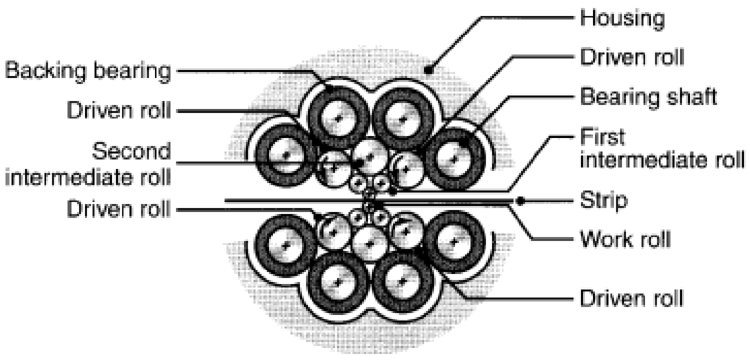


Fig. 3.4 Four high mill

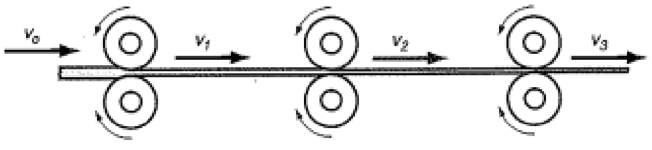
(iii) Four high mills: This mill consists of four horizontal rolls, two of smaller diameter and two much larger ones. The larger rolls are called backup rolls. The smaller rolls are the working rolls, but if the backup rolls were not there, due to deflection of rolls between stands, the rolled material would be thicker in the centre and thinner at either end.

(iv) Cluster mills: It consists of two working rolls of small diameter and four or more backing rolls. The large number of backup rolls provided becomes necessary as the backup rolls cannot exceed the diameter of working rolls by more than 2–3 times. To accommodate processes requiring high rolling loads (e.g., cold rolling of high strength steels sheets), the size of working rolls becomes small. So does the size of backup rolls and a stage may be reached that backup rolls themselves may offer deflection. So the backup rolls need support or backing up by further rolls. In the world famous SENDZIMIR MILL, as many as 20 backup rolls are used in the cluster. This mill is used for rolling stainless steel and other high strength steel sheets of thin gauge.



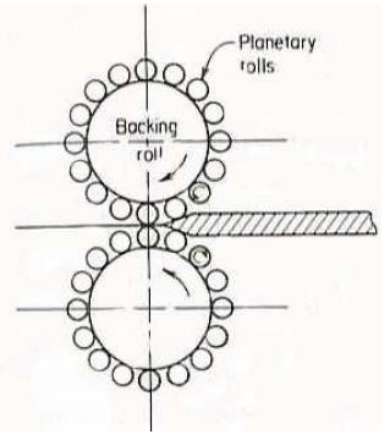
(d)

(v) Tandem rolling mill : This mill consists of a series of rolling stands . This not only reduces the handling of coils between multiple passes, but can also reduce the coil storage space required in rolling works.



(e)

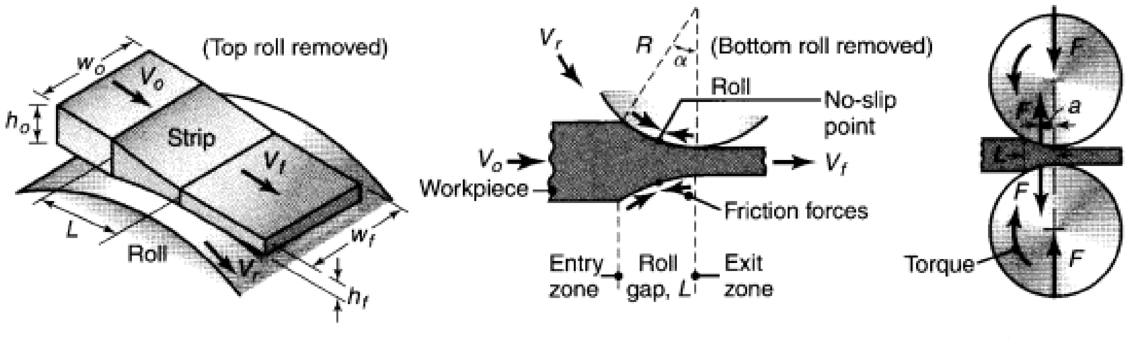
(vi) planetary mill : This mill consists of a pair of heavy back up rolls surrounded by a large number of small planetary rolls.



Flat-rolling

A metal strip of thickness h_0 enters the roll gap and is reduced to thickness h_f by a pair of rotating rolls, each powered individually by electric motors. The surface speed of the rolls is V_r. The velocity of the strip increases from its entry value of VO as it moves through the roll gap; the velocity of the strip is highest at the exit from the roll gap and is denoted as V_f. The metal accelerates in the roll gap in the same manner as an incompressible fluid flowing through a converging channel.

Because the surface speed of the rigid roll is constant, there is relative sliding between the roll and the strip along the arc of contact in the roll gap, L. At one point along the contact length (called the neutral point or no-slip point) the velocity of the strip is the same as that of the roll. To the left of this point, the roll moves faster than the strip; to the right of this point, the strip moves faster than the roll. Consequently, the frictional forces--which oppose motion between two sliding bodies-act on the strip as shown in Fig.b.



The rolls pull the material into the roll gap through a net frictional force on the material. Thus, the net frictional force must be to the right in Fig.b. This also means that the frictional force to the left of the neutral point must be higher than the friction force to the right. Although friction is necessary for rolling materials (just as it is in driving a car on a road), energy is dissipated in overcoming friction. Thus, increasing friction also increases rolling forces and power requirements. Furthermore, high friction could damage the surface of the rolled product (or cause sticking, as can occur in rolling dough). Thus, a compromise is made in practice: Low and controlled friction is induced in rolling through the use of effective lubricants.

Forward slip

$$s = \frac{(V_f - V_r)}{V_r}$$

Roll pressure distribution

Roll pressure , $p = C Y_f \frac{h}{R} e^{\mp\mu K}$,

Where $H = 2\sqrt{\frac{R}{h_f}}\tan^{-1}\left(\sqrt{\frac{R}{h_f}}\,\phi\right)$

At entry , $\varphi = \alpha$ hence , $H = H_O$ with φ replaced by α . At exit , $\varphi = 0$; hence , $H = H_f = 0$. Also , at entry and exit , $p = Y_f$

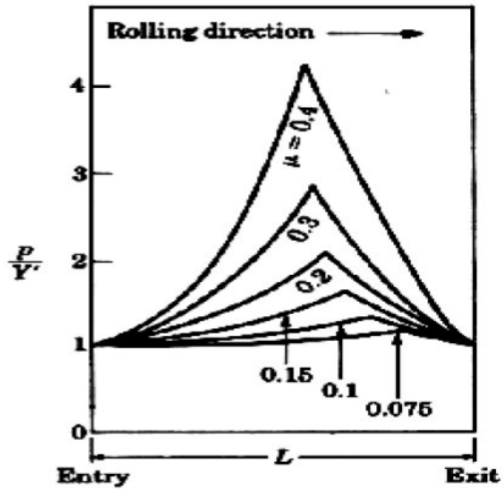
. Thus in the entry zone ,

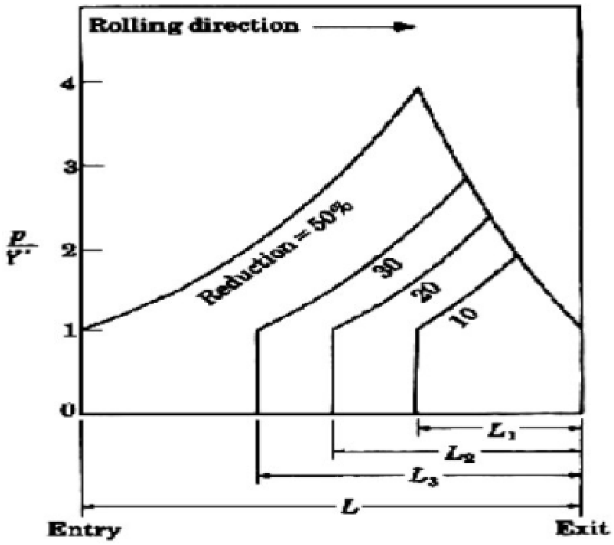
$C = \frac{R}{h} e^{\mu K}$ and $p = Y_f \frac{h}{h} e^{\mu(K-K)}$

In the exit zone , $C = \frac{R}{h}$, and hence , $p = Y_f \frac{h}{h} e^{\mu K}$

Note that the pressure p at any location in the roll gap is a function of h and its angular position φ along the arc of contact. These expressions also indicate that the pressure increases with increasing strength of the material , increasing coefficient of friction ,and increasing R/h ratio. The R/h ratio in rolling is equivalent to the a/h ratio in upsetting.

Pressure distribution (friction hill) in the roll gap is shown in the fig. Neutral point shift towards exit as friction decreases.





The effect of reduction in thickness of the strip on the pressure distribution is shown in fig. As reduction increases , the length of contact in the roll gap increases , in turn increasing the peak pressure .

Determining the location of neutral point

$\phi_n = \sqrt{\frac{h}{R}}\tan\left[\sqrt{\frac{h}{R}}\,\frac{H_n}{2}\right]$, where $H_n = \frac{1}{2}\left[H_0 - \frac{1}{\mu}\ln\frac{h}{h}\right]$

Roll Force, Torque, and Power Requirements

The roll force in flat rolling can be estimated from the formula :

$$F = L\,w\,Y_{avg}$$

where L is the roll-strip contact length, w is the width of the strip, and Y_{avg} is the average true stress

The equation is for a frictionless situation; however, an estimate of the actual roll force, including friction, may be made by increasing this calculated force by about 20%.

The torque on the roll is the product of F and a. The power required per roll can be estimated by assuming that F acts in the middle of the arc of contact; thus, in Fig.c, a = L/2. Therefore, the total power (for two rolls), is

$$\text{Power (in Kw)} = \frac{2nFLN}{60,000}$$

Reducing Roll Force

Roll forces can be reduced by the following means:

(a) Reducing friction at the roll-workpiece interface (b) Using smaller diameter rolls to reduce the contact area (c) Taking smaller reductions per pass to reduce the contact area (d) Rolling at elevated temperatures to lower the strength of the material (e) Applying front and/or back tensions to the strip

Front and back tension

The apparent compressive yield stress of the material can be reduced by applying longitudinal tension. Tensile forces in rolling can be applied either at the entry (back tension ,σ_b) or at the exit (front tension , σ_f).

Entry zone , $p = (Y_f - \sigma_b)\frac{h}{h} e^{\mu(K-K)}$, exit zone , $p = (Y_f - \sigma_f)\frac{h}{h} e^{\mu K}$

Depending on the relative magnitude of the tensile stresses applied, the neutral point may shift. This shift affects the pressure distribution ,torque, and power requirements in rolling. Tensions are particularly important in rolling thin

,high-strength materials , because such materials requires high roll forces. Front tension in practice is controlled by the torque on the coiler (delivery reel) ,around which the rolled sheet is coiled.Back tension is controlled by a braking system in the uncoiled (payoff reel).

Hot rolling

During hot working several Strain hardening (or work hardening) can occur as a result of an increase in dislocation density. However, because of the elevated temperature, sufficient internal energy may be available to initiate dynamic recovery or dynamic recrystallization. Both dynamic recovery and recrystallization serve to annihilate dislocations, causing softening. The combined effect of dynamic recovery/recrystallization is to lower the stress required for deformation. High temperature deformation properties of metals are dependent on the rate or time during which strain is applied. So, in hot rolling flow stress is calculated from the equation , σf = Cεm

The average strain rate, $\varepsilon = \frac{V}{L}\ln[\frac{h}{h}]$

Cold rolling

Cold rolling is carried out at room temperature and, compared with hot rolling, produces sheets and strips With a much better surface finish (because of lack of scale), better dimensional tolerances, and enhanced mechanical properties(because of strain hardening). However, it requires more energy (because of the higher strength of the material at room temperature) and will result in a product with anisotropic properties.

Friction in rolling

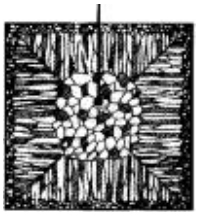
Without friction the rolls cannot pull the strip into the roll gap. On the other hand forces and power requirements will rise as friction increases. In cold rolling μ = 0.02 – 0.3 , depending on the material and lubricants. In hot rolling, μ = 0.2(with effective lubrication) – 0.7(indicating sticking, typically for steels, stainless steels, and high temperature alloy).

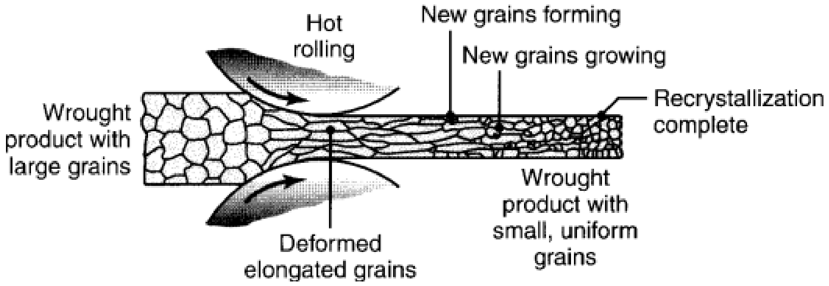
The maximum possible draft, $h_o - h_f$, is a function of friction and radius as $(h_o - h_f)_{max} = \mu^2R$

The higher the friction coefficient and the larger the roll radius , the greater is the maximum draft.

Flat-rolling Practice

The initial rolling steps (breaking down) of the material typically is done by hot rolling. A cast structure typically is dendritic, and it includes coarse and non uniform grains; this structure usually is brittle and may be porous. Hot rolling converts the cast structure to a wrought structure with finer grains and enhanced ductility, both of which result from the breaking up of brittle grain boundaries and the closing up of internal defects (especially porosity).





The product of the first hot-rolling operation is called a bloom, a slab, or a billet. A bloom usually has a square cross section, at least 150 mm on the side; a slab usually is rectangular in cross section. Blooms are processed further by shape rolling into structural shapes such as I-beams and railroad rails. Slabs are rolled into plates and sheets.
Billets usually are square (With a cross-sectional area smaller than blooms) and later are rolled into various shapes, such as round rods and bars, using shaped rolls. Hot-rolled round rods (wire rods) are used as the starting material for rod- and wire-drawing operations.

In the hot rolling of blooms, billets, and slabs, the surface of the material usually is conditioned (prepared for a subsequent operation) prior to rolling them. Conditioning is often done by means of a torch (scarfing) to remove heavy scale or by rough grinding to smoothen surfaces. Prior to cold rolling, the scale developed during hot rolling may be removed by pickling with acids (acid etching), by such mechanical means as blasting with Water, or by grinding to remove other defects as well.

Pack rolling is a flat-rolling operation in which two or more layers of metal are rolled together, thus improving productivity. Aluminum foil, for example, is pack rolled in two layers, so only the top and bottom outer layers have been in contact with the rolls. Note that one side of aluminum foil is matte, While the other side is shiny. The foil-to-foil side has a matte and satiny finish, but the foil-to-roll side is shiny and bright because it has been in contact under high contact stresses with the polished rolls during rolling.

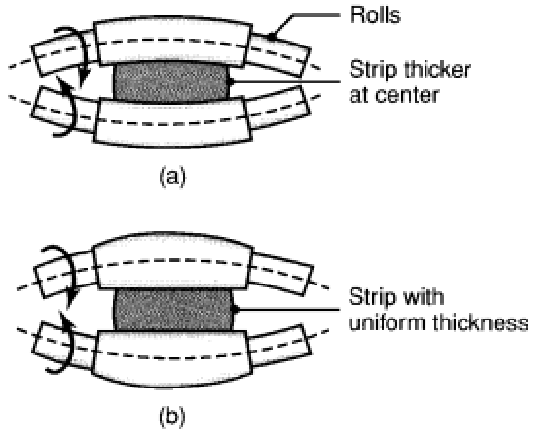
Rolled mild steel, when subsequently stretched during sheet-forming operations, undergoes yield-point elongation a phenomenon that causes surface irregularities called stretcher strains or Luder’s bands. To correct this situation, the sheet metal is subjected to a final, light pass of 0.5 to 1.5% reduction known as temper rolling or skin pass shortly before stretching.

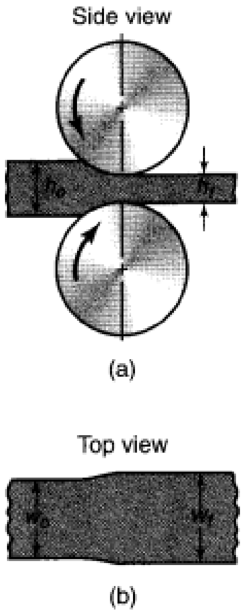
A rolled sheet may not be sufficiently flat as it leaves the roll gap, due to factors such as variations in the incoming material or in the processing parameters during rolling. To improve flatness, the rolled strip typically goes through a series of leveling rolls.

Roll deflection and flattening

Roll forces tend to bend the rolls elastically during rolling. As a result of roll bending, the rolled strip tends to be thicker at its center than at its edges (crown). The usual method of avoiding this problem is to grind the rolls in such a way that their diameter at the center is slightly larger than at their edges (camber). Because of the heat generated by plastic deformation during rolling, rolls can become slightly barrel shaped (thermal camber). Unless compensated for by some means, this condition can produce strips that are thinner at the center than at the edges. Roll forces also tend to flatten the rolls elastically, producing an effect much like the flattening of automobile tires under load.

Flattening of the rolls is undesirable, as it results, in effect, in a larger roll radius. This, in turn, means a larger contact area for the same draft, and the roll force increases because of the now larger contact area.





Spreading

In rolling plates and sheets with high width-to-thickness ratios, the width of the strip remains effectively constant during rolling. However, with smaller ratios (such as a strip with a square cross section), its width increases significantly as it passes through the rolls (an effect commonly observed in the rolling of dough with a rolling pin). This increase in width is called spreading. It can be shown that spreading increases with (a) decreasing width-to- thickness ratio of the entering strip (because of reduction in the width constraint), (b) increasing friction, and (c) decreasing ratio of the roll radius to the strip thickness. The last two effects are due to the increased longitudinal constraint of the material flow in the roll gap. Spreading can be prevented also by using additional rolls (with vertical axes) in contact with the edges of the rolled product in the roll gap (edger mills), thus providing a physical constraint to spreading.

Defects in Rolled Plates and Sheets

1. Surface defects: Surface defects include rusting and scaling, surface scratches, surface cracks, pits left on the surface of due to subsequent detachment or removal of scales which may have been pressed into the surface.

2. Structural defects :

Wavy edges : These are the result of roll bending. The strip is thinner along its edges than at its center ; thus, the edges elongate more than the center. This causes tensile stress in the centre and compressive stress in the edges. Consequently, the edges buckle because they are constrained by the central region from expanding freely in the longitudinal (rolling) direction.

Zipper cracks : These are also the result of roll bending.The tensile stress in the centre causes zipper cracks .

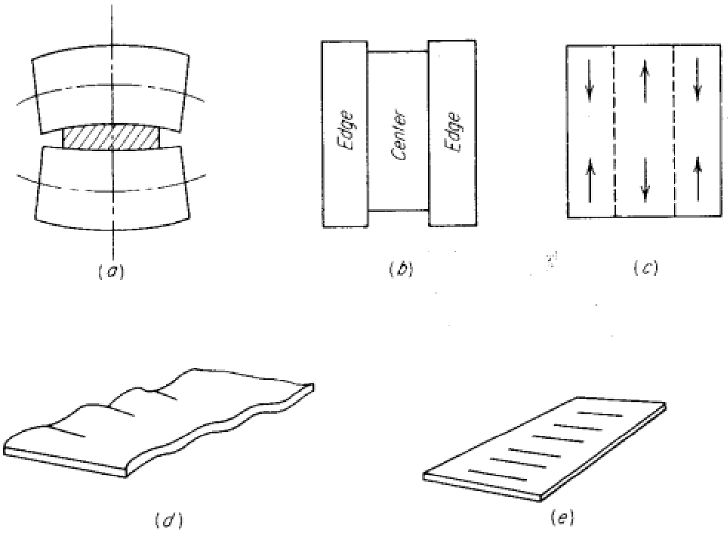


Figure 17-9 Consequences of roll bending to produce long edge.

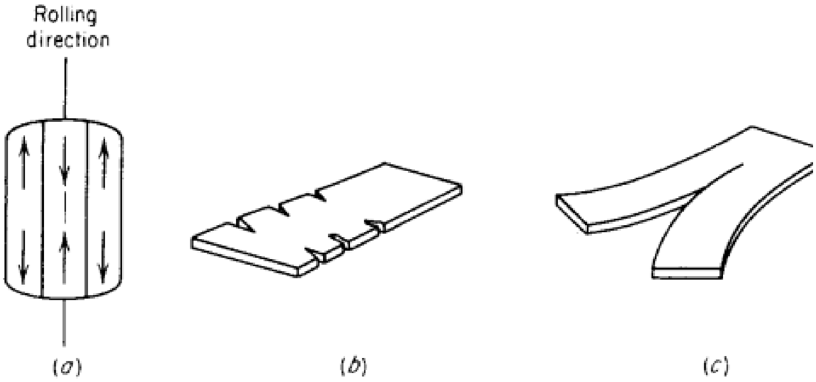
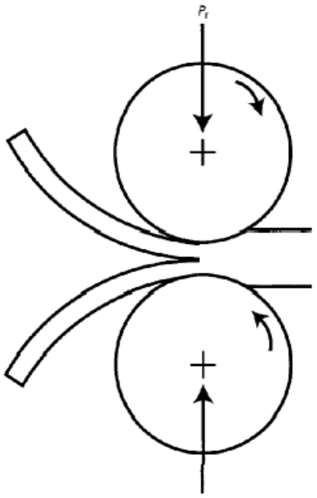


Figure 17-10 Defects resulting from lateral spread.

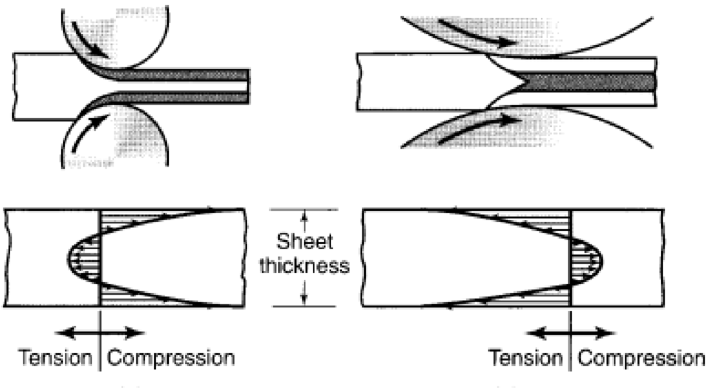


Edge cracks & center split: As the work piece passes through the rolls all elements across the width experience some tendency to expand laterally (in the transverse direction of the sheet). The tendency for lateral spread is opposed by transverse friction forces. Because of the friction hill, these are higher toward the center of the sheet so that the elements in the central region spread much less than the outer elements near the edge. Because the thickness decrease in the center of the sheet all goes into a length increase, while part of the thickness decrease at the edges goes into lateral spread, the sheet may develop a slight rounding at its ends (Fig. 17.10a). Because there is continuity between the edges and center, the edges of the sheet are strained in tension, a condition which leads to edge cracking (Fig. 17.10b). Under severe conditions the strain distribution shown in Fig. 17.10a can result in a center split of the sheet (Fig. 17.10c).

Alligatoring : It will occur when lateral spread is greater in the centre than the surface (surface in tension, centre in compression) and with the presence of metallurgical weakness along the centerline.

Residual Stresses in rolled metals

Because of non uniform deformation of the material in the roll gap, residual stresses can develop in rolled plates and sheets, especially during cold rolling. Small-diameter rolls or small thickness reductions per pass tend to plastically deform the metal more at its surfaces than in the bulk (Fig. 13.9a). This situation results in compressive residual stresses on the surfaces and tensile stresses in the bulk. Conversely, large-diameter rolls or high reductions per pass tend to deform the bulk more than the surfaces (Fig. 13.9b). This is due tothe higher frictional constraint at the surfaces along the arc of contact- a situation that produces residual stress distributions that are the opposite of those with small-diameter rolls.



Friction during deformation

As the forces required for bulk deformation are large , the die-workpiece friction forces can be significant. The forces

c_i

at the die-workpiece interface are usually described by coefficient of friction, defined as : $\mu = \frac{c_i}{p}$

v_i is the average interface frictional shear stress , p is the normal pressure (die pressure)

This definition of friction coefficient implies that the frictional force is proportional to the normal force and that there must be relative movement between the die and work- piece surfaces. Interfaces at which these conditions exist undergo *slipping friction*. If the coefficient of friction becomes large enough, a condition known as *sticking* occurs. Sticking in metalworking (also called *sticking friction*) is the tendency

for the two surfaces in relative motion to adhere to each other rather than slide. It means that the interface frictional shear stress between the surfaces exceeds the shear flow stress of the work metal ($v_i › v_W$) , thus causing the metal to deform by a shear process beneath the surface rather than slip at the surface.

Sticking friction represents an upper limit to the interface stresses that can exist. Deformation with sticking friction usually requires greater energy and, because localized internal shearing of the workpiece occurs, results in less deformation homogeneity compared to slipping friction. For these reasons it is usually desirable to avoid sticking friction during bulk deformation processes.

Lubrication to reduce friction

Lubricants serve to separate the die and workpiece surfaces, thereby reducing friction. The functions of a metalworking lubricant are : (1)Reduces deformation load, (2) Increases limit of deformation before fracture(3) Controls surface finish (4)Minimizes metal pickup on tools (5) Minimizes tool wear (6) Thermally insulates the workpiece and the tools (7) Cools the workpiece and/or the tools

Several lubrication mechanisms used in deformation are

1) Hydrodynamic lubrication

This is effective when there is a large relative velocity between the two surfaces. In such instances a continuous film of lubricant can be maintained between the two surfaces, the friction coefficient is greatly reduced and wear is almost eliminated. A familiar example of a hydrodynamically lubricated assembly is the journal bearings associated with automotive crankshafts. It is the bulk properties of the lubricant, such as viscosity, that controls the friction and wear. Hydrodynamic lubrication can be achieved and is desirable during drawing but,

, it can be undesirable during rolling operations. Hydrodynamic lubricants are most commonly formulated from a base of predominantly mineral oils.

2) Boundary lubrication

Boundary lubrication relies on a thin film of lubricant only a few molecules thick, so that the two surfaces are in contact at asperities only. Boundary lubricants are formulated from organic substances, such as fatty acids and soaps, that consist of long polar molecules that attach to, and sometimes chemically react with, the die or workpiece surface. The thin boundary films are effective at separating surfaces even under large normal forces. Boundary lubricants are most effective at low temperatures, as the long molecules break down with increasing temperature.

They can be used separately or can be formulated into mineral oil-based lubricants.

3) Mixed film lubrication

A combination of hydrodynamic and boundary lubrication, mixed film lubrication is of particular significance for metal processing lubricants. They are often mineral oil-based with additives designed to provide boundary lubrication. Such lubricants are useful to reduce friction between irregular surfaces, as illustrated in Fig.4.2.

Near asperities, where die-workpiece contact may occur, boundary lubrication predominates, but in other regions a hydrodynamic layer is created. This hydrodynamic layer can support large loads, as the incompressible lubricant is trapped in local pockets between asperities. The relative proportion of hydrodynamic to boundary lubrication that occurs depends on the lubricant viscosity and relative velocity between the die and workpiece.

4) Solidfilm lubrication

This relies on low shear strength solids to separate the die and workpiece. Unlike hydrodynamic lubricants, solid films are effective when the relative velocity between the die and workpiece is low and, unlike boundary lubricants, solids remain effective to high temperatures. Several solids have been used as metalworking lubricants, including graphite, molybdenum disulfide and a variety of glasses. Solids are particularly useful for lubrication during hot forging.

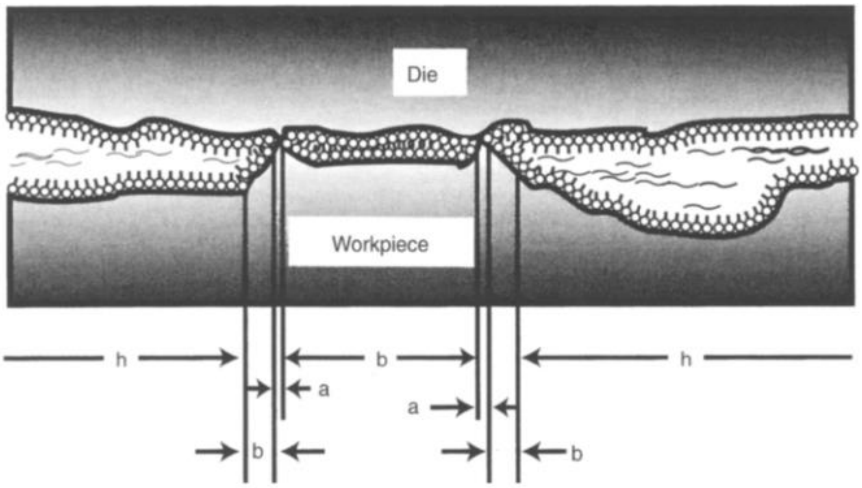
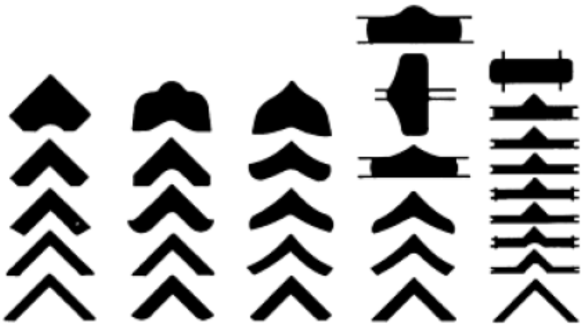


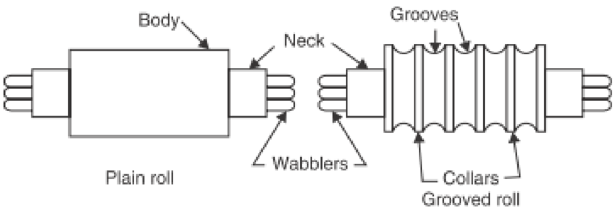
Fig. 4.2 Mixed film lubrication between die and workpiece: 'a' identifies regions of asperity contact, 'b' identifies boundary lubricated regions and 'h' identifies hydrodynamically lubricated regions.

Roll and roll pass design

Two types of rolls—Plain and Grooved are shown in Fig. Rolls used for rolling consists of three parts viz., body, neck and wabbler. The necks rest in the bearings provided in the stands and the star shaped wabblers are connected to the driving shaft through a hollow cylinder. Wabbler acts like a safety device and saves the main body of the roll from damage if too heavy a load causes severe stresses. The actual rolling operation is performed by the body of the roll.

Bars, rods and sections are produced by passing the work between the rolls having grooves cut in them. The shape to be produced on the workpiece when cut into one roll is called the groove. The shape formed when the grooves of mating rolls are matched together is called the pass.





Various passes fall into the following groups s: (i) Breakdown or roughing passes,(ii) Leader passes, and (iii) Finishing passes. Breakdown passes are meant to reduce the cross-sectional area. The leader passes gradually bring the cross-section of the material near the final shape. The final shape and size is achieved in finishing passes.
Allowance for shrinkage on cooling is given while cutting the finishing pass grooves.

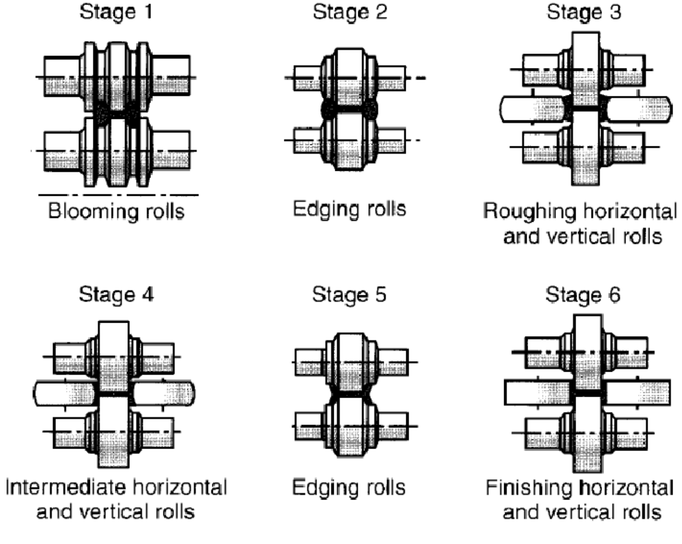
Considerations in roll pass design

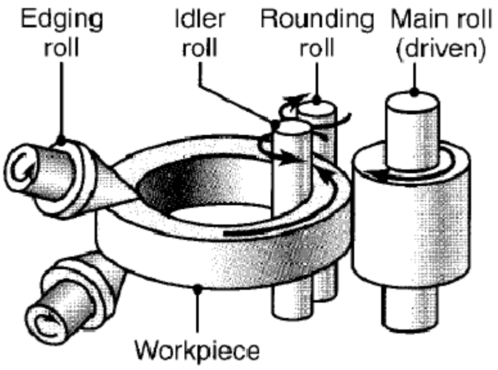
- Space should be provided in the pass for the spread of metal, otherwise the metal will be forced in to the clearance between the rolls and fins will be formed on the final product.
- In order to avoid jamming of the bar in pass, the vertical side wall of the pass are slightly inclined in reference to the roll axis.
- The relative draft ratio = $\left(\frac{h_o - h_f}{h_o}\right) x\ 100$ is to be found out .

Other processes related to rolling

Shape Rolling

Straight and long structural shapes (such as channels, I-beams, railroad rails, and solid bars) are formed at elevated temperatures by shape rolling (profile rolling), in which the stock goes through a set of specially designed rolls



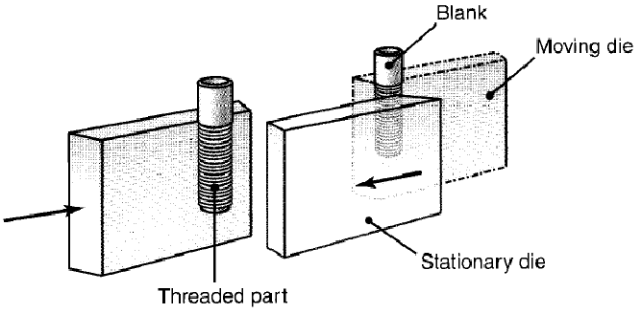


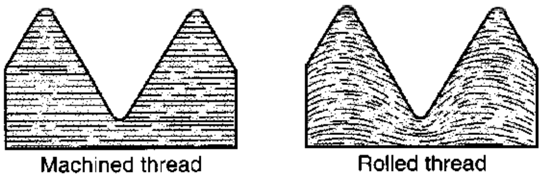
Ring Rolling

In ring rolling, a thick ring is expanded into a large-diameter thinner one. The ring is placed between two rolls, one of which is driven while the other is idle. Its thickness is reduced by bringing the rolls closer together as they rotate.

Thread Rolling

Thread rolling is a cold-forming process by which straight or tapered threads are formed on round rods or wire. The threads are formed on the rod or wire with each stroke of a pair of flat reciprocating dies. In another method, threads are formed with rotary dies, at production rates as high as 80 pieces per second. Typical products are screws, bolts, and similar threaded parts.



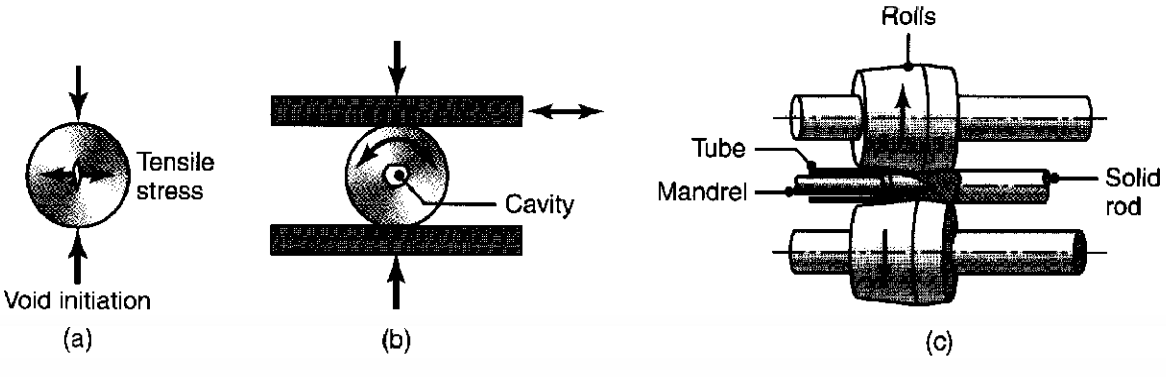


The thread-rolling process has the advantages of generating threads with good strength (due to cold working) and without any loss of material (scrap). The surface finish produced is very smooth, and the process induces compressive residual stresses on the work piece surfaces, thus improving fatigue life. Thread rolling is superior to other methods of thread manufacture, because machining the threads cuts through the grain-flow lines of the material, whereas rolling the threads results in a grain-flow pattern that improves the strength of the thread.

Rotary Tube Piercing (Mannesmann process)

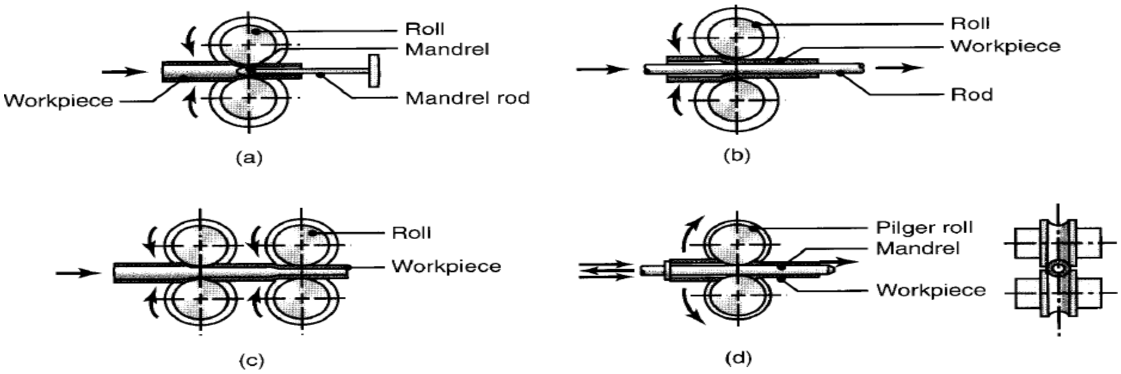
This is a hot working operation for making long, thick-Walled seamless pipe and tubing. This process is based on the principle that when a round bar is subjected to radial compressive forces, tensile stresses develop at the center of the bar. When it is subjected continuously to these cyclic compressive stresses, the bar begins to develop a small cavity at its center, which then begins to grow. Rotary tube piercing is carried out using an arrangement of rotating rolls. The axes of the rolls are skewed in order to pull the round bar through the rolls by the axial component of the rotary motion. An internal mandrel assists the operation by expanding the hole and sizing the inside diameter of the tube.

The mandrel may be held in place by a long rod, or it may be a floating mandrel without a support. Because of the severe deformation that the bar undergoes, the material must be high in quality and free from defects (since internal defects may propagate rapidly and cause premature failure of the part during forming).



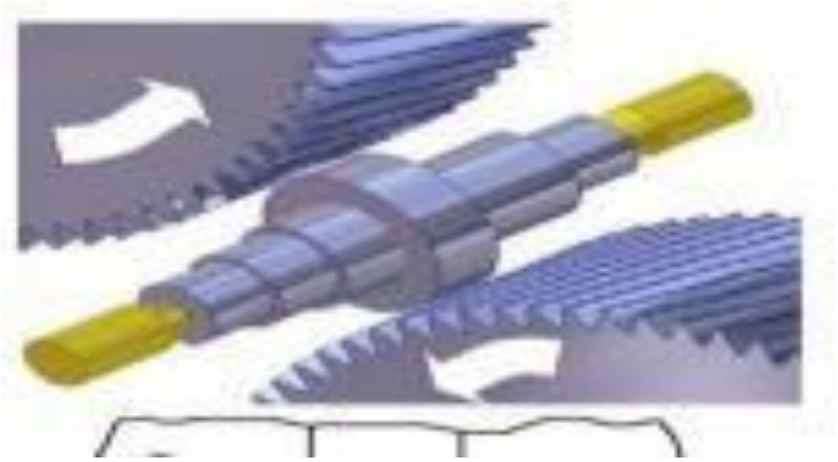
Tube Rolling

The diameter and thickness of pipes and tubing can be reduced by tube rolling, which utilizes shaped rolls. Some of these operations can be carried out either with or without an internal mandrel. In the pilger mill, the tube and an internal mandrel undergo a reciprocating motion; the rolls are specially shaped and are rotated continuously. During the gap cycle on the roll, the tube is advanced and rotated, starting another cycle of tube reduction. As a result, the tube undergoes a reduction in both diameter and Wall thickness. Steel tubing of 265 mm in diameter have been produced by this process.



Gear rolling

Gear rolling is a cold working process. The automotive industry is an important user of these products. Advantages of gear rolling compared to machining are: higher production rates, better strength and fatigue resistance, and less material waste.



MODULE 3

STRESS-STRAIN CURVES

A typical deformation sequence in a tension test is shown in Fig. 2.1b. When the load is first applied, the specimen elongates in proportion to the load, called linear elastic behavior (Fig. 2.2). If the load is removed, the specimen returns to its original length and shape, in a manner similar to stretching a rubber band and releasing it.

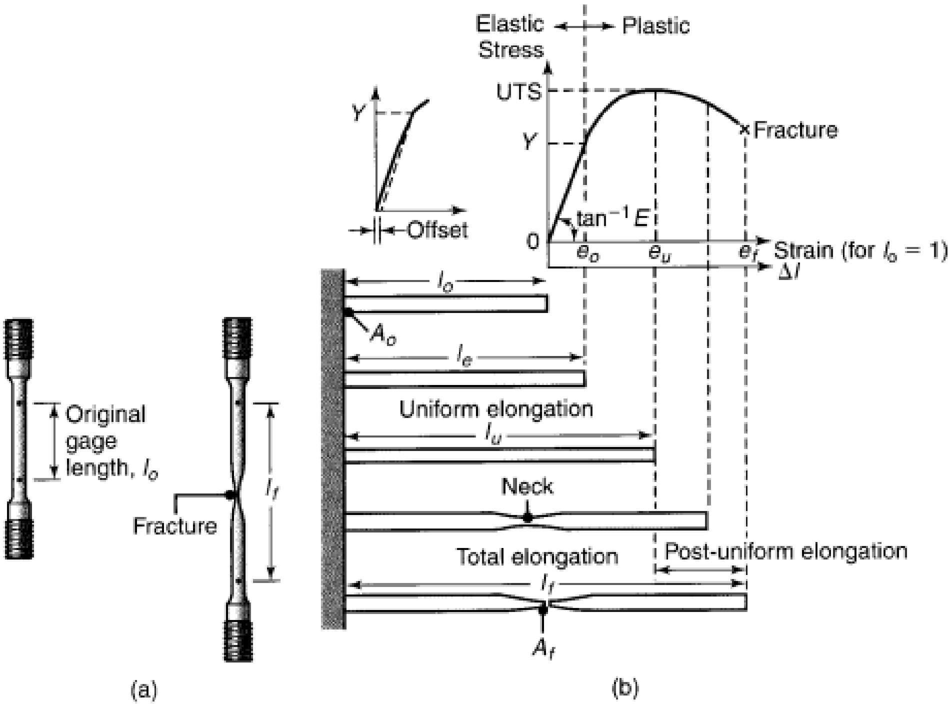


FIGURE 2.1 (a) A standard tensile-test specimen before and after pulling, showing original and final gage lengths. (b) Stages in specimen behavior in a tension test.

The engineering stress (nominal stress) is defined as the ratio of the applied load P to the original cross- sectional area, A_O, of the specimen:

$$\sigma = P / A_O$$

The engineering strain is defined as :

$$e = (l - l_o) / l_0$$

where l is the instantaneous length of the specimen.

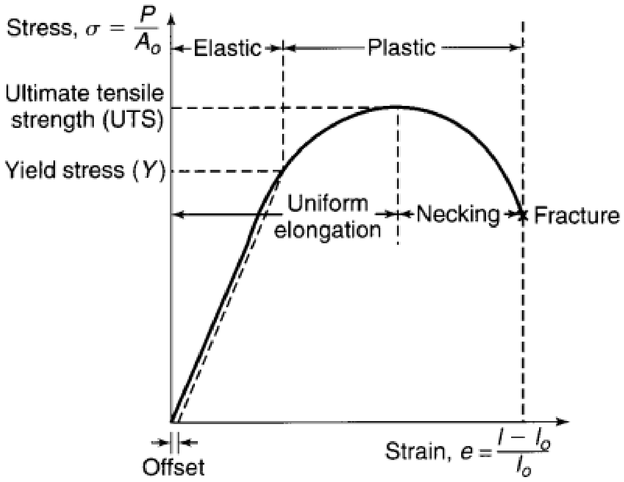


FIGURE 2.2 A typical stress–strain curve obtained from a tension test, showing various features.

As the load is increased, the specimen begins to undergo nonlinear elastic deformation at a stress called the proportional limit. At that point, the stress and strain are no longer proportional, as they were in the linear elastic region, but when unloaded, the specimen still returns to its original shape. Permanent (plastic) deformation occurs when the yield stress, Y, of the material is reached. As the load is increased further, the engineering stress eventually reaches a maximum and then begins to decrease (Fig. 2.2). The maximum engineering stress is called the tensile strength, or ultimate tensile strength (UTS), of the material. Beyond point E localized deformation starts. Point E is called instability point. The yield point defines the minimum stress required to cause plastic deformation and instability point represents maximum strain a material can withstand before the onset of necking or localized plastic deformation. The strain at the onset of localized deformation (instability) is sometimes used as an index of the formability of the material.

If the specimen is loaded beyond its ultimate tensile strength, it begins to neck. The cross- sectional area of the specimen is no longer uniform along the gage length and is smaller in the necked region. As the test progresses, the engineering stress drops further and the specimen finally fractures at the necked region (Fig. 2.1a); the engineering stress at fracture is known as the breaking or fracture stress.

The ratio of stress to strain in the elastic region is the modulus of elasticity, E, or Young's modulus

$$E = \sigma / e$$

This linear relationship is known as Hooke's law.

The modulus of elasticity is the slope of the elastic portion of the curve and hence the stiffness of the material. The higher the E value, the higher is the load required to stretch the specimen to the same extent, and thus the stiffer is the material. Compare, for example, the stiffness of metal wire with that of a rubber band or plastic sheet when they are loaded.

The elongation of the specimen under tension is accompanied by lateral contraction; this effect can easily be observed by stretching a rubber band. The absolute value of the ratio of the lateral strain to the longitudinal strain is known as Poisson's ratio and is denoted by the symbol γ.

True Stress and True Strain

Engineering stress is based on the original cross-sectional area, AO, of the specimen. However, the instantaneous cross-sectional area of the specimen becomes smaller as it elongates, just as the area of a rubber band does; thus, engineering stress does not represent the actual stress to which the specimen is subjected.

True stress is defined as the ratio of the load, R to the actual (instantaneous, hence true) cross-sectional area, A, of the specimen:

$$\sigma = P / A$$

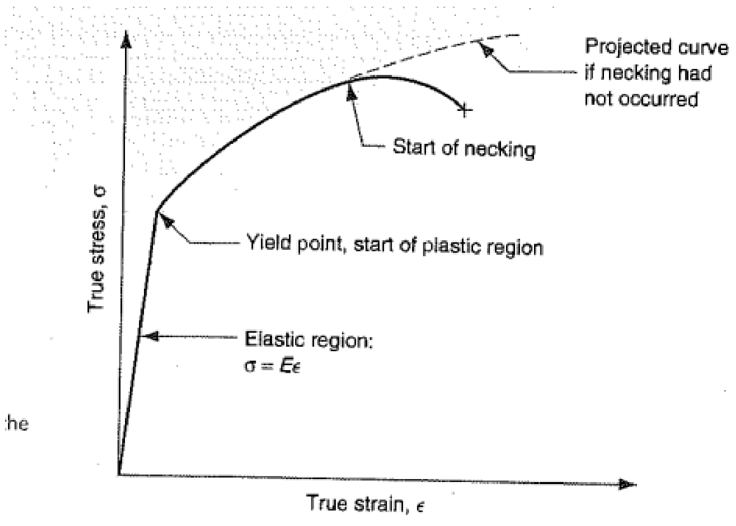
For true strain, first consider the elongation of the specimen as consisting of increments of instantaneous change in length. i e , true strain is defined as the summation of incremental strain :

S S

$\bar{S}$

$$\varepsilon = \int dl/l = ln$$

l_o = original length , l = current length



The true stress-true strain curve can be represented by the equation

$$\sigma = K\varepsilon^n$$

Where K is the strength coefficient and n is the strain-hardening (or work-hardening) exponent.

This equation is called the flow curve, and it provides a good approximation of the behavior of metals in the plastic region, including their capacity for strain hardening.

When the curve shown above is plotted on a log-log graph, it is found that the curve is approximately a straight line. The slope of the curve is equal to the exponent n. Thus, the higher the slope, the greater is the strain-hardening capacity of the material--that is, the stronger and harder it becomes as it is strained. Note that K is the true stress at a true strain of unity.

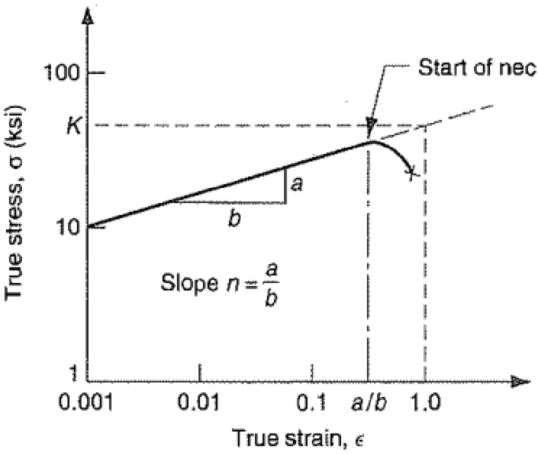


FIGURE 3.5 True stress–strain curve plotted on log–log scale.

Y_f is known as flow stress and is defined as the true stress required to continue plastic deformation at a particular strain or the instantaneous value of stress to keep the metal "flowing". It is the yield strength of a material as a function of strain, which can be expressed as

$$Y_f = K\varepsilon^n$$

Physical significance of strain hardening exponent

Metals with a low strain-hardening exponent respond poorly to cold working. The strain hardening exponent n is useful in determining the behavior of materials during many working operations. For example, the high n value of austenitic stainless steels is an indication of poor machinability. This is because the cutting action of the tool causes strain hardening ahead of the tool. Due to the high n value, this causes a large increase in strength and hardness. Thus the cutting tool is always working against higher-strength material, requiring larger cutting forces.

In contrast, a high n value is desirable for sheet formability, in which resistance to local necking, or reduction in sheet thickness, is necessary. When a high n value material begins to neck, the deforming region rapidly strain hardens, causing subsequent plastic deformation to occur in the surrounding softer metal. This produces a long diffuse neck, as seen in Fig. 3.9. In contrast, necking in a material with a low n value occurs more locally, causing failure at a lower strain. It is noteworthy that many plastics strain harden rapidly, providing them with good sheet forming characteristics, but often causing poor cutting properties.

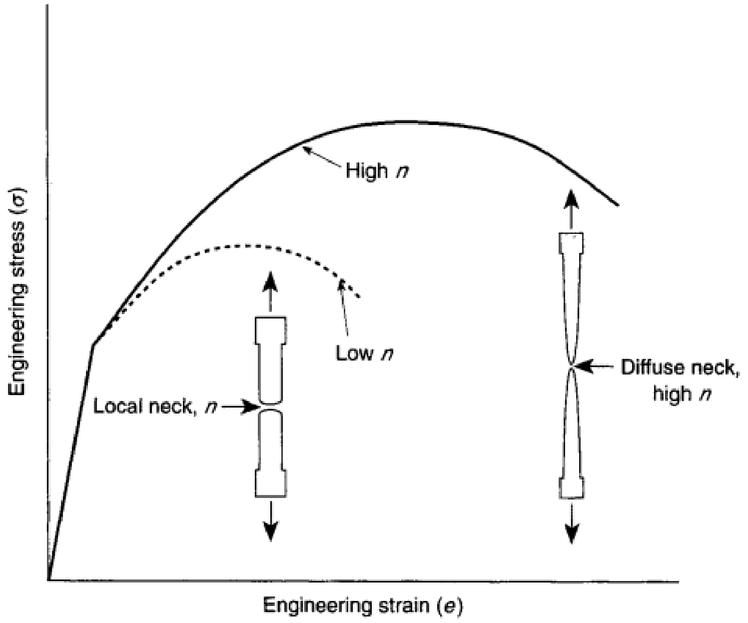


Fig. 3.9 Schematic engineering stress–strain curve for a low n and a high n material, to illustrate the effect of strain hardening on necking.

Strain rate

The rate at which strain develops in a material is defined as strain rate. Units of strain rate are s^{-1}.Many materials considered to be ductile behave as brittle solids when the strain rates are high. When materials are subjected to high strain rates we refer to this type of loading as impact loading.

Strain-Rate Sensitivity(m)

The effect of strain rate on strength properties is known as Strain-Rate Sensitivity (m). This describes how fast strain hardening occurs in response to plastic deformation.

The mechanical behavior of sheet steels under high strain rates is important not only for shaping, but also for how well the steel will perform under high-impact loading. The crashworthiness of sheet steels is an important consideration for the automotive industry. Steels that harden rapidly under impact loading are useful in absorbing mechanical energy.

When plotted as true stress versus strain rate (for a constant value of true strain) a linear relationship is often found. The equation of such a plot is

$\text{In}\,\sigma = m\,\text{In}\,\varepsilon + \text{In}\,C \quad \sigma = C$
ε^{m}

m is the strain rate sensitivity exponent

C is the strain rate strength constant.

A positive value of m implies that material will resist necking. High values of m and n mean the material can exhibit a better formability in stretching.

m - up to 0.5 for cold working

- .05 – 0.4 for hot working
- 0.3 – 0.85 for superplastic materials

Forging

Forging is a basic process in which the workpiece is shaped by compressive forces applied through various dies and tooling. Forging may be carried out at room temperature (cold forging) or at elevated temperatures (warm or hot forging) depending on the homologous temperature;

Homologous temperature = $\frac{T}{T}$

Where T – Temperature of metal during working
    T -melting temperature of metal

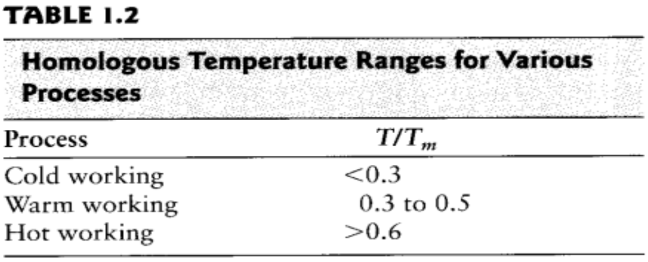


TABLE 1.2

Homologous Temperature Ranges for Various Processes

Process	T/T_m
Cold working	<0.3
Warm working	0.3 to 0.5
Hot working	>0.6

Classification of forging

1) Open die forging
2) Impression die forging
3) Closed die forging

Open die forging

Open-die forging involves placing a solid cylindrical work piece between two flat dies and reducing its height by compressing it, an operation that is also known as upsetting.

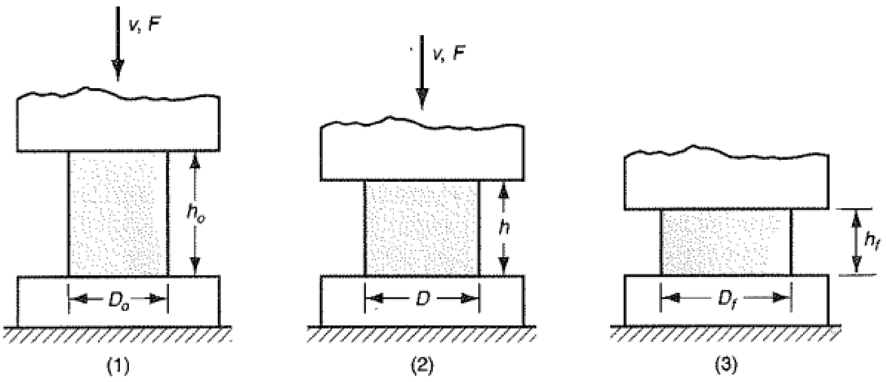


FIGURE 19.10 Homogeneous deformation of a cylindrical workpart under ideal conditions in an open-die forging operation: (1) start of process with workpiece at its original length and diameter, (2) partial compression, and (3) final size.

Because in plastic deformation, the volume of the cylinder remains constant, any reduction in height is followed by an increase in diameter.

The reduction in height = $(h_o - h_1) / h_o * 100\%$

Engineering strain, $e_1 = (h_o - h_1)/h_o$ True strain,
$\varepsilon_1 = \ln(h_o / h_1)$ Engineering strain rate, $\dot{e} = -$
v / h_o True strain rate, $\varepsilon = -v/h$

h_o – Original height , h – Instantaneous height , v –Relative velocity between dies

Barreling

Barreling is caused primarily by frictional forces that oppose the outward flow of the work piece at the die interfaces and thus can be minimized by using an effective lubricant. Barreling also can develop in upsetting hot Work pieces between cold dies. The material at or near the die surfaces cools rapidly, while the rest of the work piece remains relatively hot. Consequently, the material at the top and bottom of the work piece has higher resistance to deformation than the material at the center. As a result, the central portion of the work piece expands laterally to a greater extent than do the ends. Barreling from thermal effects can be reduced or eliminated by using heated dies. Thermal barriers, such as glass cloth, at the die-work piece interfaces also can be used for this purpose.

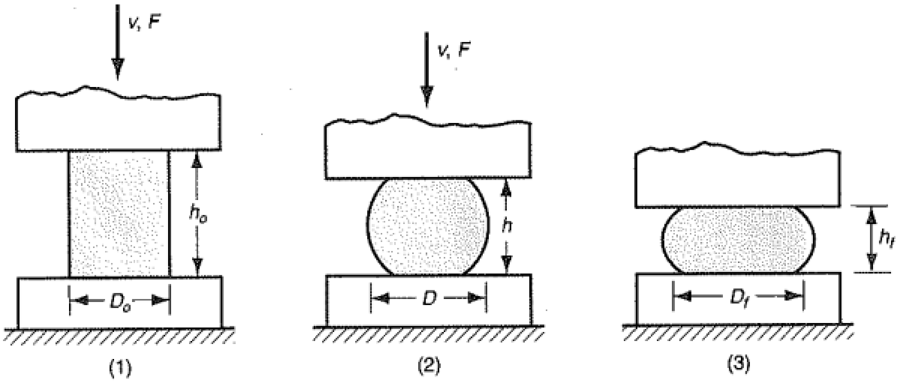


FIGURE 19.11 Actual deformation of a cylindrical workpart in open-die forging, showing pronounced barreling: (1) start of process, (2) partial deformation, and (3) final shape.

Forces and work of deformation under ideal condition

If friction at the work piece-die interface is zero and the material is perfectly plastic with a yield stress of Y, the normal compressive stress on the cylinder specimen is uniform and at a level Y. Force at any height h_1 is

$$F = Y A_1 \quad \text{, Where} \; - A_1 = (A_o h_o)/ h_1$$

Work done per unit volume in homogenous deformation is equal to the area of stress – strain curve between the appropriate strain values.

M s

$\frac{}{V} = \int_0$ ads = u , Specific energy

s

Work W = Volume*

f_{O} ads

Considering an average flow stress $\bar{Y}$

Work = Volume* $\bar{Y}$ * ε_1

Where $\bar{Y} = \frac{Ks}{n+1}$

Analysis

Slab method

Forging of a rectangular work piece in plain strain

Consider the case of simple compression with friction. As the flat dies compress the part and reduce its thickness, the workpart expands laterally. This movement at die-work interface causes frictional forces acting in the opposite direction to the motion. The difference between the horizontal stresses acting on the side faces of the element is due to the presence of frictional stresses on the element. Let's assume that the lateral stress distribution σ_x, is uniform along the height h of the element.

The next step in the analysis is to balance the horizontal forces, because the element must be in static equilibrium.

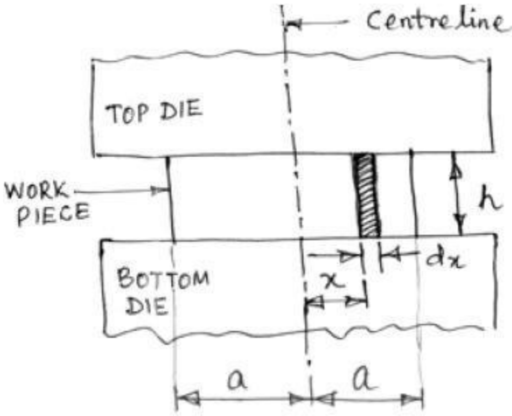


Fig.2. UPSET FORGING OF SLAB.

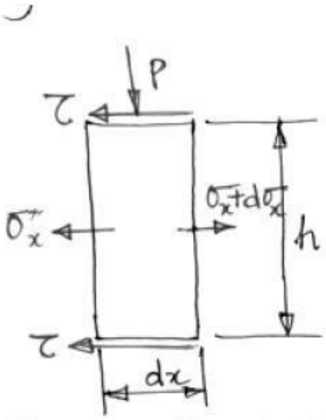


Fig.3. ENLARGED ELEMENT

$(\sigma_x+d\sigma_x)h-\sigma_x h+2\mu\sigma_y dx=0$ $d\sigma_x h + 2\mu\sigma_y dx =0$

$$d\sigma_x + \frac{2\mu\sigma_y dx}{h} = 0 \text{ ----------- (1)}$$

Distortion energy criterion for plane strain is

$$\sigma_y - \sigma_x = \frac{2}{\sqrt{3}}$$

$Y = Y'$

Hence $d\sigma_x = d\sigma_y$

Equation (1) →

$$d\sigma_x = -\frac{2\mu o y dx}{h}$$

$$\frac{do}{a} = -\frac{2\mu}{h}dx$$

$$\frac{do}{a} = -\frac{2\mu}{h}dx$$

$$\sigma_y = C\, e^{-2\mu x/h} \text{ ------------ } (2)$$

Boundary conditions, at $x=a, \sigma_x=0, \sigma_y=Y'$ (i e, at edge of specimen)

$C = Y' e^{-2\mu a/h}$

$P = \sigma_y = Y' e^{-2\mu(a-X)/h}$, i e, $\frac{P}{F} = e^{-2\mu(a-X)/h}$ -----(3)

$$\sigma_x = \sigma_y - Y' = Y'[e^{-2\mu(a-X)/h} - 1]$$

Equation (3) is plotted in the figure

Pressure increases exponentially toward the centre of the part, and it increases with a/h ratio and increasing friction. The pressure distribution curve is referred to as “Friction hill “. The pressure with friction is higher than it is without friction because the work required to overcome friction must be supplied by the upsetting force.

Also an approximate expression for average pressure

$$P_{av} = Y'\left[1 + \frac{\mu a}{h}\right]s$$

Forging force , F is the product of the average pressure and the contact area

$$F = P_{av} * 2a * \text{width}$$

Forging under sticking condition

Frictional stress acting at the work piece-die interface is μP. As P increases towards the centre, μP also increases. However , the value of μP cannot be higher than the shear yield stress , K , of the material. The condition when $\mu P \geq K$ is known as sticking.

$K = Y / 2$ in plain strain

Sticking condition reflects the fact that the material does not move relative to the die surface.

$$P = Y'\left[1 + \frac{a-s}{h}\right]$$

1) Open die forging : Here the work piece is deformed under two falt dies. The height of the work piece is reduced. This process is known as upsetting. Open die forging allows free deformation of at least some work piece surfaces. The die surfaces may be flat or , more generally have cavities of various shapes. Often open die components are produced by repeated blows imparted by a mechanical hammer. The desired shape is obtained by manually manipulating the work piece between blows.

Several open-die forging operations are,

- fullering
- edging
- cogging

In fullering, material is distributed away from an area. In edging, it is gathered into a localized area. A cogging operation consists of a sequence of forging compressions along the length of a workpiece to reduce cross section and increase length. It is used in the industry to produce blooms and slabs from cast ingots.
The term incremental forging is sometimes used.

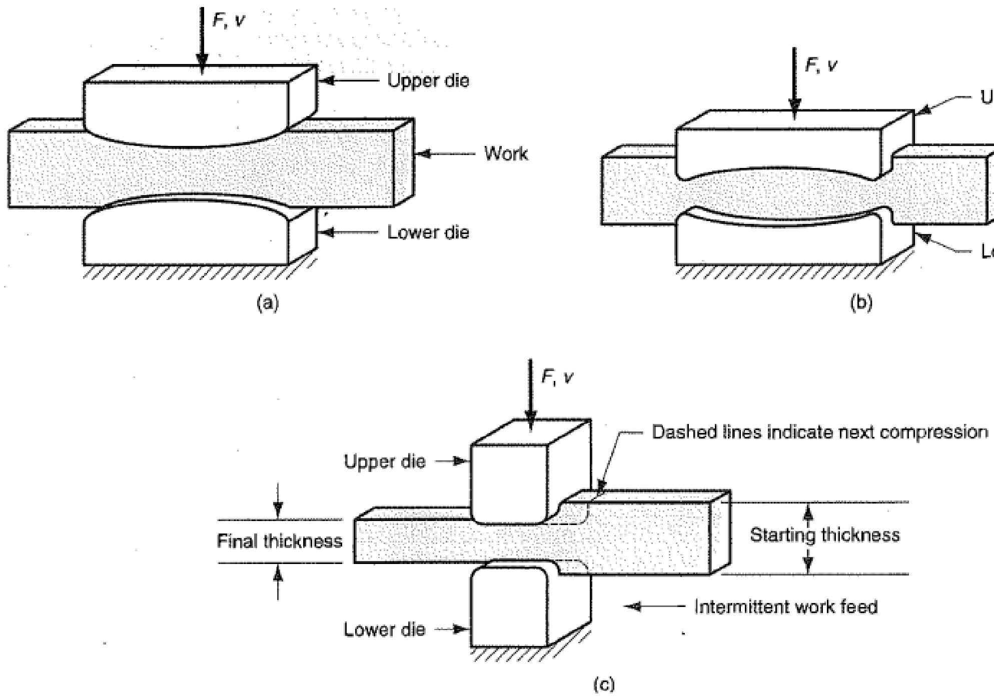
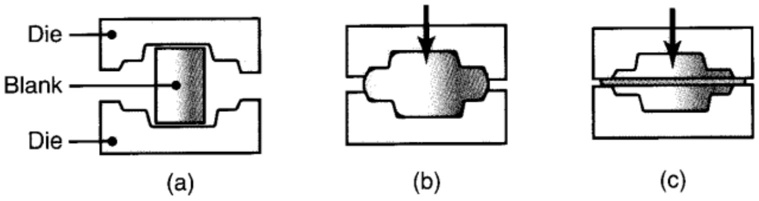


FIGURE 19.13 Several open-die forging operations: (a) fullering, (b) edging, and (c) cogging.

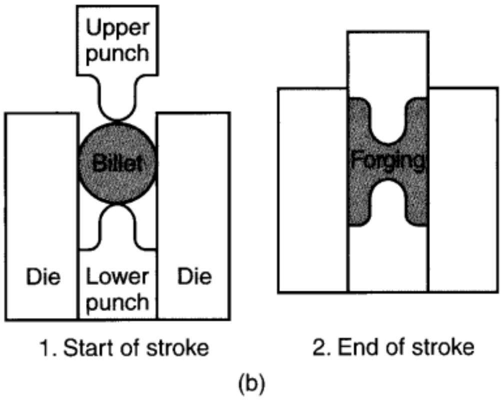
2) Impression die forging

In impression-die forging, the workpiece takes the shape of the die cavity while being forged between two shaped dies. This process usually is carried out at elevated temperatures to lower the required forces and attain enhanced ductility in the workpiece. Note in Fig that, during deformation, some of the material flows outward and forms a flash. The flash has an important role in impression-die forging: The high pressure and the resulting high frictional resistance in the flash presents a severe constraint on any outward flow of the material in the die. Thus, based on the principle that in plastic deformation the material flows in the direction of least resistance (because it requires less energy), the material flows preferentially into the die cavity, ultimately filling it completely.



3) Closed die forging

Here the workpiece is completely trapped in the die and no flash is generated. Economy of forging is thus increased , but die design and process variables must be carefully controlled.
Regardless, the term closed-die forging is often applied to impression die forging with flash generation, whereas open-die forging generally applies to operations with simple dies and tooling and with large deformations.



Other forging processes

Precision Forging : Precision forging requires (a) special and more complex dies, (b) precise control of the blank's volume and shape, and (c) accurate positioning of the blank in the die cavity. Also, because of the higher forces required to obtain fine details on the part, this process requires higher capacity equipment.

Aluminum and magnesium alloys are particularly suitable for precision forging because of the relatively low forging loads and temperatures that they require; however, steels and titanium also can be precision forged.

Isothermal forging : Also known as hot-die forging, the dies in this process are heated to the same temperature as hot blank. In this way cooling of workpiece is eliminated , the low flow stress of the material is maintained during forging , and material flows easier within the die cavities. The dies are generally made of Ni alloys and complex parts with good dimensional accuracy can be forged in one stroke in hydraulic presses.

Orbital forging : Orbital forging is an example of incremental forging in which the die moves along an orbital path and forms the part in individual steps. Here deformation occurs by means of a cone-shaped upper die that is simultaneously rolled and pressed in to the workpart.

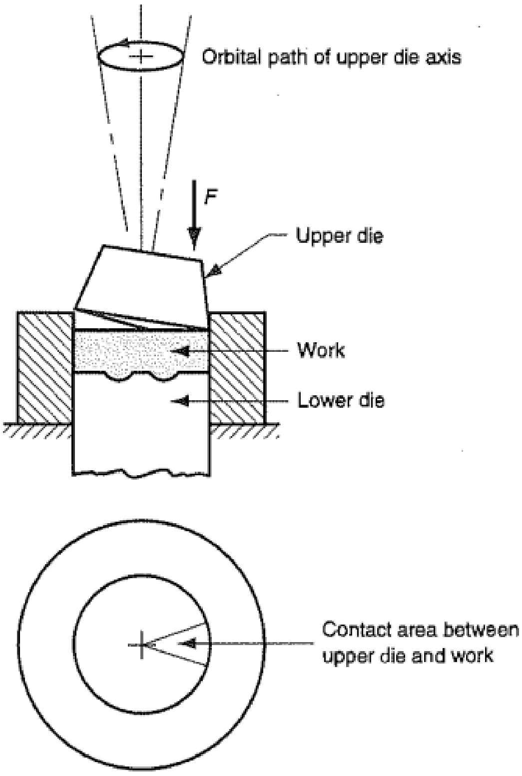
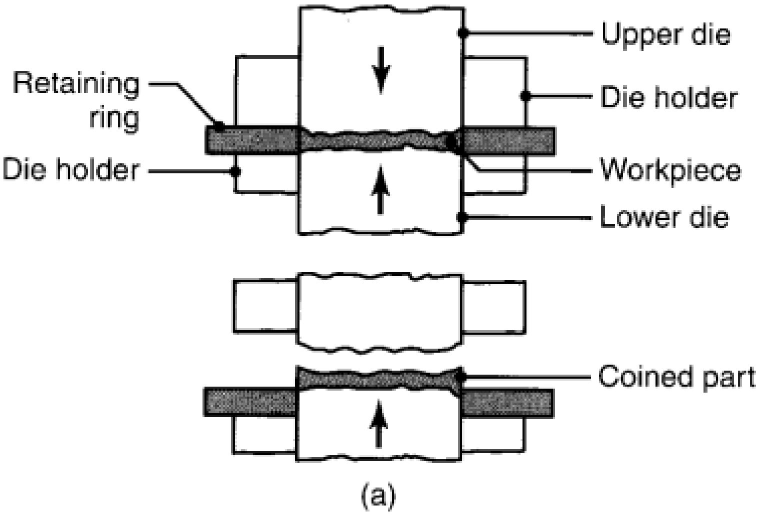


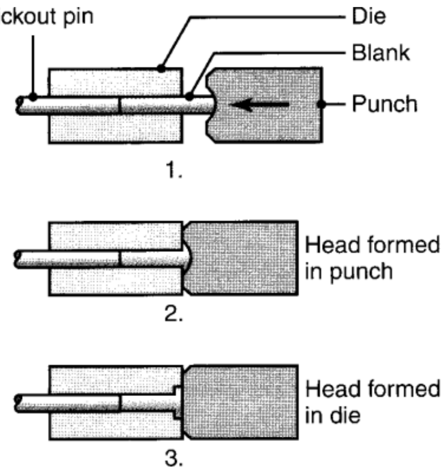
FIGURE 19.27 Orbital forging. At end of deformation cycle, lower die lifts to eject part.

Miscellaneous forging operations

Coining : This is essentially a closed-die forging process that is typically used in the minting of coins, medallions, and jewelry. The blank or slug is coined in a completely closed die cavity. In order to produce fine details (for example, the detail on newly minted coins), the pressures required can be as high as five or six times the strength of the material. Marking parts with letters and numbers also can be done rapidly through coining. In addition, the process is used with forgings and other products to improve surface finish and to impart the desired dimensional accuracy with little or no change in part size. Called sizing, this process requires high pressures.

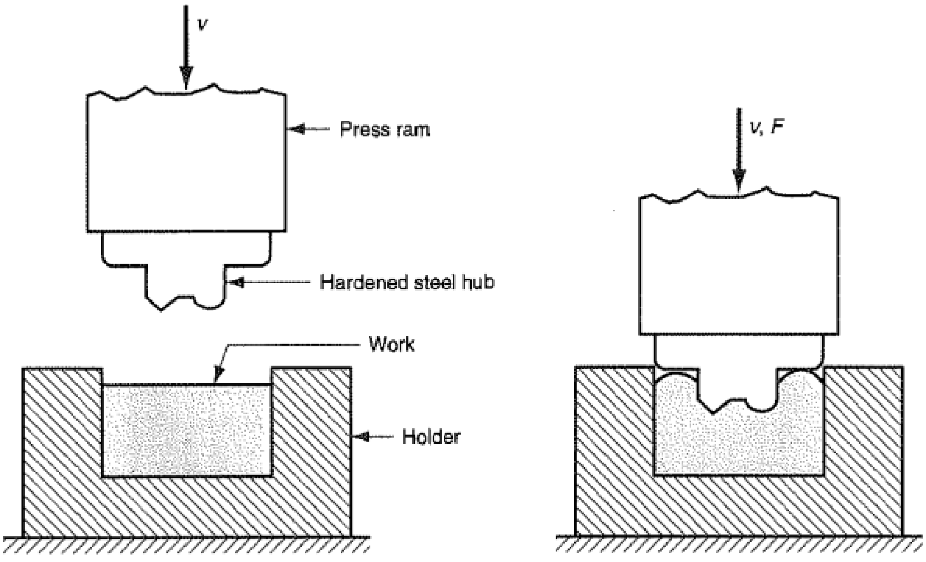


Heading : Also called upset forging, heading is essentially an upsetting operation, usually performed on the end of a round rod or wire in order to increase the cross section. Typical products are nails, bolt heads, screws, rivets, and various other fasteners.



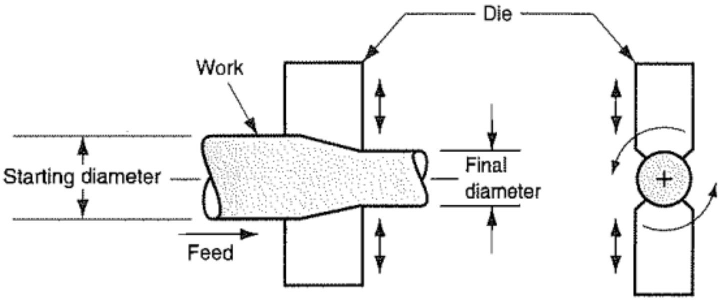
Piercing : This is a process of indenting (but not breaking through) the surface of a work piece with a punch in order to produce a cavity or an impression . The work piece may be confined in a container (such as a die cavity) or may be unconstrained. The deformation of the work piece will depend on how much it is constrained from flowing freely as the punch descends. A common example of piercing is the indentation of the hexagonal cavity in bolt heads.

Hubbing : This process consists of pressing a hardened punch with a particular tip geometry into the surface of a block of metal. The cavity produced is subsequently used as a die for forming operations, such as those employed in the making of tableware. The die cavity usually is shallow, but for deeper cavities, some material may be removed from the surface by machining prior to hubbing.



(1) (2)

Rotary Swaging : In this process (also known as radial forging, rotary forging, or simply swaging), a solid rod or tube is subjected to radial impact forces by a set of reciprocating dies of the machine . The die movements are obtained by means of a set of rollers in a cage in an action similar to that of a roller bearing. The work piece is stationary and the dies rotate (while moving radially in their slots), striking the work piece at rates as high as 20 strokes per second. In die-closing swaging machines, die movements are obtained through the reciprocating motion of wedges . The dies can be opened wider than those in rotary swagers, thereby accommodating large-diameter or variable-diameter parts. In another type of machine, the dies do not rotate, but move radially in and out. Typical products made are screwdriver blades and soldering-iron tips.



Roll Forging : In this operation (also called cross rolling), the cross section of a round bar is shaped by passing it through a pair of rolls With profiled grooves (Fig. 13.13). Roll forging typically is used to produce tapered shafts and leaf springs, table knives, and hand tools; it also may be used as a preliminary forming operation, to be followed by other forging processes.

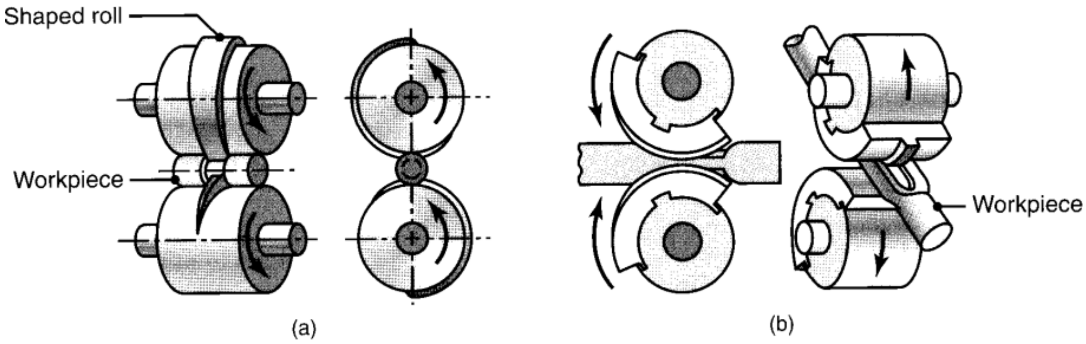


FIGURE 13.13 Two examples of the roll-forging operation, also known as *cross-rolling.* Tapered leaf springs and knives can be made by this process. *Source*: After J. Holub.

Skew-rolling : A process similar to roll forging is skew rolling, typically used for making ball bearings (Fig. 13.14a). Round wire or rod is fed into the roll gap, and roughly spherical blanks are formed continuously by the action of the rotating rolls. Another method of forming near-spherical blanks for ball bearings is to shear pieces from a round bar and then upset them in headers between two dies with hemispherical cavities (Fig. 13.l4b). The balls subsequently are ground and polished in special machinery.

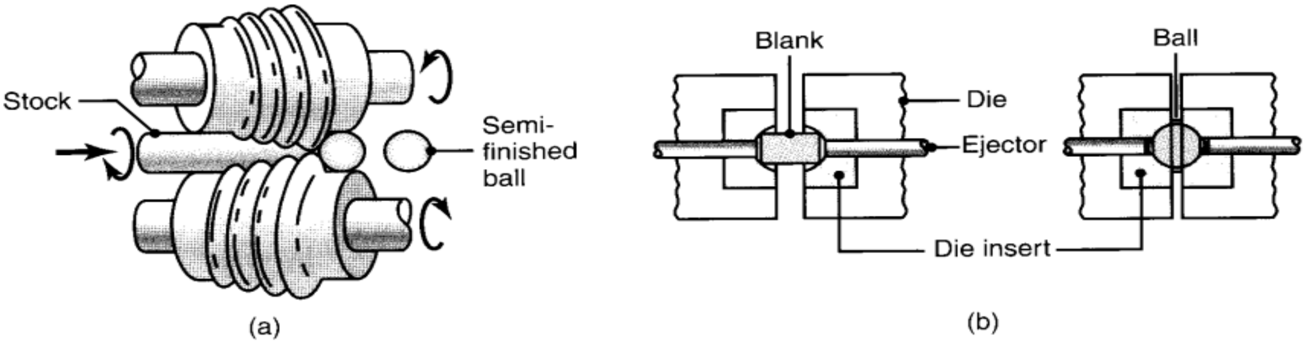


FIGURE 13.14 (a) Production of steel balls by the skew-rolling process. (b) Production of steel balls by upsetting a cylindrical blank. Note the formation of flash. The balls made by these processes subsequently are ground and polished for use in ball bearings.

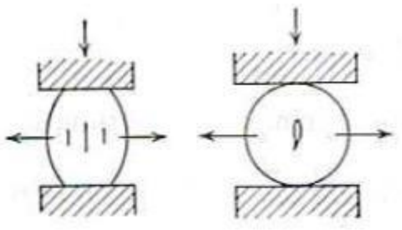
Forgeability of Metals

Forgeability is generally defined as the capability of a material to undergo deformation without cracking. Various tests have been developed to quantify forgeability.

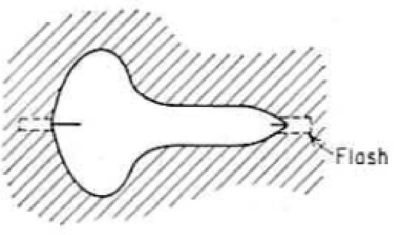
1. upsetting test
2. hot twist test

In the upsetting test, a solid, cylindrical specimen is upset between flat dies, and the reduction in height at which cracking on the barreled surfaces begins is noted . The greater the deformation prior to cracking, the greater the forgeability of the metal. The second method is the hot-twist test, in which a round specimen is twisted continuously in the same direction until it fails. This test is performed on a number of specimens and at different temperatures, and the number of complete turns that each specimen undergoes before failure at each temperature is plotted. The temperature at which the maximum number of turns occurs then becomes the forging temperature for maximum forgeability. The hot-twist test has been found to be useful particularly for steels.

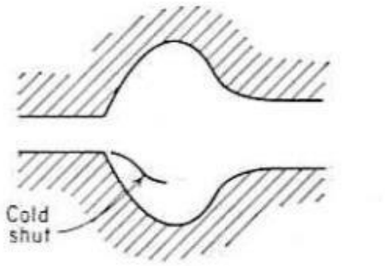
Forging Defects



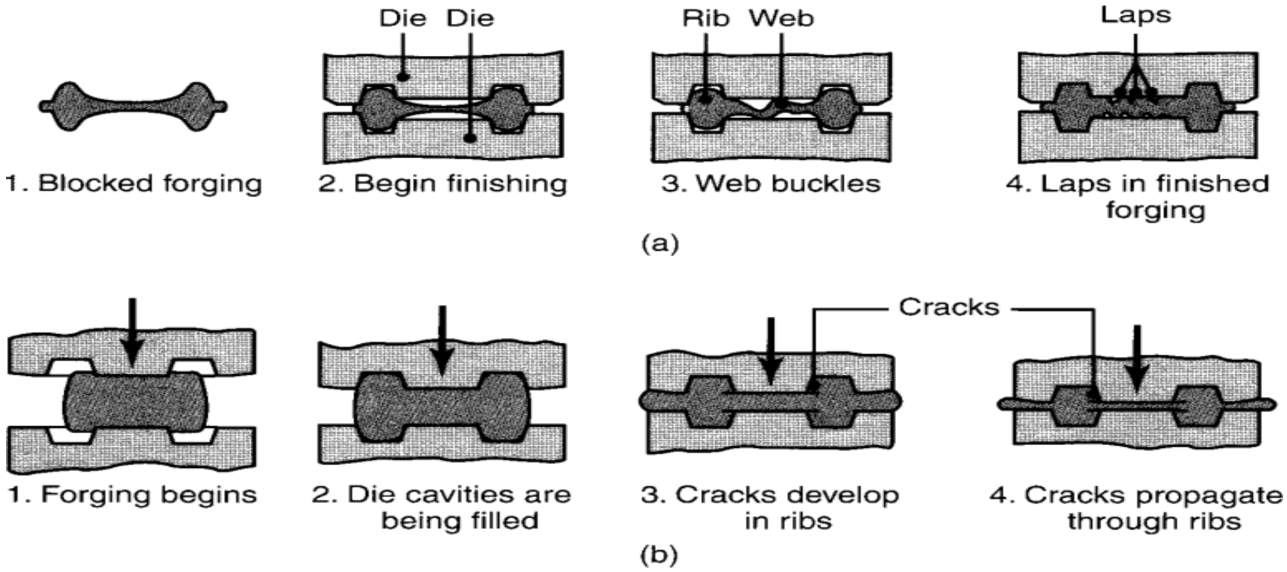
1. Surface cracking : It is due to temperature differential between surface and centre, or excessive working of the surface at too low temperature.
2. Buckling : A slender cylinder may buckle instead of upsetting uniformly. Therefore it is advisable to limit the ratio h_0 / d_0 to 2 when friction is high.
3. Internal cracking : It is due to secondary tensile stress.
4. Forging laps: If there is an insufficient volume of material to fill the die cavity completely, the web may buckle during forging and develop laps.
5. Cold shut or fold : It is due to flash or fin from prior forging steps is forced into the work piece.
6. Flash line crack : It occurs after trimming, more often in thin work pieces. Therefore should increase the thickness of the flash.
7. Pitted surface : It is due to oxide scales occurring at high temperature stick on the dies.



Cracking at the flash

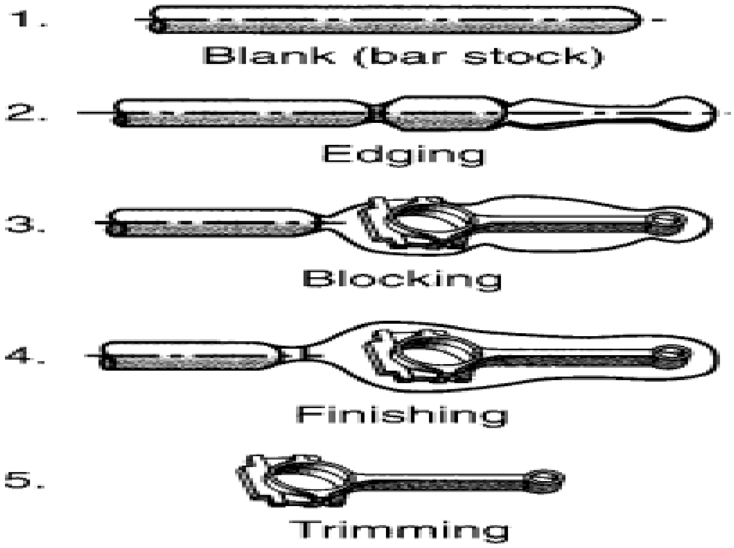


Cold shut or fold



Die Design and Die Materials

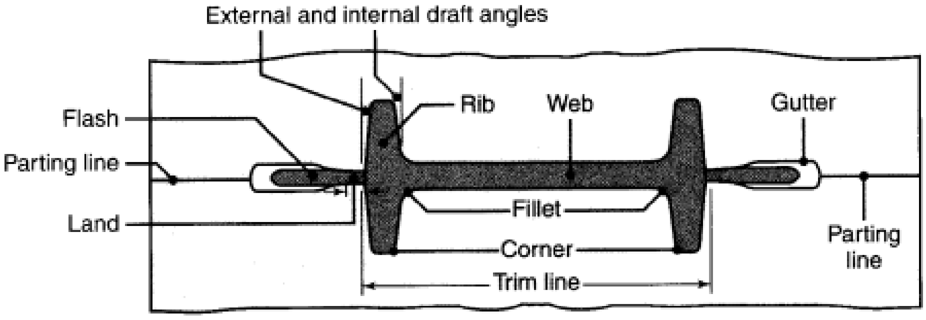
The most important rule in die design is the fact that the part will flow in the direction of least resistance. Thus, the workpiece intermediate shapes should be planned so that they properly fill the die cavities.



Preshaping

In a properly preshaped workpiece, the material should not flow easily into the flash (otherwise die filling will be incomplete), the grain flow pattern should be favorable for the products' strength and reliability, and sliding at the workpiece-die interfaces should be minimized in order to reduce die wear.

Die terminology and Design Features



Parting line :

For most forgings, the parting line is located at the largest cross section of the part. For simple symmetrical shapes, the parting line is normally a straight line at the center of the forging, but for more complex shapes, the line may not lie in a single plane. The dies are then designed in such a way that they lock during engagement, in order to avoid side thrust, balance forces, and maintain die alignment during forging.

Flash gutter : After sufficiently constraining lateral flow to ensure proper die filling, the flash material is allowed to flow into a gutter, so that the extra flash does not increase the forging load excessively. A general guideline for flash thickness is 3% of the maximum thickness of the forging.

land : The length of the land is usually two to five times the flash thickness.

Draft angles : Draft angles are necessary in almost all forging dies in order to facilitate removal of the part from the die. Upon cooling, the forging shrinks both radially and longitudinally, so internal draft angles (about 7° to 1O°) are made larger than external ones (about 3° to 5°).

Fillets and corner radii : Small radii generally are undesirable because of their adverse effect on metal flow and their tendency to wear rapidly (as a result of stress concentration and thermal cycling). Small fillet radii also can cause fatigue cracking of the dies. As a general rule, these radii should be as large as can be permitted by the design of the forging.

Webs and ribs : A web is a thin portion of forging that is parallel to the parting line ,while a rib is a thin portion that is perpendicular to the parting line. These part features causes difficulty in metal flowing as they become thinner.

Allowances : Machining allowance should be provided at flanges, at holes, and at mating surfaces.

Die Materials

Most forging operations (particularly for large parts) are carried out at elevated temperatures. General requirements for die materials therefore are;

- Strength and toughness at elevated temperatures
- Hardenability and ability to harden uniformly
- Resistance to mechanical and thermal shock
- Wear resistance, particularly resistance to abrasive wear, because of the presence of scale in hot forging.

Common die materials are tool and die steels containing chromium, nickel, molybdenum, and vanadium.

Forging Machines

Hydraulic Presses : These presses operate at constant speeds and are load limited, or load restricted. In other words, a press stops if the load required exceeds its capacity. Large amounts of energy can be transmitted to a work piece by a constant load throughout a stroke-the speed of which can be controlled. Because forging in a hydraulic press takes longer than in the other types of forging machines described next, the work piece may cool rapidly unless the dies are heated. Compared with mechanical presses, hydraulic presses are slower and involve higher initial costs, but they require less maintenance.

Mechanical Presses : These presses are basically of either the crank or the eccentric type (Fig. 14.17a). The speed varies from a maximum at the center of the stroke to zero at the bottom of the stroke; thus, mechanical presses are stroke limited. The energy in a mechanical press is generated by a large flywheel powered by an electric motor. A clutch engages the flywheel to an eccentric shaft. A connecting rod translates the rotary motion into a reciprocating linear motion. A knuckle joint mechanical press is shown in Fig. 14.17b. Because of the linkage design, very high forces can be applied in this type of press.

Screw Presses : These presses (Fig. 14.17c) derive their energy from a flywheel; hence, they are energy limited. The forging load is transmitted through a large vertical screw, and the ram comes to a stop when the flywheel energy is dissipated. Screw presses are used for various open-die and closed-die forging operations. They are suitable particularly for small production quantities, especially thin parts with high precision, such as turbine blades. Press capacities range from 1.4 to 280 MN.

Hammers : Hammers derive their energy from the potential energy of the ram, which is converted into kinetic energy; hence, they are energy limited. Unlike hydraulic presses, hammers (as the name implies) operate at high speeds, and the resulting low forming time minimizes the cooling of a hot forging. Low cooling rates then allow the forging of complex shapes, particularly those with thin and deep recesses. To complete the forging, several successive blows usually are made in the same die. Hammers are available in a variety of designs and are the most versatile and the least expensive type of forging equipment.

Drop Hammers : In power drop hammers, the ram’s down stroke is accelerated by steam, air, or hydraulic pressure at about 750 kPa. Ram weights range from 225 to 22,500 kg, with energy capacities reaching 1150 k]. In the operation of gravity drop hammers (a process called drop forging), the energy is derived from the free-falling ram. The available energy of a drop hammer is the product of the ram’s weight and the height of its drop. Ram weights range from 180 to 4500 kg, with energy capacities ranging up to 120 kJ.

Counterblow Hammers : These hammers have two rams that simultaneously approach each other horizontally or vertically to forge the part. As in open-die forging operations, the part may be rotated between blows for proper shaping of the work piece during forging. Counterblow hammers operate at high speeds and transmit less vibration to their bases. Capacities range up to 1200 kJ.

High-energy-rate Forging Machines : In these machines, the ram is accelerated rapidly by inert gas at high pressure and the part is forged in one blow at a very high speed. Although there are several types of these machines, various problems associated with their operation and maintenance, as well as die breakage and safety considerations, have greatly limited their use in industry.

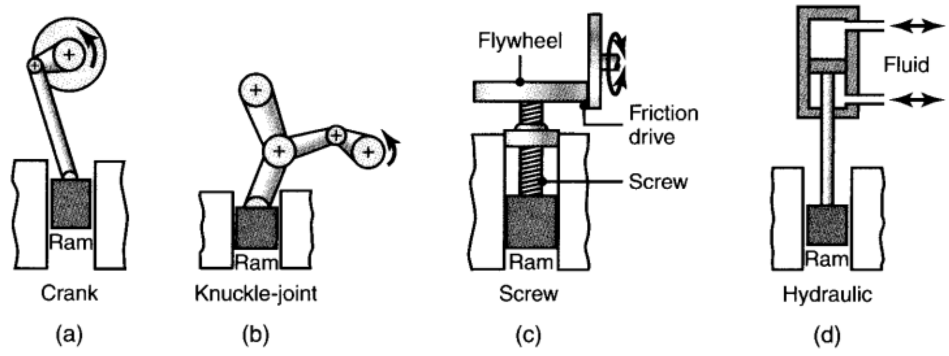


FIGURE 14.17 Schematic illustration of the principles of various forging machines. (a) Mechanical press with an eccentric drive; the eccentric shaft can be replaced by a crankshaft to give up-and-down motion to the ram. (b) Knuckle-joint press. (c) Screw press. (d) Hydraulic press.

Heating devices

Forgeable metals are heated either in a hearth or in a furnace. The hearths are widely used for heating the metals for carrying out hand forging operations. Furnaces are also commonly used for heating metals for heavy forging.

Box or batch type furnaces : These furnaces are the least expensive furnaces widely used in forging shops for heating small and medium size stock. There is a great variety of design of box-type furnaces, each differing in their location of their charging doors, firing devices and method, employed for charging their products.

Rotary-hearth furnaces :These are set to rotate slowly so that the stock is red to the correct temperature during one rotation. These can be operated by gas or oil fuels

Continuous or conveyor furnaces : These furnaces are of several types and are preferred for larger stock. They have an air or oil-operated cylinder to push stock end-to-end through a narrow furnace. The pieces are charged at one end, conveyed through the furnace and moved at other end at the correct temperature for the forging work.

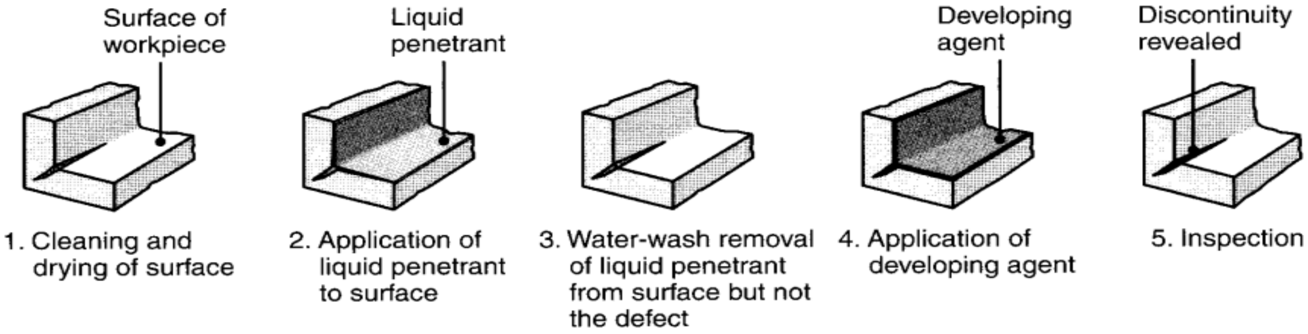
Induction furnaces : These furnaces are very popular because induction greatly decreases scale formation and can often be operated by one person. The furnace requires less maintenance than oil or gas-fired furnaces.

Resistance furnaces : These furnaces are faster than induction furnaces, and can be automated easily. In resistance heating furnace, the stock is connected to the circuit of a step-down transformer. Fixtures are also equipped along with furnace for holding different length, shape, and diameter of stock.

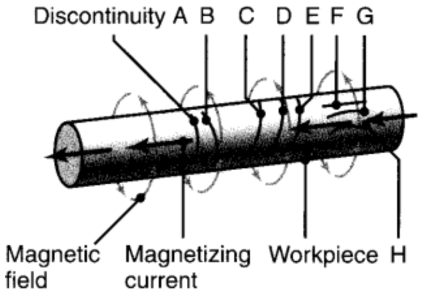
Nondestructive Testing

Nondestructive testing (NDT) is carried out in such a manner that product integrity and surface texture remain unchanged. Nondestructive-testing techniques generally require considerable operator skill, and interpreting test results accurately may be difficult because the observations can be subjective.

Liquid Penetrants : In this technique, fluids are applied to the surfaces of the part and allowed to penetrate into cracks, seams, and pores. By capillary action, the penetrant can seep into cracks as small as 0.1 ,um in width. Two common types of liquids used for this test are (a) fluorescent penetrants, with various sensitivities and which fluoresce under ultraviolet light, and (b) visible penetrants, using dyes (usually red) that appear as bright outlines on the work piece surface.



Magnetic-particle Inspection : This technique consists of placing fine ferromagnetic particles on the surface of the part. The particles can be applied either dry or in a liquid carrier, such as water or oil. When the part is magnetized with a magnetic field, a discontinuity (defect) on the surface causes the particles to gather visibly around the defect.



Ultrasonic Inspection : In this technique, an ultrasonic beam travels through the part. An internal defect (such as a crack) interrupts the beam and reflects back a portion of the ultrasonic energy. The amplitude of the energy reflected and the time required for its return indicate the presence and location of any flaws in the work piece.

Acoustic Methods : The acoustic-emission technique detects signals (high-frequency stress waves) generated by the work piece itself during plastic deformation, crack initiation and propagation, phase transformation, and abrupt reorientation of grain boundaries. Bubble formation during the boiling of a liquid and friction and wear of sliding interfaces are other sources of acoustic signals.

Radiography : Radiography uses X-ray inspection to detect such internal flaws as cracks and porosity. The technique detects differences in density within a part. For example, on an X-ray film, the metal surrounding a defect is typically denser and, hence, shows up as lighter than, the flaws. This effect is similar to the way bones and teeth show up lighter than the rest of the body on X-ray films. The source of radiation is typically an X-ray tube, and a visible, permanent image is made on a film or radiographic paper.

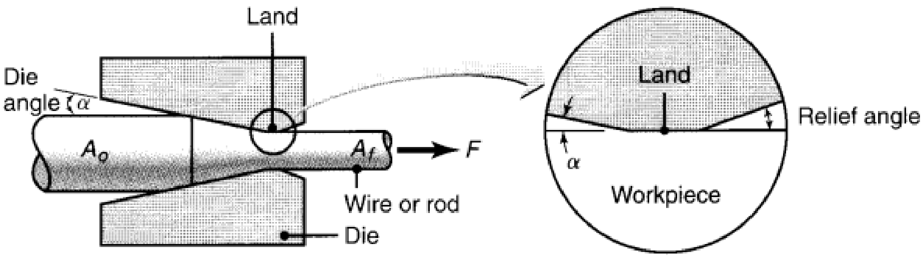
Eddy-current Inspection : This method is based on the principle of electromagnetic induction. The part is placed in or adjacent to an electric coil through which alternating current (exciting current) flows at frequencies ranging from 60 Hz to 6 MHZ. The current causes eddy currents to flow in the part. Defects in the part impede and change the direction of the eddy currents and cause changes in the electromagnetic field. These changes affect the exciting coil (inspection coil), the voltage of which is monitored to determine the presence of flaws.

Thermal Inspection : Thermal inspection involves using contact- or noncontact-type heat-sensing devices that detect temperature changes. Defects in the work piece(such as cracks, debonded regions in laminated structures, and poor joints) cause a change in temperature distribution. In thermograpic inspection, materials such as heat-sensitive paints and papers, liquid crystals, and other coatings are applied to the work piece surface. Any changes in their color or appearance indicate defects. The most common method of noncontact-thermo graphic inspection uses infrared detectors (usually infrared scanning microscopes and cameras), which have a high response time and sensitivities of 1°C. Thermometric inspection utilizes devices such as thermocouples, radiometers, and pyrometers, and sometimes meltable materials, such as wax-like crayons.

Holography : The holography technique creates a three-dimensional image of the part by utilizing an optical system . Generally used on simple shapes and highly polished surfaces, this technique records the image on a photographic film.

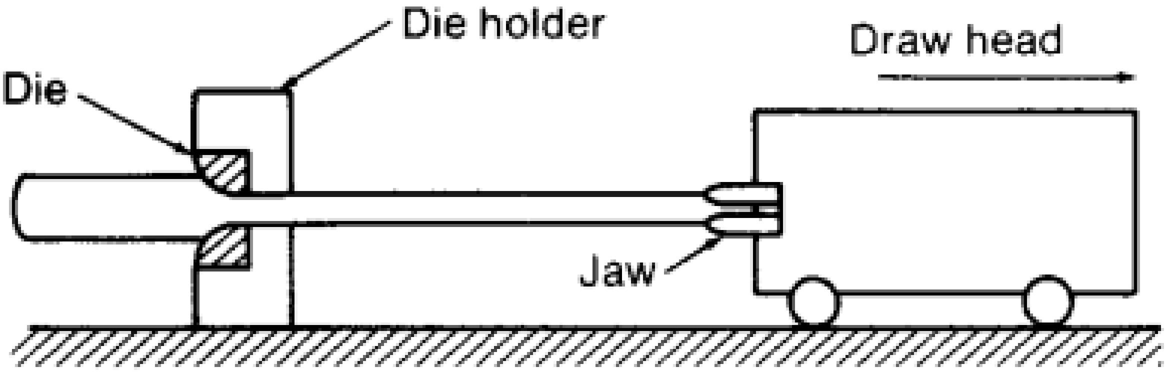
Wire Drawing Process

In wire drawing, the cross section of a long rod or wire is reduced or changed by pulling (hence the term drawing) it through a die called a draw die. Thus, the difference between drawing and extrusion is that in extrusion the material is pushed through a die, whereas in drawing it is pulled through it. The plastic flow is caused by compression force arising from the reaction of metal with the die. Rod and wire products cover a very wide range of applications, including shafts for power transmission, machine and structural components, blanks for bolts and rivets, electrical wiring, cables, tension-loaded structural members, welding electrodes, springs, paper clips, spokes for bicycle wheels, and stringed musical instruments.



The major process variables in drawing are:

reduction in cross-sectional area, die angle, friction along the die-workpiece interface, and drawing speed.



Mechanics of Wiredrawing

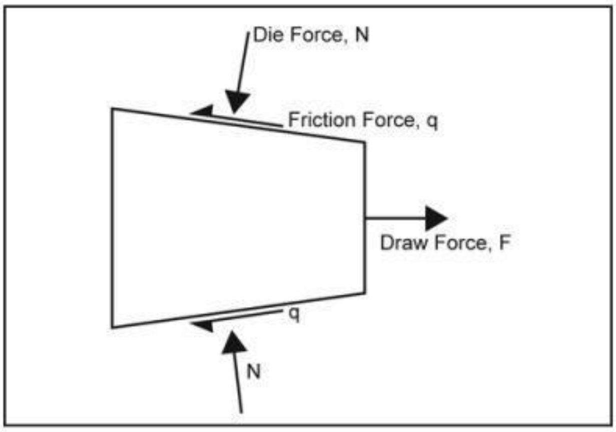


Fig. 1. Free body diagram showing the primary forces operating in wiredrawing.

Draw force, F, represents the total force that must be applied at the die block to overcome friction at the die surface and resistance of the deforming material. Because the draw force is being transmitted by unsupported material, the draw force must be limited to prevent any plastic deformation from occurring outside of the die. Thus, yield stress of the drawn wire rep-resents an upper limit to the allowable draw stress. Accepted drawing practice normally limits draw stress to 60% of the yield strength of the drawn wire. Draw stress is found by dividing the draw force by the cross-sectional area of the drawn wire.

Drawing Force : (under ideal and frictionless conditions)

Æ

$$— \qquad F = Y_{av} A_f \ln(_{\text{Æ}})$$

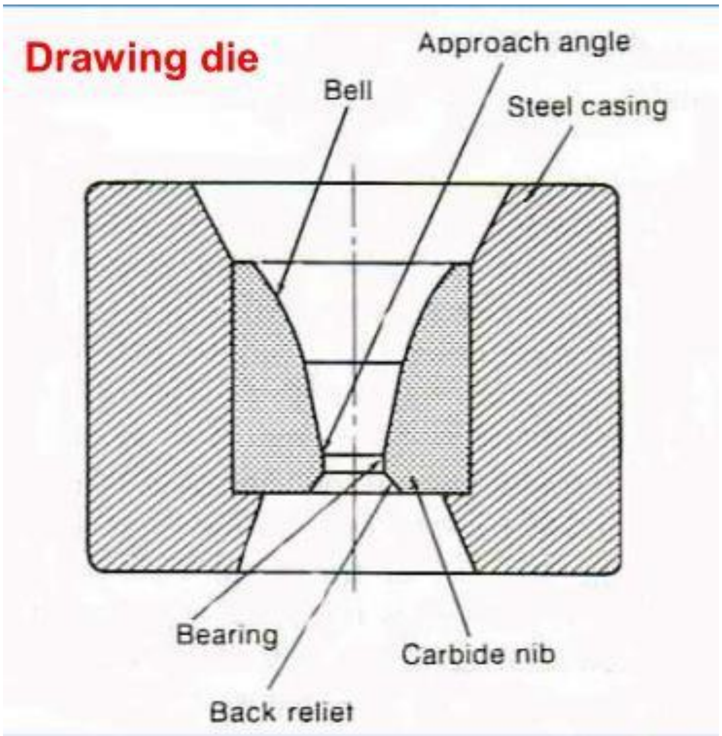
Y_{av} - average true stress of the material in the die gap

Because more work has to be done to overcome friction, the force increases with increasing friction.

Effect of Friction

Layers at the wire surface will not only undergo a change in cross section, but they will also deform in shear because of drag presented by the die surface. Even for highly polished die surfaces and hydrodynamic lubrication, a certain amount of frictional work will be present. Frictional work dominates at low die angles where surface drag is increased as a result of higher contact length in the approach zone for a given reduction. Frictional work can be decreased by using a larger approach angle and, to a lesser extent, by improving lubrication or die surface condition. In addition to surface condition and lubrication, coefficient of friction is inversely related to drawing speed.

Wire drawing die



Shape of the bell causes hydrostatic pressure to increase and promotes the flow of lubricant into the die.

The approach angle – where the actual reduction in diameter occurs, giving the half die angle α

The bearing region produces a frictional drag on the wire and also remove surface damage due to die wear, without changing dimensions.

The die nib made from cemented carbide or diamond is encased for protection in a thick steel casing

The back relief allows the metal to expand slightly as the wire leaves the die and also minimises abrasion if the drawing stops or the die is out of alignment.

Die Materials: Die materials for drawing typically are tool steels and carbides. For hot drawing, cast-steel dies are used because of their high resistance to wear at elevated temperatures. Diamond dies are used for drawing fine wire with diameters ranging from 2 µm to 1.5 mm. They may be made from a single-crystal diamond or in polycrystalline form with diamond particles in a metal matrix (compacts). Because of their very low tensile strength and toughness, carbide and diamond dies typically are used as inserts or nibs, which are supported in a steel casing.

Lubrication : The following are the basic methods of lubrication used in wire drawing :

Wet drawing, in which the dies and the rod are immersed completely in the lubricant

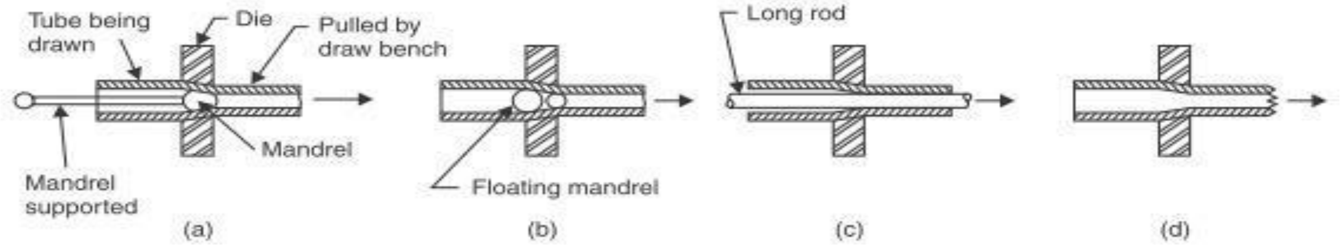
° Dry drawing, in which the surface of the rod to be drawn is coated with a lubricant by passing it through a box filled with the lubricant (stuffing box)

° Metal coating, in which the rod or wire is coated with a soft metal, such as copper or tin, that acts as a solid lubricant

° Ultrasonic vibration of the dies and mandrels; in this process, vibrations reduce forces, improve surface finish and die life, and allow larger reductions per pass without failure.

Tube drawing

Tube drawing does not mean manufacturing a tube from solid raw material. It means lengthening a tube reducing its diameter.



Drawing Practice

As in all metalworking processes, successful drawing requires careful selection of process parameters. In drawing, reductions in the cross-sectional area per pass range up to about 45%. Usually, the smaller the initial cross section, the smaller the reduction per pass. Reductions of higher than 45% may result in lubricant breakdown, leading to surface-finish deterioration. Although most drawing is done at room temperature, drawing large solid or hollow sections can be done at elevated temperatures in order to reduce forces. A light reduction (sizing pass) also may be taken on rods to improve their surface finish and dimensional accuracy.

A rod or wire has to have its tip reduced in cross section in order to be fed through the die opening and be pulled. This typically is done by swaging the tip of the rod or wire in a manner similar to that shown in and b; this operation is called pointing. Drawing speeds depend on the material and on the reduction in cross- sectional area. They may range from 1 to 2.5 m/s for heavy sections to as much as 50 m/s for very fine wire, such as that used for electromagnets. Intermediate annealing between passes may be necessary to maintain sufficient ductility of the material during cold drawing. High-carbon steel wires for springs and for musical instruments are made by heat treating (patenting) the drawn wire; the microstructure obtained is fine pearlite.

Bundle Drawing : Although very fine wire can be produced by drawing, the cost can be high. One method employed to increase productivity is to draw many wires (a hundred or more) simultaneously as a bundle.

The wires are separated from one another by a suitable metallic material with similar properties, but lower chemical resistance (so that it subsequently can be leached out from the drawn-wire surfaces).

Wire Drawing equipment

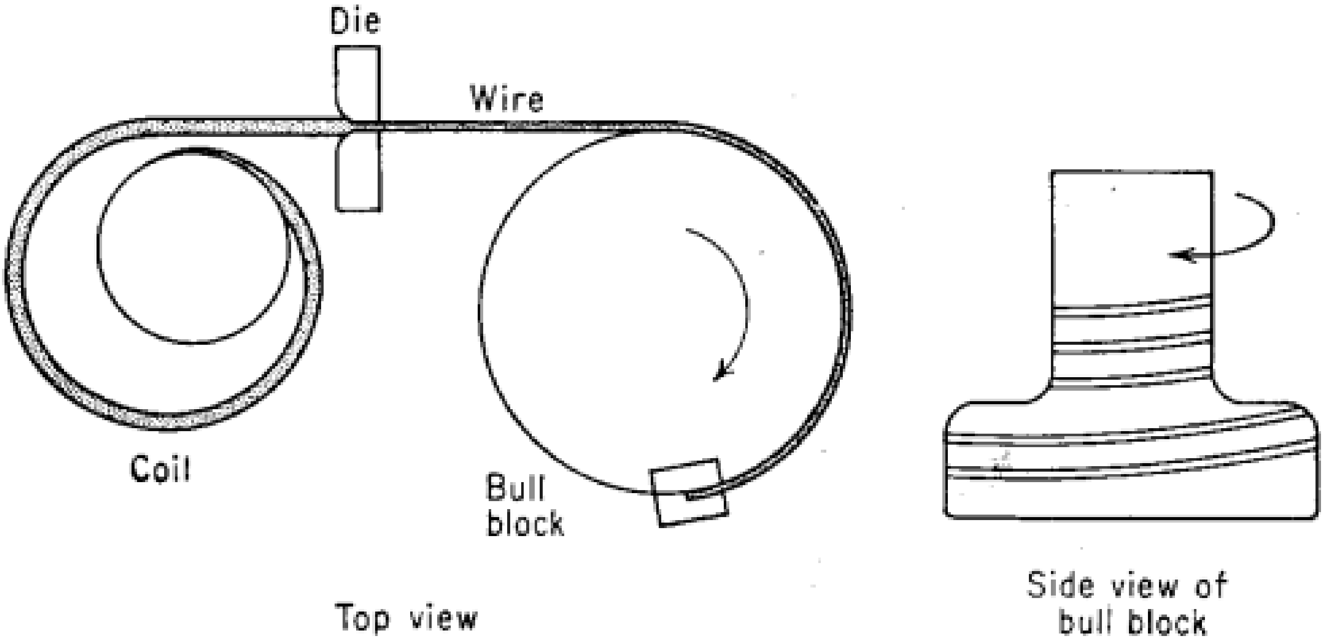
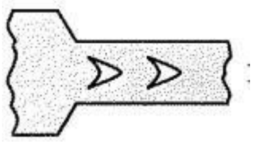
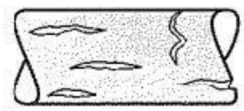


Figure 19-2 Wiredrawing equipment (schematic).

Drawing Defects and Residual Stresses

Chevron cracking (central burst) : These cracks are attributed to a state of hydrostatic tensile stress at the centerline in the deformation zone in the die, a situation similar to the necked region in a tensile-test specimen



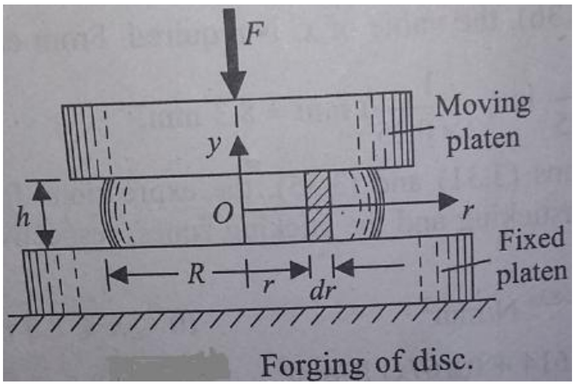


Seams : which are longitudinal scratches or folds in the material.

Residual stresses : Because they undergo non-uniform deformation during drawing, cold-drawn products usually have residual stresses. Residual stresses can be significant in causing stress-corrosion cracking of the part over time. Moreover, they cause the component to warp if a layer of material subsequently is removed such as by slitting, machining or grinding.

Forging of a solid cylindrical workpiece

Figure shows a typical open die forging of a circular disc at the end of the operation (ie, when F is maximum) when the disc has a thickness h and a radius R.



Forging of disc.

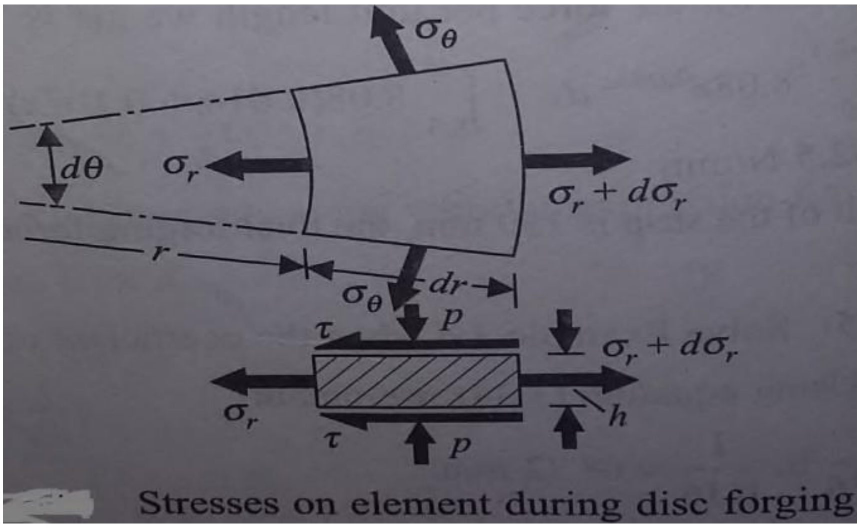
The origin of the cylindrical coordinate system r,θ,y is taken at the centre of the disc. An element of the disc, subtending an angle d θ at the centre, between the radii r and r+dr is shown in figure along with the stresses acting on it. In our analysis here we make the following assumptions

1) The forging force F attains its maximum value at the end of the operation

2) The coefficient of friction μ between the work piece and dies (platens) is constant

3) The thickness of the work piece is small as compared with its other dimensions, and the variations of the stress field along the y direction is negligible

4) The entire workpiece is in the plastic state during the process



Stresses on element during disc forging

Considering the cylindrical symmetry, it can be shown that $\sigma_\theta = \sigma_r$ and both σ_θ and σ_r are independent of θ. The following are the radial forces acting on the element.

1. $\sigma_r\, h\, r\, d\theta$
2. $(\sigma_r + d\sigma_r)\, h\, (r+dr) d\theta$

d0

3. $\sigma_\theta\, h\, dr \sin_{2}$ — x 2

4. $\tau\, r\, d\theta\, dr$ x 2

Now, considering the radial equilibrium of the element we have ,

d0

$(\sigma_r + d\sigma_r)h(r+dr)d\theta - \sigma_r hrd\theta - 2\,\sigma_\theta\, h$ ~~dr~~ $\sin_{2} - 2\,\tau\, r\, d\theta\, dr = 0$

d0

$(rdr + \sigma_r\, dr + r\, d\sigma_r + dr\, d\sigma_r)\, hd\theta - \sigma_r hrd\theta - 2\sigma_\theta\, h\, dr \sin_{2} - 2\tau\, rd\theta dr$ — $=0$

d0

$r\sigma_r hd\theta + \sigma_r dr\, hd\theta + r\, d\sigma_r\, hd\theta + dr\, d\sigma_r\, hd\theta - \sigma_r h\, r\, d\theta - 2\sigma_\theta\, h\, dr \sin_{2} - 2$ —

$\tau\, r\, d\theta\, dr = 0$

The term $r\,\sigma_r hd\theta$ cancels out , and as dθ is common we can remove it ,therefore we can write,

$\sigma_r\, dr\, h + r\, d\sigma_r\, h + dr\, d\sigma_r\, h - \sigma_r h\, dr - 2\tau\, rdr = 0$ (for small angles $\sin\theta \approx \theta$)

we can neglect the higher order term $drd\sigma_r h$ r $h\, d\sigma_r$ -
$2\,\tau\, rdr = 0$

$h\, d\sigma_r - 2\,\tau\, dr = 0$---------------------------------(1)

Distortion energy criterion is

$\sigma_y - \sigma_x = Y$ --(2)

Yield stress $Y = \sqrt{3}\, K$, where K = shear yield stress differentiating , equation (1) changes to

$$d\sigma_x = d\sigma_y$$

ie, $d\sigma_r = -dp$--------------------------------(3)

Substituting eqn (3) in eqn (1) , we get

$$h\,dp + 2\tau\,dr = 0 \text{ -----------------------------(4)}$$

In this case beyond a certain radius r_s ,sliding takes place at the interface to allow the radial expansion of the workpiece. Hence ,

$$\tau = \mu p \qquad (r_s \le r \le R), \text{ -------------------- (5)}$$

$\tau = K$ $(0 \le r \le r_s)$ ------------------------------ (6)

Thus in these two zones , eqn (4) takes the forms

$$\frac{dp}{p} + \frac{2\mu}{h}\,dr = 0 \qquad (r_s \le r \le R)$$

$$dp + \frac{2K}{h}\,dr = 0 \qquad (0 \le r \le r_s)$$

Integrating these two equations, we get

$$p = C_1 e^{-\frac{2\mu r}{h}} \qquad (r_s \le r \le R) \text{------------------------(7)}$$

$$p = C_2 - \frac{2K}{h} r \qquad (0 \le r \le r_s) \text{---------------------------- (8)}$$

As the periphery of the disc is free, at r = R, $\sigma_r = 0$. So from eqn (3) , $p = \sqrt{3}K$ (at r = R) (9)

Using eqn (9) in eqn (7), we obtain

$$C_1=\sqrt{3}Ke\,\frac{2\mu R}{h}\text{--}(10)$$

At $r = r_s$, equating the right – hand sides of eqns (5) & (6) the value of p we obtain is $\frac{K}{\mu}$. So, from equations (5)&(6),

$$\frac{K}{\mu} = \sqrt{3}\,K\,e^{\frac{2\mu(R - r_c)}{h}}$$

Or

$$r_s = \left(R - \frac{h}{2\mu}\ln\frac{1}{\sqrt{3}\,\mu}\right) \text{--(11)}$$

Now, at $r = r_s$, using eqn (8) along with eqn (11), we get

$$p = \frac{K}{\mu} = C_2 - \frac{2K}{h}\,r_s = C_2 - \frac{2K}{h}\left(R - \frac{h}{2\mu}\ln\frac{1}{\sqrt{3}\,\mu}\right)$$

Or

$$C_2 = K\left[\frac{2R}{h} + \frac{1}{\mu}\left(1 + \ln\sqrt{3}\mu\right)\right] \text{----------------------------- (12)}$$

Finally, the expressions for the pressure in the nonsticking and the sticking zone can be written as

$$p = \sqrt{3}\,K\,e^{\frac{2\mu(R - r)}{h}} \qquad (r_s \le r \le R) \text{----------------------(13)}$$

$$p = \frac{2K}{h}(R - r) + \frac{K}{\mu}\left(1 + \ln(\sqrt{3}\mu)\right) \qquad (0 \le r \le r_s) \text{----------------------- (14)}$$

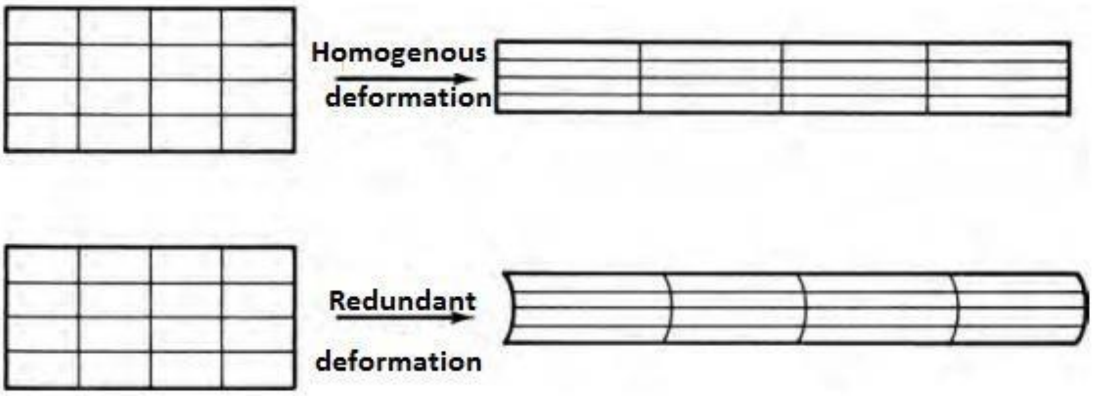
The total forging force is

$$F = 2\pi \left[\int_{0}^{r_c} e_2 r \, dr + \int_{r_c}^{R} e_1 r \, dr \right] \text{---} (15)$$

Where p_1 and p_2 are the pressures given by eqns (13) & (14) respectively.

Redundant work and redundant deformation

The energy to complete an operation can be divided into the ideal work, w_i , that would be required for the shape change in the absence of friction and inhomogeneous flow, the work against friction, w_f , and the redundant work, w_r .ie , In addition to the ideal work, there is work against friction between work and tools, w_f ,and work to do redundant or unwanted deformation, w_r . Figure below illustrates the redundant work in drawing or extrusion. If the deformation were ideal, plane sections would remain plane. In real processes, the surface layers are sheared relative to the center. The material undergoes more strain than required for the diameter reduction and consequently strain hardens more and is less ductile.



Comparison of ideal and actual deformation to illustrate the meaning of redundant work.

Mechanics of Wiredrawing

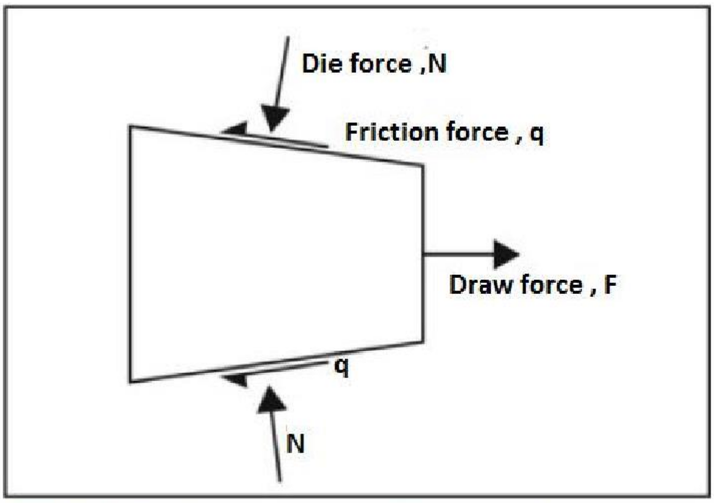


Fig . Free body diagram showing the primary forces operating in wiredrawing

Draw force, F, represents the total force that must be applied at the die block to overcome friction at the die surface and resistance of the deforming material. Because the draw force is being transmitted by unsupported material, the draw force must be limited to prevent any plastic deformation from occurring outside of the die. Thus, yield stress of the drawn wire rep- resents an upper limit to the allowable draw stress. Accepted drawing practice normally limits draw stress to 60% of the yield strength of the drawn wire. Draw stress is found by dividing the draw force by the cross-sectional area of the drawn wire.

Drawing stress

1. Ideal deformation

The drawing stress, σ_d for the simplest case of ideal deformation (no friction or redundant work) is given by;

$$\sigma_d = Y \ln\left[\frac{Æ_o}{Æ_f}\right]$$

For strain hardening materials, Y is replaced by an average flow stress, $\bar{Y}$.

$$\bar{Y} = \frac{K\varepsilon_1^n}{n+1}$$

The drawing force, F, is

$$F = \bar{Y}A_f \ln\left[\frac{Æ_o}{Æ_f}\right]$$

2. Ideal deformation and friction

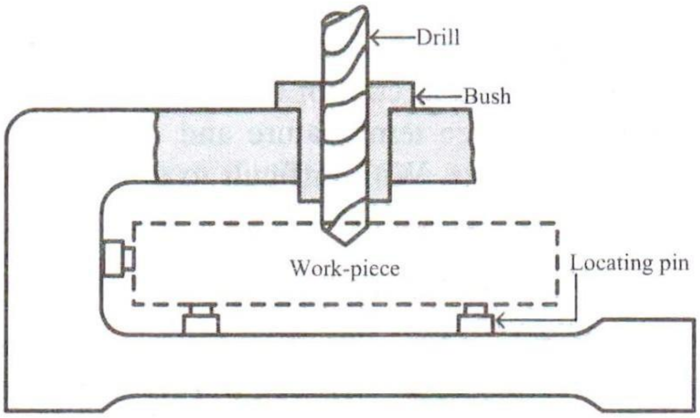
MODULE -4

JIGS AND FIXTURES

Jigs and fixtures are special purpose tools which are used to facilitate production (machining, assembling and inspection operations) when machined products are to be produced on a mass scale. The mass production of work-pieces is based on the concept of inter- changeability according to which every part will be produced within an established tolerance. Jigs and fixtures provide a means of manufacturing interchangeable parts since they establish a relation, with predetermined tolerances, between the work and the cutting tool. They are specially designed so that a large number of components can be machined or assembled identically, and to ensure inter-changeability of components. They eliminate the necessity of a special set up for each individual part. Once a jig or fixture is properly set up, any number of duplicate parts may be readily produced without additional set up.

Jig

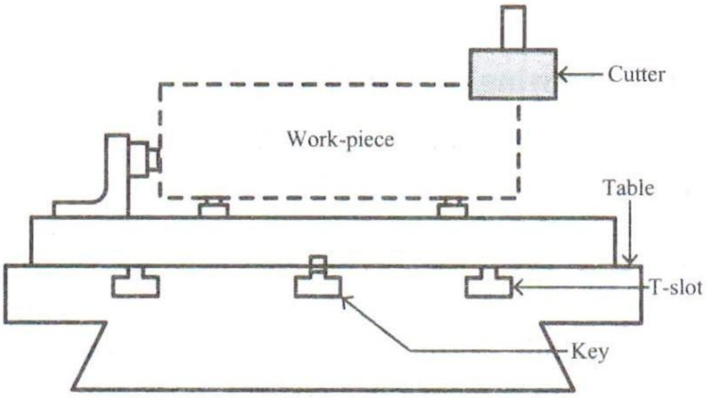
A jig is a device in which a component is held and located for a specific operation in such a way that it will guide one or more cutting tools to the same zone of machining. The usual machining operations for jigs are drilling and reaming. Jigs are usually fitted with hardened steel bushings for guiding drills or cutting tools. The most common jigs are drilling jigs, reaming jigs, assembly jigs, etc. When these are used, they are usually not fastened to machine tools or table but are free to be moved so as to permit the proper registering of the work and the tool. A simple drilling jig is shown in the figure. In the figure shown, the work-piece to be drilled is held and positioned in the drilling jig. Bushes guide the drills to the desired location(s) in the work-piece.



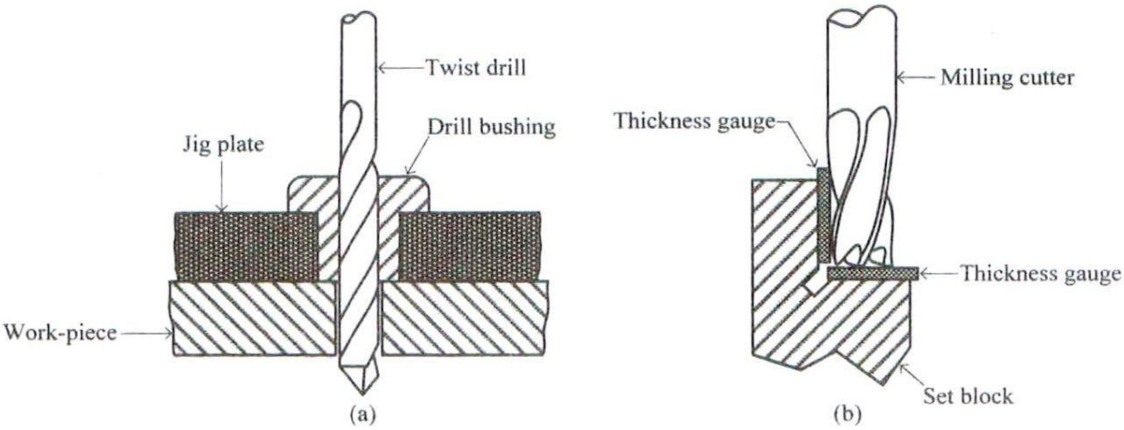
Fixture

A fixture is a production tool that locates, holds and supports the work securely in a fixed orientation with respect to the tool so that the required machining operations can be performed. The setting of the tool is done by machine adjustment and a setting block or by using slip gauges. A fixture is bolted or clamped to the machine table. It is usually heavy in construction. A simple fixture is shown in the figure. Fixtures vary in design from relatively simple tools to expensive complicated devices. These are most frequently attached to some machine tool or table. Consequently they are associated in name with the particular machine tool with which they are used, e.g., milling fixtures, broaching fixtures, assembly fixtures, etc. A fixture can be used in almost any operation that requires a precise relationship in the position of a tool to a work-piece.

Locating pins are stops or pins which are inserted in the body of jig or fixture, against which the work-piece is pushed to establish the desired relationship between the work-piece and the jig or fixture. To assure interchangeability, the locating elements are made from hardened steel. The purpose of clamping elements is to exert a force to press a work-piece against the locating elements and hold it there in opposition to the action of the cutting forces. In the case of a jig, a hardened bushing is fastened on one or more sides of the jig, to guide the tool to its proper location in the work. However, in the case of a fixture, a target or set block is used to set the location of the tool with respect to the work-piece within the fixture. Most jigs use standard parts such as drill bushings, screws, jig bodies and many other parts. Fixtures are made from grey cast iron or steel by welding or bolting. Fixtures are usually massive bodies because they have to withstand large dynamic forces. Because the fixtures are in between the machine and the work-piece their rigidity and the rigidity of their fastening to the machine table are most important. Jigs are positioned or supported on the machine table with the help of feet which slide or rest on the machine table. If the drill size is quite large, either stops are provided or the jig is clamped to the machine table to withstand the high drilling torque. Fixtures are clamped or bolted to the machine table.



DIFFERENCES BETWEEN JIGS AND FIXTURES



(a) *Jig*

(b) *Fixture*

Often the terms 'jig' and 'fixture' are confused or used interchangeably; however, there are clear distinctions between these two tools. Both jigs and fixtures hold, support, and locate the work-piece. A jig, however, guides the cutting tool. A fixture references the cutting tool. The differentiation between these types of work-holders is in their relation to the cutting tool. As shown in the figure (a), jigs use drill bushings to support and guide the tool. Fixtures, figure (b) use set blocks and thickness, or feeler, gages to locate the tool relative to the work-piece.

Following are the differences between jigs and fixtures.

1) Essential difference between a jig and fixture is that the jig incorporates bushes that guide the tools whereas, the fixture holds the component being machined with the cutters working independently, of it.
2) Jigs are used on drilling, reaming, tapping and counter boring operations, while fixtures are used in connection with turning, milling, grinding, shaping, planing and boring operations.
3) Whereas jigs are connected with operations, fixtures most commonly are related to specific machine tools.
4) Jigs are lighter than fixtures, for quick handling; fixtures are heavier in construction and bolted rigidly on the machine table.

Advantages of using jigs and fixtures

1) Jigs and fixtures provide easy means for manufacture of interchangeable parts and, thus, facilitate easy and quick assembly.
2) Reduced manufacturing costs (since large number of identical and interchangeable parts are produced) using jigs and fixtures.
3) Large reduction in fatigue to the operator (since there is considerable reduction in manual handling operations).
4) Complex and heavy components can be easily machined (since such parts can be rigidly held in proper location for machining in jigs and fixtures).
5) Owing to high clamping rigidity (offered by jigs and fixtures), higher speeds, feeds and depth of cut can be used and increased machining accuracy owing to the automatic location of the work and guidance of the tool.

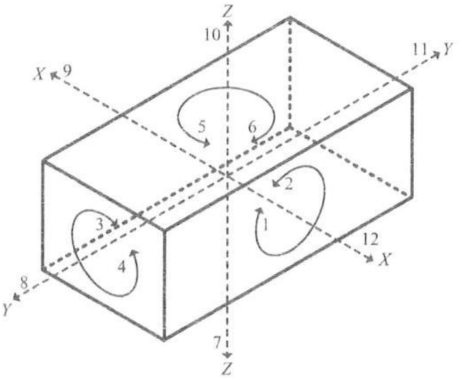
Main components of jigs and fixtures

In order to fulfill their basic functions, both jigs and fixtures should process the following components or elements.

1) Sturdy and rigid body.
2) Locating elements.
3) Clamping elements.
4) Tool guiding elements (for jigs) or tool setting elements (for fixtures).
5) Positioning elements (these elements include different types of fastening devices).
6) Indexing elements (not always provided).

Degrees of freedom

A work-piece free in space can move in an infinite number of directions. For analysis, this motion can be broken down into twelve directional movements, or 'degrees of freedom'. Notice the 12 degrees of freedom consisting of 6 axial degrees of freedom and 6 radial degrees of freedom as shown in the figure. The axial degrees of freedom permit straight-line movement in both directions along the three principal axes, shown as X, Y, and Z. The radial degrees of freedom permit rotational movement, in both clockwise and counter clockwise radial directions, around the same three axes.

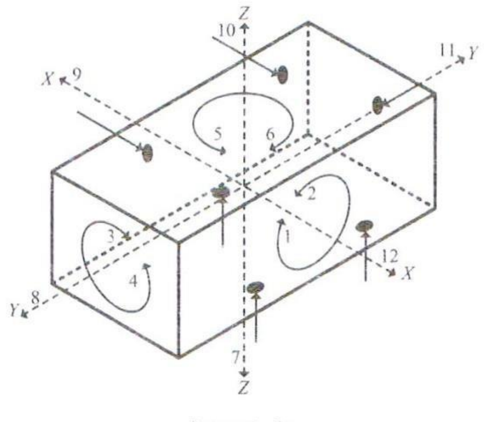


For accurate machining, the work-piece is to be placed and held in correct position and orientation in the fixture (or jig) which is again appropriately located and fixed with respect to the cutting tool (part of machine tool) and the machine tool (machine tool represent machine its self such as lathe, milling machine, etc., used to cut a metal in the desires shape). It has to be assured that the work-piece, once fixed or clamped, does not move at all. Any solid body may have maximum twelve degrees of freedom as indicated in the figure. By properly locating, supporting and clamping the blank it's all degrees of freedom are to be arrested as typically shown in the figure.

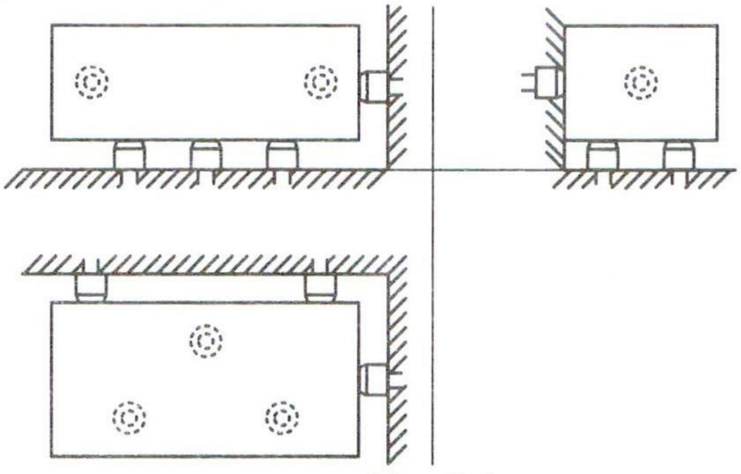
PRINCIPLES OF LOCATION

The term, ***'location'*** refers to the method of establishing correct relative position of the work-piece with respect to the cutting tool. In order to decide upon the location method, one has to consider the work-piece shape, surfaces and features that are likely to obstruct the tool movement or access direction. The correct positioning of the work-piece essentially requires restricting all the degrees of freedom of the work-piece. This is done with the help of locators, which must be strong enough to resist the cutting forces while maintaining the position of the work-piece. The basic principles of location are explained below.

1) ***3-2-1 Principle-*** A widely used method of restricting the 12 degrees of freedom is to uses the 3- 2-1 principle, so-called because it consists of three steps that employ three pins, then two pins, then one fixed pins of known location. Since that adds up to six fixed points, it's also known as the ***six point location principle***. Application of 3-2- 1 principle generally gives rise to proper arresting of all the motions.



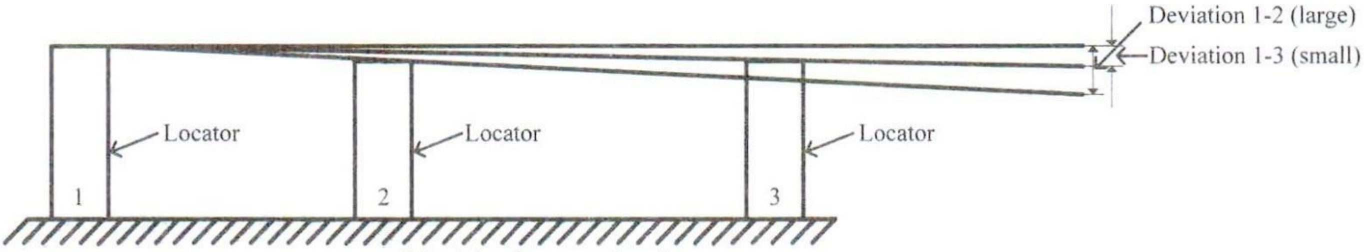
Isometric view



Orthographic view

In 3-2-1 method, three pins are inserted in the base of the body restrict five motions viz., ***1*** and ***2*** rotation about the axis XX", ***3*** and ***4*** rotation about axis YY and downward motion ***7*** along Z axis. Inserting two more pins in a plane perpendicular to the plane containing the first three pins will restrict the rotation about Z axis (***5*** and ***6***) and also restrict the axial movement along X axis (degree of freedom ***9***). Another pin is inserted in the vertical face of the body to restrict degree of freedom ***11***. Three degrees of freedom viz., ***8***, ***10*** and ***12*** are still free. To restrict these three more pins are needed. But this will completely enclose the work-piece making its loading and unloading into jigs and fixture impossible. The rest three degrees of freedom are arrested by three external forces usually provided directly by clamping. This is the most common locating method employed for ***square*** or ***rectangular parts***. The use of pin type locators offers more accuracy as the area of contact is less.

2) ***The principle of mutually perpendicular planes -*** An ideal location of a component is achieved when it is located on six locating points ('3- 2- 1 principle') in three mutually perpendicular planes. Other arrangements are possible but not desirable.
3) ***Principle of least point -*** In order to secure location in any one plane, points more than necessary should not be used. However, if more points are used such as for finished surface, the extra ones should only be inserted because they serve a useful purpose and care must be taken that they do not damage the location.
4) ***Principle of extreme position -*** On any one work-piece surface, locating points should be chosen as far apart as possible.

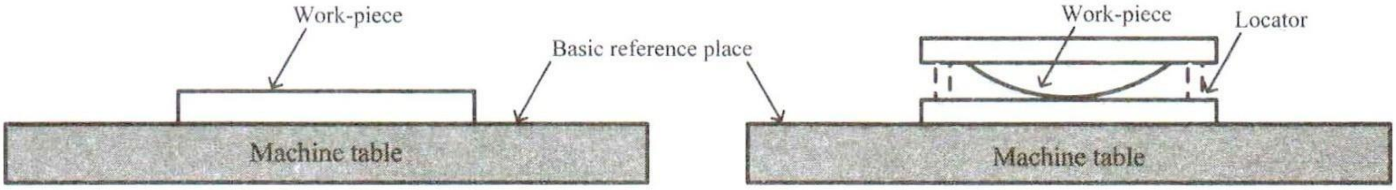


From the figure, it can be seen that, for a given displacement of any locating point from another, the resulting deviation decreases as the distance between the points increases.

LOCATING METHODS

Depending upon the nature of surfaces to be located, most commonly methods of locating surfaces are explained below.

Locating from plane surfaces - The basic reference for locating is a flat plane, generally a machine table. The machine table is usually at right angles or parallel with the machines' feed movements. All locating devices are made with regard to the basic reference plane (machine table). If the work-piece has a flat side to mate with the machine table, the machine table becomes the locating surface.

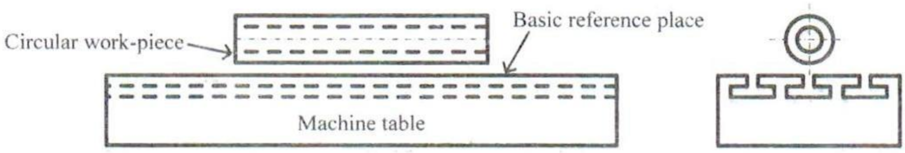


a) Work-piece with flat side

b) Work-piece without flat side

If the work-piece does not have a flat side to mate with the machine table, the flat plane of the machine table cannot be used as a locating surface. A minimum of three points (or locators) must be used to locate the work-piece shown in the figure (b), although four or more may be used to provide adequate support. It should be noted that a minimum of three locators will always theoretically establish the same location of the work-piece. The number of adjustable supports would depend upon the shape, strength and size of the work-piece.

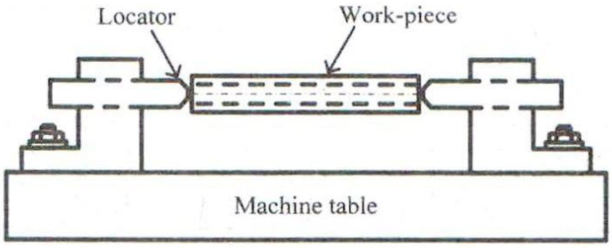
Locating from circular surfaces **-** The basic reference for locating from circular surfaces is the flat plane of the machine-tool table surface. However, instead of locating the flat plane of the work-piece parallel to the reference plane, it is necessary to locate the axis of the circular work-piece as shown in the figure.



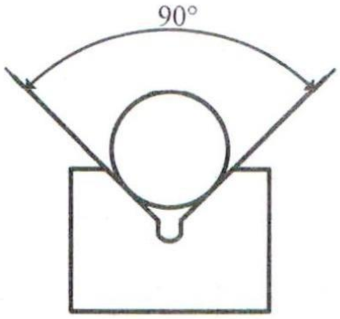
Circular work-piece must be located with its axis parallel with the basic reference plane.

One of the common methods of locating from a circular surface is by using cones, a method commonly referred to as conical location and usually employed when locating is done from a hole. Conical locators are used mainly to locate rough unmachined cylinders in castings and forgings.

Closely related to conical location is the V method, used primarily to locate round work-pieces or work-pieces with convex circular surfaces. It has been found that the best general Vangie is 90°. Smaller included angles hold a round work-piece more securely but are more susceptible to location errors.

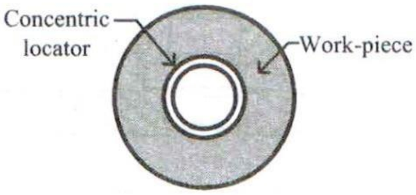


Conical locator



V locator

Concentric locating **-** Concentric locators locate a work-piece from its axis. This axis may or may not be in the center of the work-piece. The most-common type of concentric location is a locating pin placed in a hole.



LOCATING DEVICES

There are several methods of locating; few of them are discussed below.

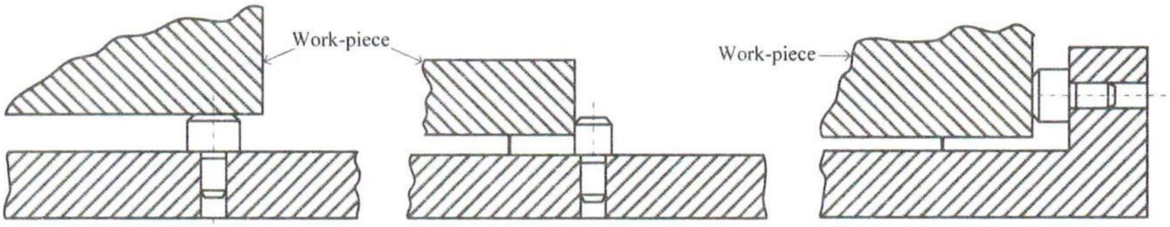
Locating blanks for machining in lathes - In lathes, where the job rotates, the blanks are located by the following methods.

a) Fitting into self centering chuck.
b) Fitting into 4- independent jaw chuck and dead centre.
c) In self- centering collets.
d) In between live and dead centres.
e) By using mandrel fitted into the head stock - spindle.
f) Fitting in a separate fixture which is properly clamped on a driving plate which is coaxially fitted into the lathe spindle.

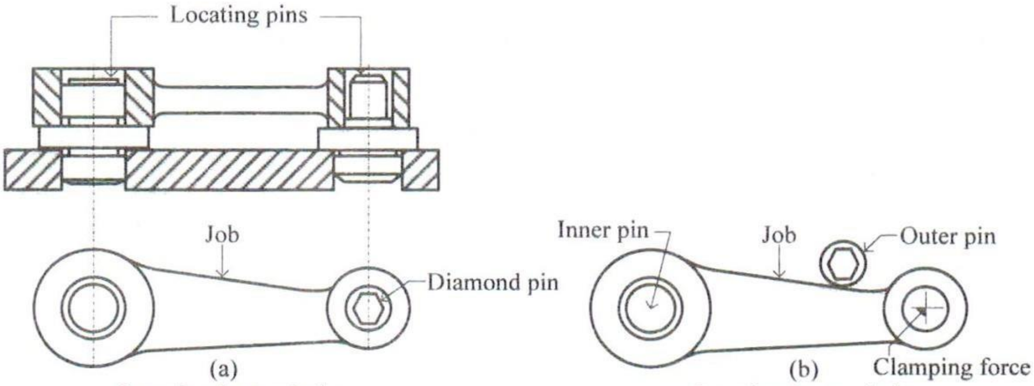
Locating for machining other than lathes - In machine tools like drilling machine, boring machine, milling machine, planing machine, broaching machine and surface grinding machine the job remains fixed on the bed or work table of those machine tools. Fixtures are mostly used in tpe aforesaid machine tools and jig specially for drilling, reaming, etc. for batch production. For machining in those jigs and fixtures, the blank is located in several ways which include the followings.

1) Locating by flat surfaces

The figure typically shows locating jobs by their flat surfaces using various types of flat ended pins and buttons.



2) Locating by holes



(a)
Locating by two holes

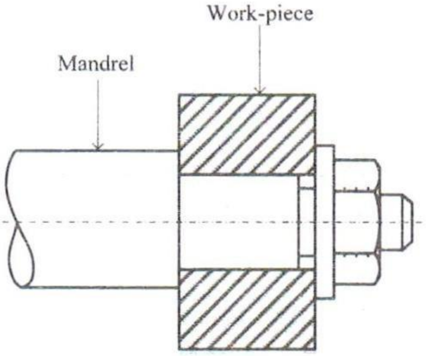
(b)
Locating by one hole

In several cases, work-pieces are located by pre-machined (drilled, bored or pierced) holes, such as below.

i. Locating by two holes as shown in the figure (a) where one of the pins has to be diamond shaped to accommodate tolerance on the distance between the holes and their diameters.
ii. Locating by one hole and an external pin which presents rotation of the blank around the inner pin as indicated in figure (b).

3) Locating on mandrel or plug

Ring or disc type work-pieces are conveniently located on mandrel or single plug as shown in the figure.



CLAMPING DEVICES

In jigs and fixtures, the work-piece or blank has to be strongly and rigidly clamped against the supporting surfaces and also the locating features so that the blank does not get displaced at all under the cutting forces during machining. A clamp is a device that holds the work-piece firmly against the locators provided and also resists all the forces generated by the cutting action of the tool on the work-piece. The most common example of a clamp is the bench vice, where the movable jaw of the vice exerts force on the work-piece thereby holding it in the correct location in the fixed jaw of the vice. A clamping device ensures proper location and centering of the work-piece.

Basic requirements of clamping devices

1. To force the work-piece to remain in firm contact with locating pins or surfaces.
2. To rigidly hold the work-piece in a jig or fixture against all forces.
3. To exert just sufficient pressure on the work-piece.
4. To not to damage the work-piece it holds.

Principles Of Clamping

While designing for clamping the following factors essentially need to be considered.

1) Clamping need to be strong and rigid enough to hold the blank firmly during machining.
2) Clamping should be easy, quick and consistently adequate.
3) Clamping should be such that it is not affected by vibration, chatter or heavy pressure.
4) The way of clamping and unclamping should not hinder loading and unloading the blank in the jig or fixture.
5) The clamp and clamping force must not damage or deform the work-piece.
6) Clamping operation should be very simple and quick acting when the jig or fixture is to be used more frequently and for large volume of work clamps.
7) Clamping system should comprise of less number of parts for ease of design, operation and maintenance.
8) The wearing parts should be hard or hardened and also be easily replaceable.
9) Clamping force should act on heavy part(s) and against supporting and locating surfaces.
10) Clamping force should be away from the machining thrust forces.
11) Clamping method should be fool proof and safe.

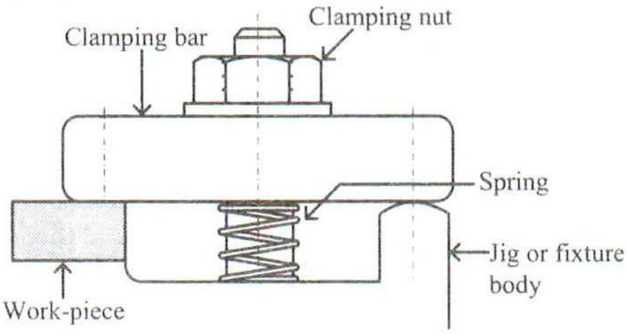
Types of clamps

The type of clamp to be used depends on the shape and size of the work-piece, the type of jig or fixture being used and the work to be done. There a number of clamps used by tool designers for clamping the work-piece properly. Different variety of clamps used with jigs and fixtures are classified into different categories are discussed below.

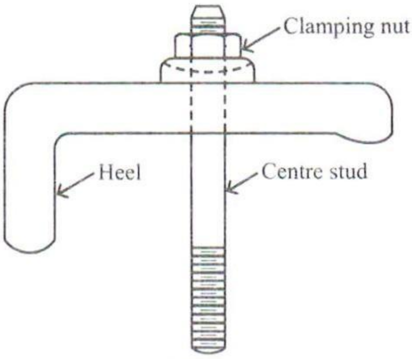
Strap clamp - Strap clamp are made of rectangular plates and act like levers. This type clamping is done with the help of the lever pressure acting as a strap on the workpiece.

Different types of strap clamps are discussed below.

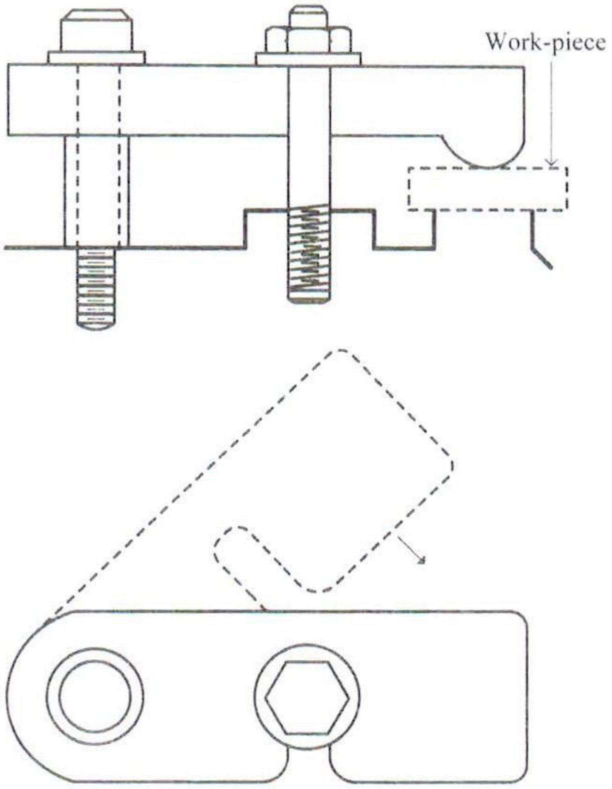
a) ***Bridge clamp -*** It is very simple and reliable clamping device. The clamping force is applied by the spring loaded clamping nut. The relative positions of the nut, the point of contact of the clamp with the work and with outer support should be carefully considered, since the compressive force of the nut is shared between the work-piece and the clamp support. To release the work-piece, the nut named as clamping nut is unscrewed. The spring lifts the lever to release the work-piece.



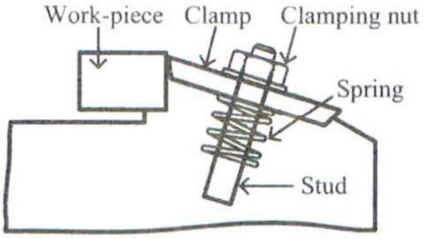
b) ***Heel clamp -*** Heel clamp consist of strap, centre stud and a heel. The design differs from the simple bridge clamp in that a heel is provided in the outer end of the clamp to guide its sliding motion for loading and unloading the work-piece. By tightening the stud, the clamping force is transferred to the work-piece. Heel pin is the fulcrum about which the lever acts, while clamping force is applied at the stud by tightening the screw. The work-piece is loaded into the jig or fixture or removed from these, by unscrewing the clamping nut.



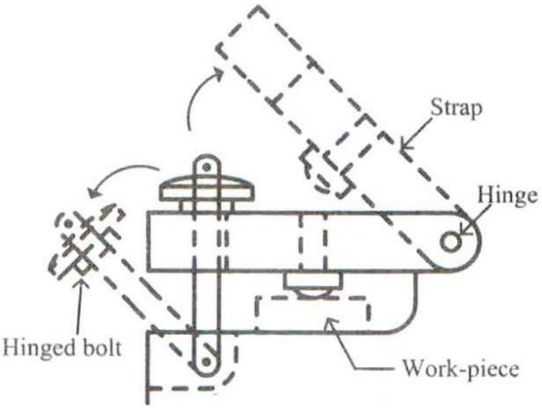
c) ***Swinging strap clamp-*** Swinging strap clamp is a special type of clamp which provides a means of entry for loading and unloading the work-piece. For this, the strap can be swung out or in. A swing strap clamp is shown in the figure.



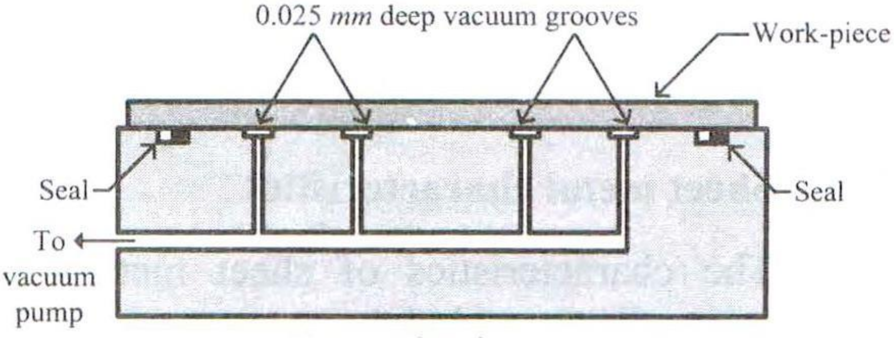
***Side clamp* -** A side clamp is also known as edge clamp. In this case the surface to be machined is always clamped above the clamping device. This clamping device is recommended for fixed length work-piece. The clamping device is illustrated in the figure. Releasing and clamping of the work-piece can be accomplished by unscrewing and screwing of the clamping nut respectively.



***Hinged clamp* -** Several times, the requirement in a jig is that the strap (latch) should be completely lifted up for loading and unloading the work-piece. Hinged clamp has a hinged bolt and hinged strap/plate which when swung apart gives space to mount the workpiece. An example of hinged clamp is shown in the figure. The upper strap is locked on one side by means of the hinged bolt. This clamp provides rapid clearance for loading and unloading the work-piece.



Vacuum clamping **-** Vacuum clamping is convenient for securing thin flat sheets which are vulnerable to distortion under heavy clamping force. Vacuum clamping provides light clamping. The holding face is provided with 0.025 mm deep grooves which serve as vacuum ducts. The clamping face is circumscribed by a rubber seal groove all around. The seal in the groove segregates the clamping vacuum area from the space outside the seal. The vacuum pressure is usually limited to 1 kg/cm^2. The figure shows a vacuum holding fixture, distribution grooves and rubber seal.



Magnetic clamping- Magnetic clamping uses electromagnetism for holding and is often used to hold ferrous metals or work-pieces made from other magnetic materials. It is independent of the component geometry to a certain degree. Magnetic clamping force can be developed by permanent magnets or electromagnets. In permanent magnet type, the work-piece to be clamped is placed on the work surface of the clamp. Below the working surface, there are a number of permanent magnets. When the lever is in 'ON' position, the magnetic flux passes through the work-piece to complete the magnetic circuit. When the lever is in OFF' position, the magnetic flux passes through the working surfaces of the clamp only and not through the work-piece, thus unclamping the work-piece. This is done by aligning the magnets with a number of non-magnetic separators. In electromagnetic clamp, direct current is used for clamping the work-piece on electromagnetic devices. These magnets are more powerful than permanent magnet type clamps. Compared to other clamping methods, magnetic clamping is relatively weak. Magnetic clamping is widely used for grinding, and can be used for light milling and turning. It is fast and convenient.

MODULE -5

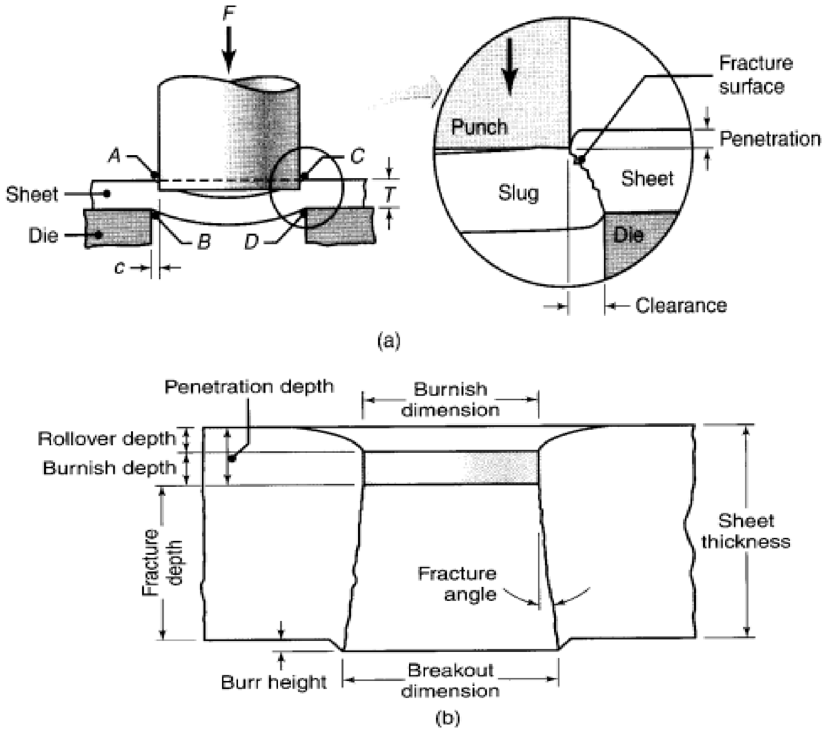
SHEET METAL FORMING

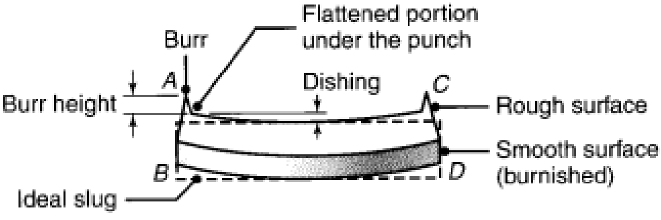
Comaprison between sheet metal forming and bulk deformation processes

Unlike the bulk forming deformation processes described in the earlier chapters, sheet forming is carried out generally in the plane of the sheet by tensile forces. The application of compressive forces in the plane of the sheet is avoided because it leads to buckling, folding, and wrinkling of the sheet. While in bulk forming processes the intention is often to change the thickness or lateral dimensions of the workpiece , in sheet forming processes decreases in thickness should be avoided because they could lead to necking and failure. Another basic difference between bulk forming and sheet forming is that sheet metals, by their very nature, have a high ratio of surface area to thickness

Shearing

Before a sheet-metal part is made, a blank of suitable dimensions first is removed from a large sheet (usually from a coil) by shearing. This sheet is cut by subjecting it to shear stresses, generally using a punch and a die. The typical features of sheared edge of sheet & slug are shown in fig.





(c)

Shearing generally starts with the formation of cracks on both the top and bottom edges of the workpiece (at points A and B, and C and D, in Fig. 16.2a). These cracks eventually meet each other and complete separation occurs. The rough fracture surfaces are due to the cracks; the smooth and shiny burnished surfaces on the hole and the slug are from the contact and rubbing of the sheared edge against the walls of the punch and die, respectively.

The major processing parameters in shearing are

1)The shape of the punch and die 2)The speed of punching

3) Lubrication 4) The clearance, c, between the punch and the die.

Clearance

The clearance c in a shearing operation is the distance between the punch and die. Typical clearances in conventional pressworking range between 4% and 8% of the sheet metal thickness t. The clearance is a major factor in determining the shape and the quality of the sheared edge. If the clearance is too small, then the fracture lines tend to pass each other, causing a double burnishing and larger cutting forces. If the clearance is too large, the metal becomes pinched between the cutting edges and an excessive burr results. As the clearance increases, the zone of deformation becomes larger and the sheared edge becomes rougher. The sheet tends to be pulled into the clearance region, and the perimeter or edges of the sheared zone become rougher. Unless such edges are acceptable as produced, secondary operations may be required to make them smoother (which will increase the production cost).

The recommended clearance can be calculated by the following formula:

$c = A_c t$: where A_c – clearance allowance , t – thickness

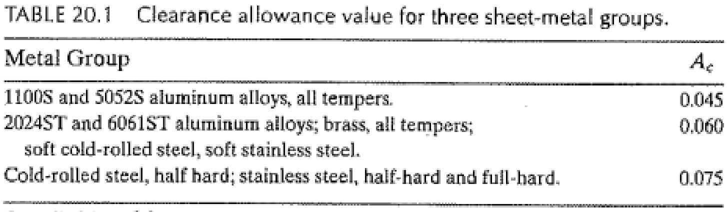
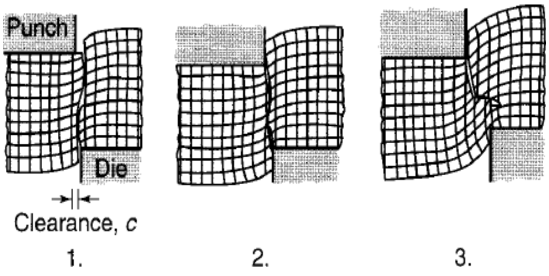
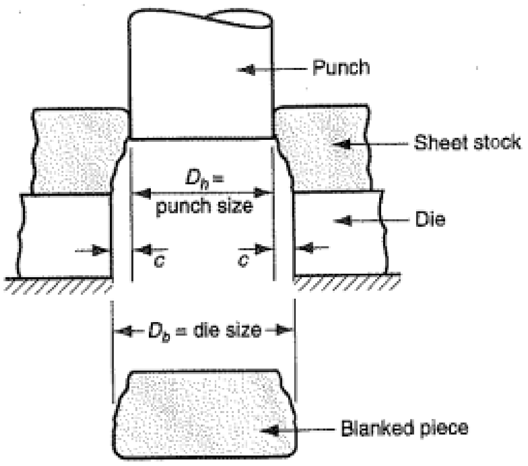


TABLE 20.1 Clearance allowance value for three sheet-metal groups.

Metal Group	A_c
1100S and 5052S aluminum alloys, all tempers.	0.045
2024ST and 6061ST aluminum alloys; brass, all tempers; soft cold-rolled steel, soft stainless steel.	0.060
Cold-rolled steel, half hard; stainless steel, half-hard and full-hard.	0.075



The die opening must always be larger than the punch size. Whether to add the clearance value to the die size or subtract it from the punch size depends on whether the part being cut out is a blank or a slug. Because of the geometry of the sheared edge, the outer dimension of the part cut out of the sheet will be larger than the hole size.



Thus, punch and die sizes for a round blank of diameter D_b are determined as Blanking punch diameter = D_b — 2c ; Blanking die diameter = D_b

Punch and die sizes for a round hole of diameter D_h, are determined as Hole punch diameter = D_h ; Hole die diameter = D_h + 2c

In order for the slug or blank to drop through the die, the die opening must have an angular clearance of 0.25^0 to 1.5° on each side.

Edge quality can be improved with increasing punch speed; speeds may be as high as 10 to 12 m/s. Sheared edges can undergo severe cold working due to the high shear strains involved. Work hardening of the edges then will reduce the ductility of the edges and thus adversely affect the formability of the sheet during subsequent operations, such as bending and stretching.

The ratio of the burnished area to the rough areas along the sheared edge (a) increases with increasing ductility of the sheet metal and (b) decreases with increasing sheet thickness and clearance. The extent of the deformation zone in depends on the punch speed. With increasing speed, the heat generated by plastic deformation is confined to a smaller and smaller zone. Consequently, the sheared zone is narrower, and the sheared surface is smoother and exhibits less burr formation. A burr is a thin edge or ridge, as shown in Figs. 16.2b and c. Burr height increases with increasing clearance and ductility of the sheet metal. Dull tool edges contribute greatly to large burr formation. The height, shape, and size of the burr can significantly affect subsequent forming operations.

Punch Force

The force required to punch out a blank is basically the product of the shear strength of the sheet metal and the total area being sheared along the periphery. The maximum punch force, F, can be estimated from the equation,

$$\mathbf{F = 0.7TL(UTs)}$$

where T is the sheet thickness, L is the total length sheared (such as the perimeter of a hole), and UTS is the ultimate tensile strength of the material. As the clearance increases, the punch force decreases, and the wear on dies and punches also is reduced.

Friction between the punch and the workpiece can, however, increase punch force significantly. Furthermore, in addition to the punch force, a force is required to strip the punch from the sheet during its return stroke. This second force, which is in opposite direction of the punch force, is difficult to estimate because of the many factors involved in the operation.

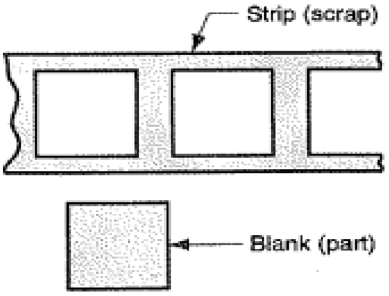
Shearing Operations

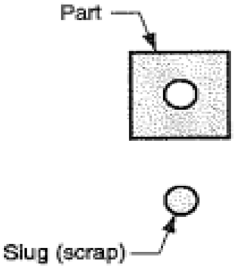
The most common shearing operations are punching-where the sheared slug is scrap (Fig. 16.4a) or may be used for some other purpose-and blanking-where the slug is the part to be used and the rest is scrap. The operations described next, as well as those described throughout the rest of this chapter, generally are carried out on computer-numerical- controlled machines with quick-change tool holders. Such machines are useful, particularly in making prototypes of sheet-metal parts requiring several operations to produce

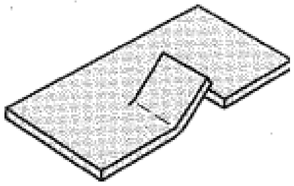
Die Cutting

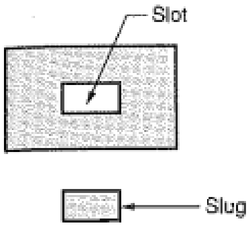
This is a shearing operation that consists of the following basic processes :

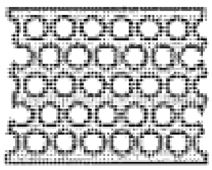
- Perforating: punching a number of holes in a sheet
- Parting: shearing the sheet into two or more pieces
- Slitting : Shearing operations can be carried out by means of a pair of circular blades. In slitting, the blades follow either a straight line, a circular path, or a curved path.
- Blanking : involves cutting of the sheet metal along a closed outline in a single step
- Punching : is similar to blanking except that the separated piece is scrap, called the slug. The remaining stock is to separate the piece from the surrounding stock is the desired part.
- Notching: removing pieces (or various shapes) from the edges
- Lancing: leaving a tab without removing any material.
- Slotting : a punching operation that cuts out an elongated or rectangular hole
- Seminotching : removes a portion of metal from the interior of the sheet . The difference is that the metai removed by seminotching creates part of the blank outline, while punching and slotting create holes in the blank.
- Nibbling : In nibbling, a machine called a nibbler moves a small straight punch up and down rapidly into a die. A sheet is fed through the gap and many overlapping holes are made.

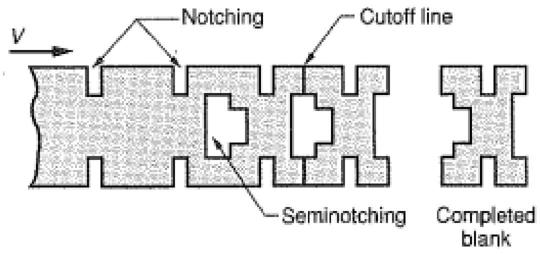


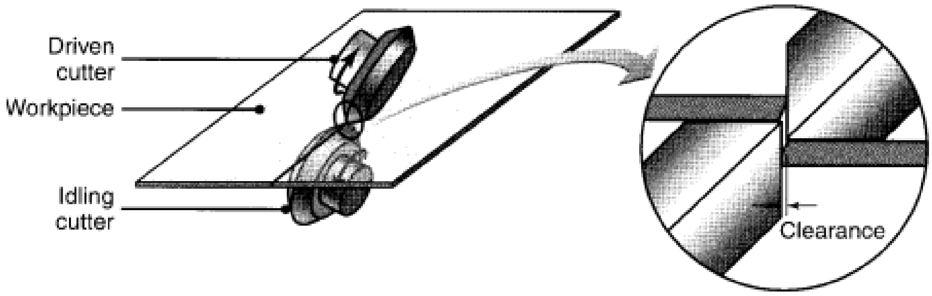












Perforated sheet metals with hole diameters ranging from around 1 mm to 75 mm have uses as filters, as screens, in ventilation, as guards for machinery, in noise abatement, and in Weight reduction of fabricated parts and structures. They are punched in crank presses at rates as high as 300,000 holes per minute, using special dies and equipment.

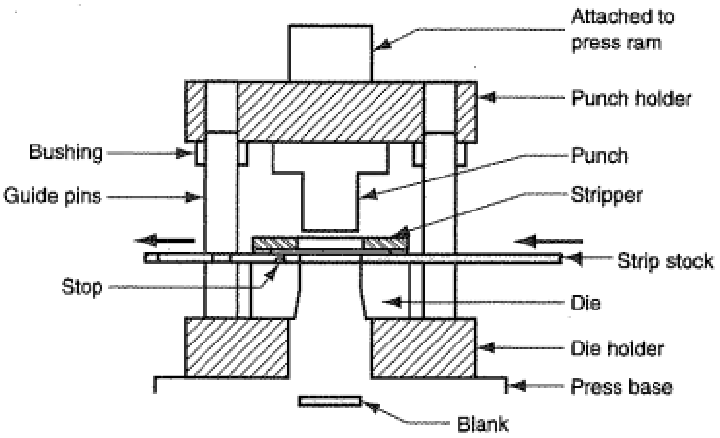
Fine Blanking

Very smooth and square edges can be produced by fine blanking. One basic die design is shown in fig. A V-shaped stinger or impingement mechanically locks the sheet tightly in place and prevents the type of distortion of the material.

Characteristics and Type of Shearing Dies

The term stamping die is sometimes used for high - production dies.

Components of a Stamping Die : The components of a stamping die to perform a simple blanking operation are illustrated in Fig. The working components are the punch and die, which perform the cutting operation. They are attached to the upper and lower portions of the die set, respectively called the punch holder (or upper shoe) and die holder (lower shoe). The die set also includes guide pins and bushings to ensure proper alignment between the punch and die during the stamping operation. The die holder is attached to the base of the press, and the punch holder is attached to the ram. Actuation of the ram accomplishes the press working operation.



In addition to these components, a die used for blanking or hole- punching must include a means of preventing the sheet metal from sticking to the punch when it is retracted upward after the operation. The newly created hole in the stock is the same size as the punch, and it tends to cling to the punch on its withdrawal. The device in the die that strips the sheet metal from the punch is called a stripper. For dies that process strips or coils of sheet metal, a device is required to stop the sheet metal as it advances through the die between press cycles. That device is called a stop.

Types of Stamping Dies

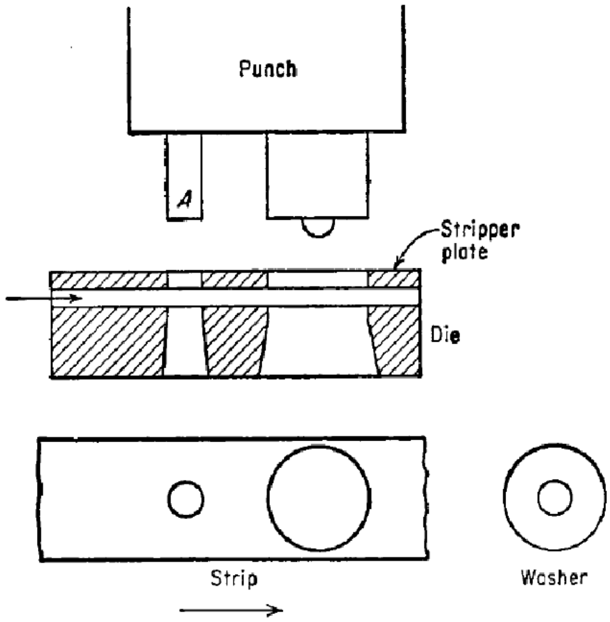
1. **Simple Die**
2. **Compound Die**
3. **Combination Die**
4. **Progressive Die**

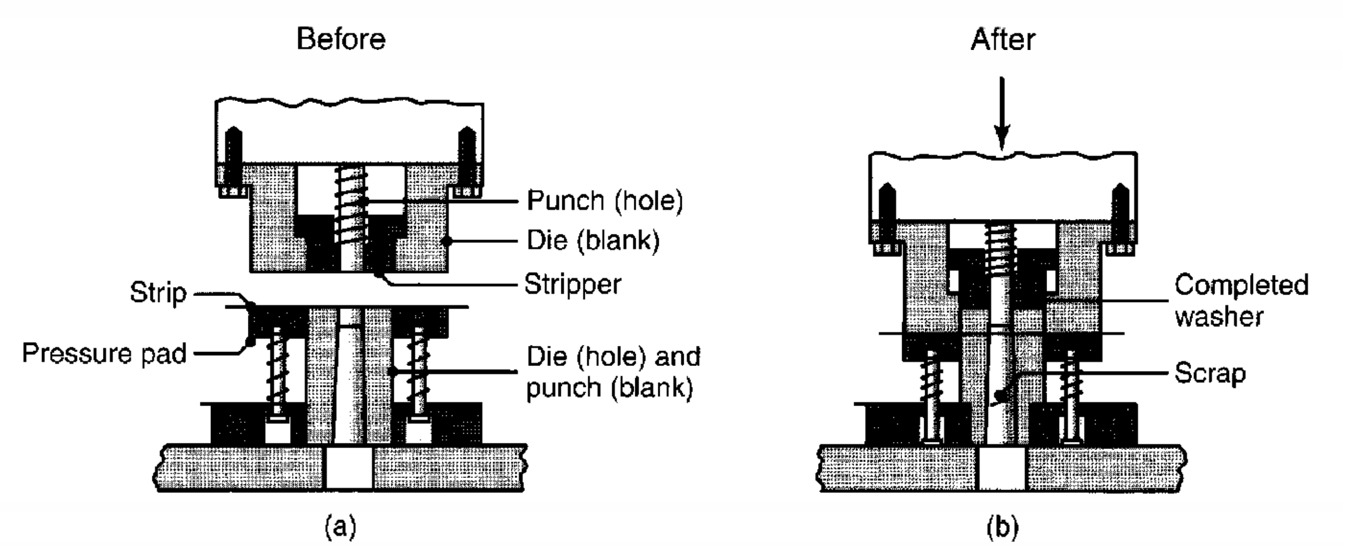
SIMPLE DIE : performs a single blanking operation with each stroke of the press.

COMPOUND DIE : performs two operations at a single station, such as blanking and punching, or blanking and drawing. A good example is a compound die that blanks and punches a washer.

COMBINATION DIE : it performs two operations at two different stations in the die. Examples of applications include blanking two different parts (e.g., right-hand and left-hand parts), or blanking and then bending the same part.

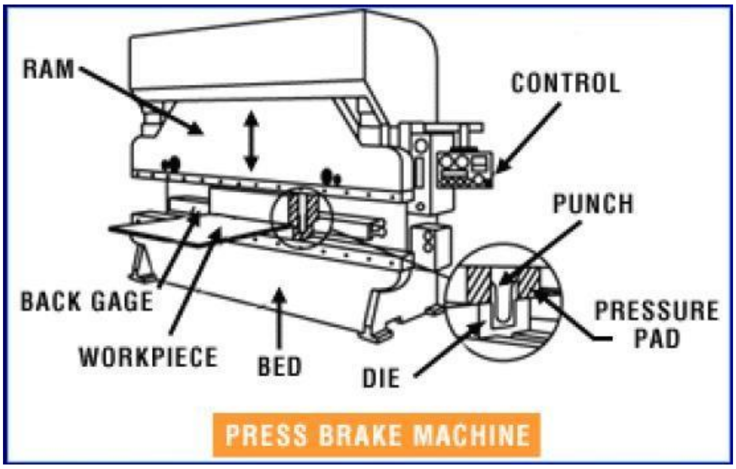
PROGRESSIVE DIE : performs two or more operations on a sheet□metal coii at two or more stations with each press stroke. The part is fabricated progressively. The coil is fed from one station to the next and different operations (e.g., punching, notching, bending,and blanking) are performed at each station. When the part exits the final station it has been completed and separated (cut) from the remaining coil.



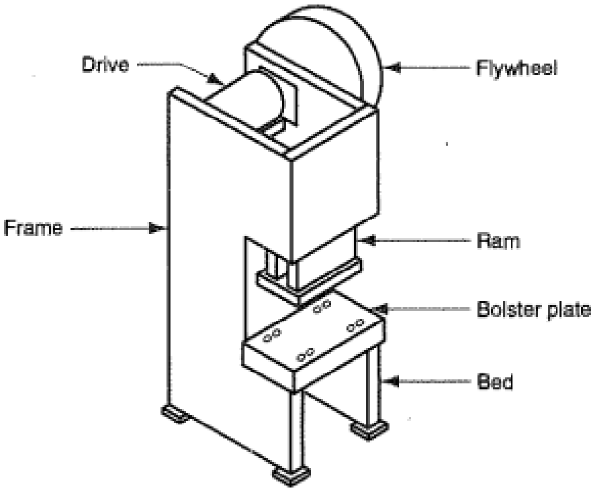


Presses used in sheet metal forming

A press used for sheet metalworking is a machine too} with a stationary bed and a powered ram (or slide) that can be driven toward and away from the bed to perform various cutting and‘ forming operations. The capacity of a press is its ability to deliver the required force and energy to accomplish the stamping operation. This is determined by the physical size of the press and by its power system. The power system refers to whether mechanical or hydraulic power is used and the type of drive used to transmit the power to the ram. Production rate is another important aspect of capacity.



Type of press frame refers to the physical construction of the press. There are two types of frames in common use: gap frame and straight sided frame.



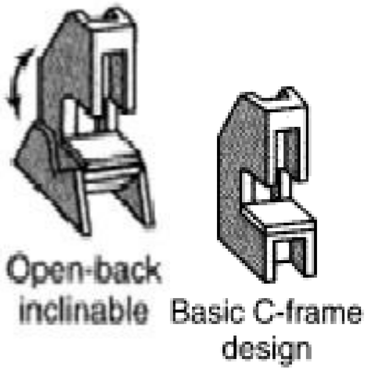
Punches and dies should also be in proper alignment so that a uniform clearance is maintained around the entire periphery. The die is usually attached to the bolster plate of the press, which, in turn, is attached to the main press frame. The punch is attached to the movable ram, enabling motion in and out of the die with each stroke of the press.

Gap Frame Presses

The gap frame has the general configuration of the letter C and is often referred to as a C frame. Gap frame presses provide good access to the die, and they are usually open in the back to permit convenient ejection of stampings or scrap. The principal types of gap frame press are (a) solid gap frame, (b) adjustable bed, (c) open back inclinable, (d) press brake, and (e) turret press.

The solid gap frame (sometimes called simply a gap press) has one-piece construction. Presses with this frame are rigid, yet the C-shape allows convenient access from the sides for feeding strip or coil stock. They are available in a range of sizes, with capacities up to around 9,000 kN (1,000 tons).

The press brake is a gap frame press with a very long and narrow bed.



Gap-frame presses, where the frames have the shape of the letter C, are among the most versatile and commonly preferred presses. They provide unobstructed access to the dies from three directions and permit large work pieces to be fed into the press. Gap-frame presses are available in a wide range of sizes, from small bench types of about 1 metric ton up to 300 metric tons or more.

Open-back presses allow for the ejection of products or scrap through an opening in the back of the press frame. Inclinable presses can be tilted, so that ejection can be assisted by gravity or compressed air jets. As a result of these features, open-back inclinable (OBI) presses are the most common form of gap-frame press. The addition of an adjustable bed allows the base of the machine to raise or lower to accommodate different work pieces

Turret presses are especially useful in the production of sheet metal parts with numerous holes or slots that vary in size and shape. Turret presses have a C-frame. The conventional ram and punch is replaced by a turret containing many punches of different sizes and shapes. The turret works by indexing (rotating) to the position holding the punch to perform the required operation. Beneath the punch turret is a corresponding die turret that positions the die opening for each punch. Between the punch and die is the sheet metal blank.

Straight sided Frame Presses

For jobs requiring high tonnage, press frames with greater structural rigidity are needed. Straighvsided presses have full sides, giving it a box-like appearance. This construction increases the strength and stiffness of the frame. As a result, capacities up to 35,000 kN (4000 tons) are available in straight-sided presses for sheet metalwork. Large presses of this frame type are used for forging.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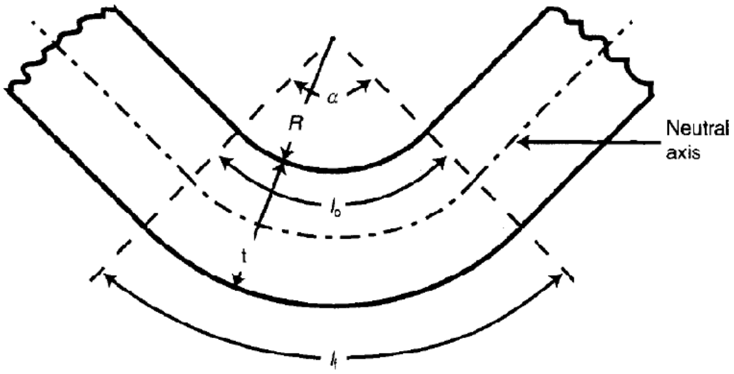
Bending

Bending is the process by which a straight length is transformed into a curved length. It is a very common forming process for changing sheet and plate into channel, drums, tanks, etc. In addition, bending is part of the deformation in many other forming operations. The bend radius R is defined as the radius of curvature on the concave, or inside, surface of the bend. During bending the sheet outer radius is in tension, while the inner radius is in compression. Neutral line retains the original length. For large R neutral line is at the centre. But for tight R neutral line shift towards compressive side. For a given sheet thickness h , tensile & compressive strains increases with decreasing R / t ratio.The smaller the radius of curvature, the greater the decrease in thickness on bending.



α= bend angle , R = bend radius , t = thickness

Bend allowance

Bend allowance, A_b, is the length of the neutral axis in the bend; it is used to determine the length of the blank for a part to be bent.

$$A_b = 2\pi\ (\alpha/360)\ (R+K_{ba}t)$$

K_{ba}, is factor to estimate stretching , $K_{ba} = 0.33$, $R < 2t$

$=0.50$, $R \geq 2t$

Minimum Bend Radius (Bendability)

The radius at which a crack first appears appears at the outer fibers of a sheet being bent is referred to as the minimum bend radius. It can be shown that the engineering strain on the outer and inner fibers of a sheet during bending is given by the expression

$$e = \frac{1}{\left(\frac{2R}{t}\right)+1}$$

Thus, as R/t decreases (that is, as the ratio of the bend radius to the thickness becomes smaller), the tensile strain at the outer fiber increases and the material eventually develops cracks. The bend radius is usually expressed (reciprocally) in terms of the thickness, such as 2t, 3t, 4t, and so on. Thus, a 3t minimum bend radius indicates that the smallest radius to which the sheet can be bent without cracking is three times its thickness.

The minimum bend radius, R, is, approximately,

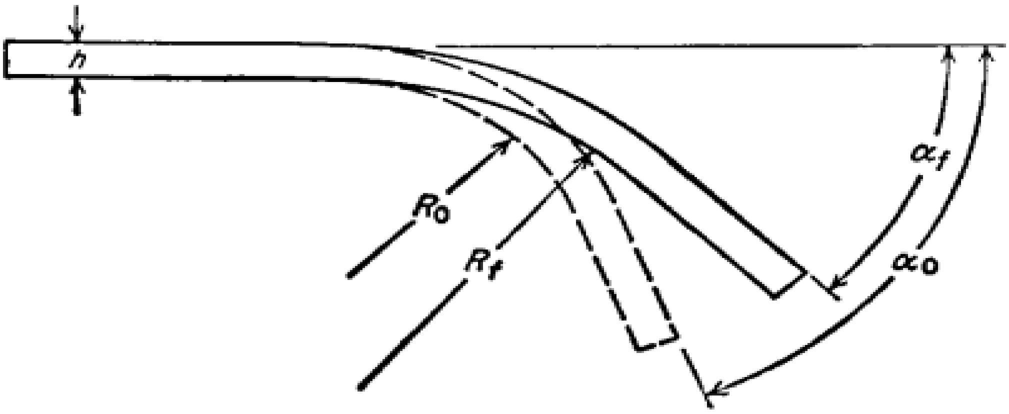
$$R = t\left(\frac{50}{r} - 1\right)$$

where r is the tensile reduction of area of the sheet metal. Thus, for r = 50, the minimum bend radius is zero; that is, the sheet can be folded over itself in much the same way as a piece of paper is folded. To increase the bendability of metals, we may increase their tensile reduction of area either by heating or bbending in a high-pressure environment (which improves the ductility of the material). Bendability also depends on the edge condition of the sheet. Since rough edges are points of stress concentration, bendability decreases as edge roughness increases.

Anisotropy of the sheet is another important factor in bendability. Cold rolling results in anisotropy by preferred orientation or by mechanical fibering due to the alignment of any impurities,inclusions, and voids that may be present, as shown in Fig.Prior to laying out or nesting blanks for subsequent bending, caution should be exercised to cut in the proper direction from a rolled sheet.

Spring back

When the bending pressure is removed at the end of the deformation 0peration, elastic energy remains in the bent part, causing it to recover partially toward its original shape. This elastic recovery is called spring back .



R_o R_o a 3 R_o a

—— —— —— —— ——

$$R_f = 4(E \qquad h) - 3(E \qquad h) + 1$$

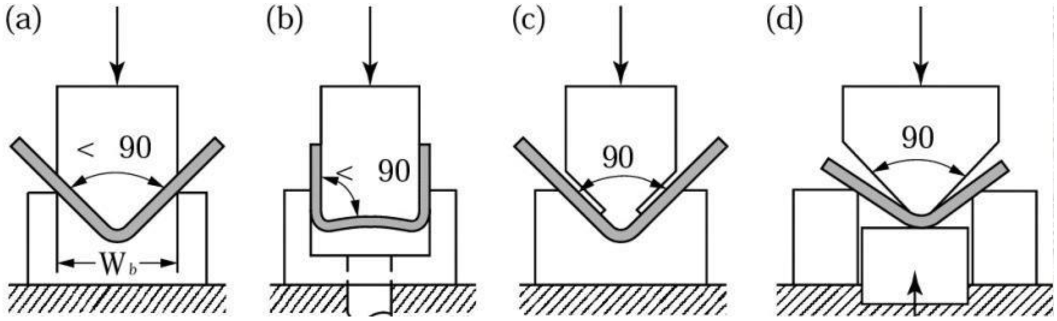
E – modulus of elasticity , σ – yield stress, R_o – original bend radius , R_f- final bend radius

Springback increases

(a) as the R/h ratio increase,(b) and the yield stress of material increases ,(c) as the elastic modulus, E, decreases.

Compensation for springback

Compensation for springback can be accomplished by several methods. Two common methods are overbending and bottoming. In overbending, the punch angle and radius are fabricated slightly smaller than the specified angle on the final part so that the metal springs back to the desired value. Bottoming involves squeezing the part at the end of the stroke, thus plastically deforming it in the bend region.

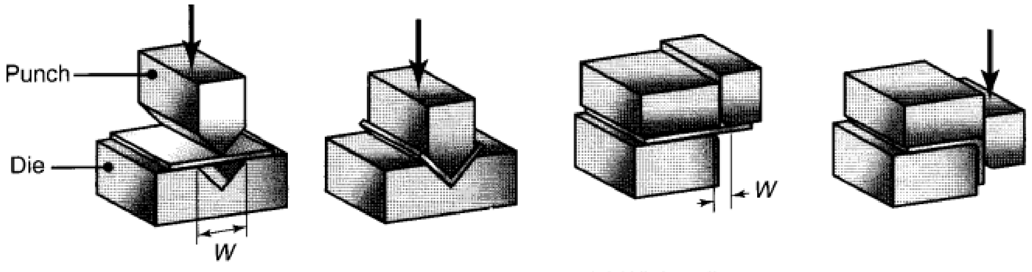


Bending Force

The bending force is a function of the strength of the material, the length, L, of the bend, the thickness, T, of the sheet, and the die opening, W.

maximum bending force, $P = \frac{kFLT^2}{M}$

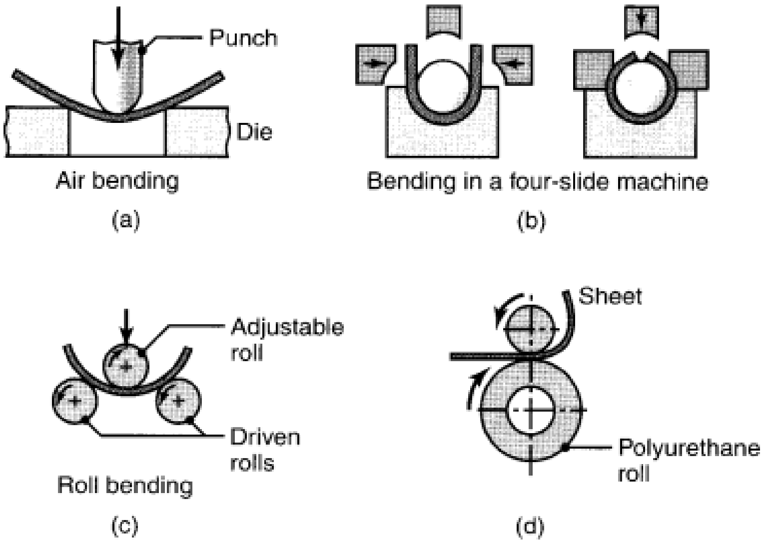
Where the factor k ranges from about 0.3 for a Wiping die, to about 0.7 for a U-die ,to about 1.3 for a V-die and Y is the yield stress of the material.



(a) V-die (b) Wiping die

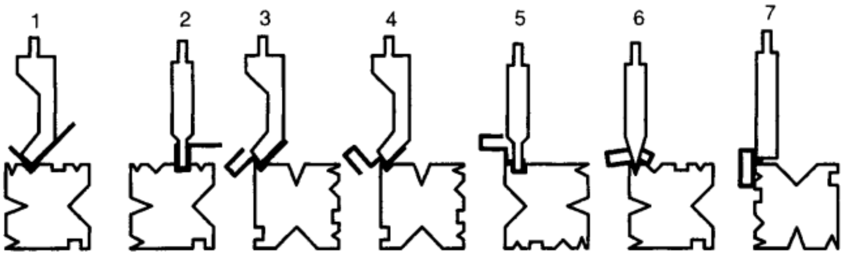
The force in die bending varies throughout the bending cycle. It increases from zero to a maximum, and it may even decrease as the bend is completed. The force then increases sharply as the punch reaches the bottom of its stroke and the part touches the bottom of the die.

various bending operations



Press-brake Forming

Sheet metal or plate can be bent easily with simple fixtures using a press. Sheets or narrow strips that are 7 m or even longer usually are bent in a press brake.



Bending in a Four-slide Machine

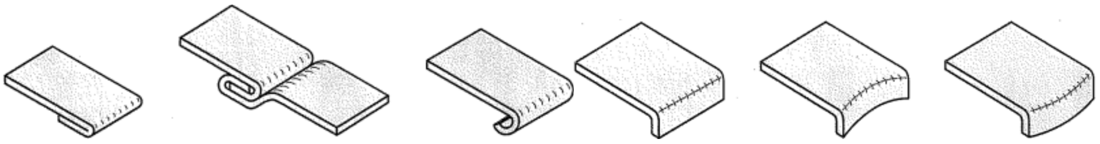
In these machines, the lateral movements of the dies are controlled and synchronized with the vertical die movement to form the part into desired shapes. This process is useful in making seamed tubing and conduits, bushings, fasteners, and various machinery components.

Roll Bending

In this process, plates are bent using a set of rolls. By adjusting the distance between the three rolls, various curvatures can be obtained. This process is flexible and is used widely for bending plates for applications such as boilers, cylindrical pressure vessels, and various curved structural members.

Beading

In beading, the periphery of the sheet metal is bent into the cavity of a die. The bead imparts stiffness to the part by increasing the moment of inertia of that section. Also, beads improve the appearance of the part and eliminate exposed sharp edges that can be hazardous.



Flanging

Flanging is a bending Operation in which the edge of a sheet metal part is bent at a 90° angle (usually) to form a rim or flange. It is often used to strengthen or stiffen sheet metal.

Hemming

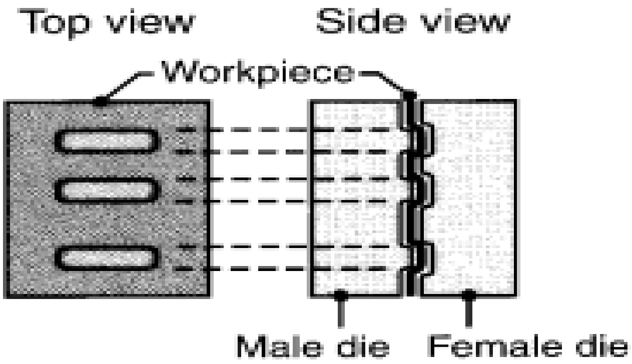
Hemming involves bending the edge of the sheet over on itself, in more than one bending step. This is often done to eliminate the sharp edge on the piece, to increase stiffness, and to improve appearance.

Seaming

Seaming is a related operation in which two sheet metal edges are assembled.

Embossing

This is an operation consisting of shallow or moderate draws made with male and female matching shallow dies. Embossing is used principally for the stiffening of flat sheet-metal panels and for purposes of decorating, numbering, and lettering, such as letters on the lids of aluminum beverage cans.



Bulging

This process involves placing a tubular, conical, or curvilinear part into a split-female die and then expanding the part, usually with a polyurethane plug. The punch is then retracted, the plug returns to its original shape (by total elastic recovery), and the formed part is removed by opening the split dies. Typical products made are coffee or water pitchers, beer barrels, and beads on oil drums. For parts with complex shapes, the plug (instead of being cylindrical) may be shaped in order to apply higher pressures at critical regions of the part. The major advantages of using polyurethane plugs is that they are highly resistant to abrasion and wear; furthermore, they do not damage the surface finish of the part being formed.

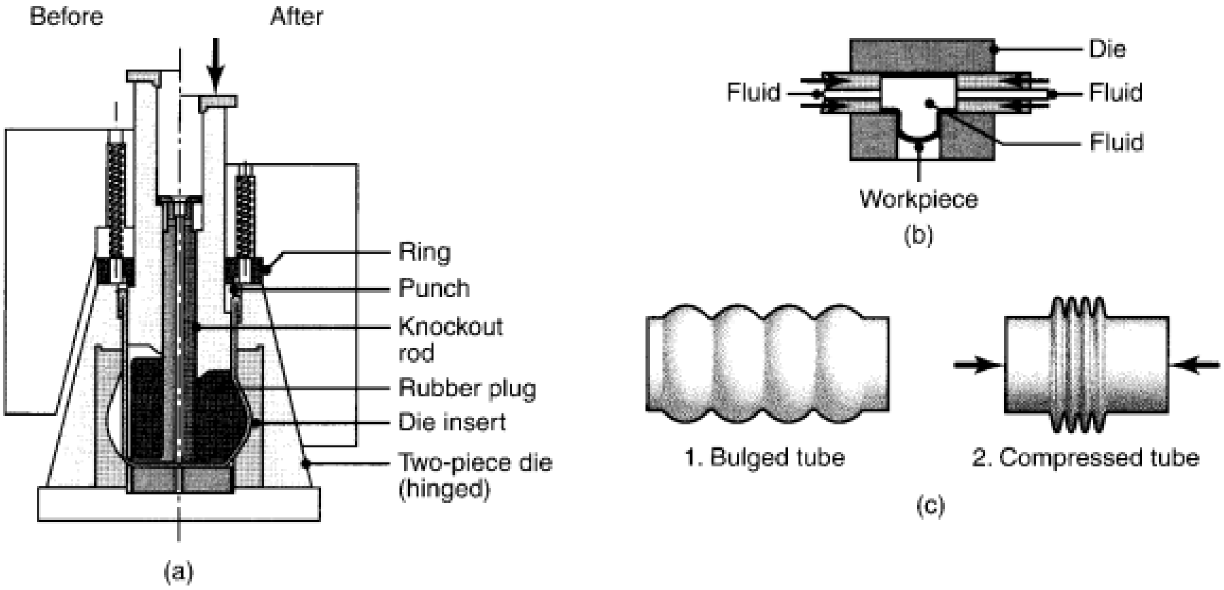


Fig: (a) The bulging of a tubular part with a flexible plug. Water pitchers can be made by this method. (b) Production of fittings for plumbing by expanding tubular blanks under internal pressure. The bottom of the piece is then punched out to produce a “T.” (c) Steps in manufacturing bellows.

Spinning

A method of making tank heads, television cones, and other deep parts of circular symmetry is spinning .The metal blank is clamped against a form block which is rotated at high speed. The blank is progressively formed against the block, either with a manual tool or by means of small-diameter work rolls. In the spinning process the blank thickness does not change but its diameter is decreased.

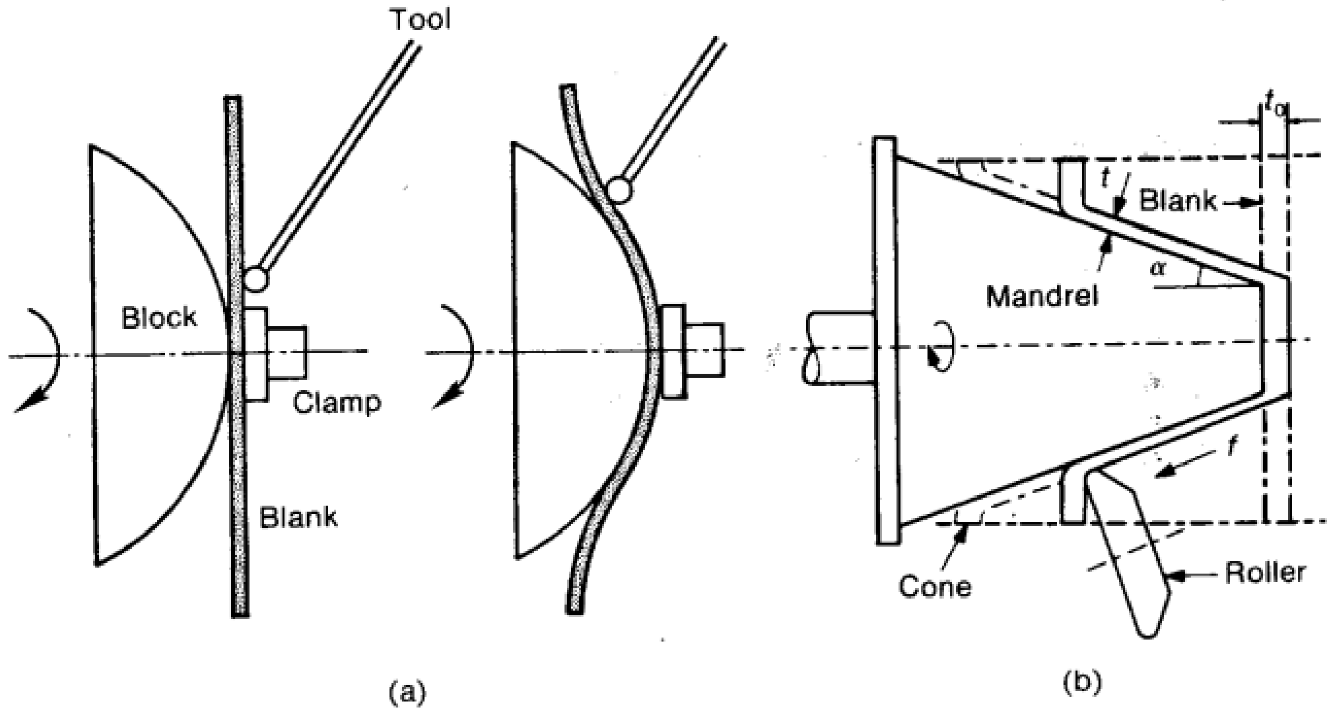


Fig: a) Manual spinning b) shear spinning

Shear Spinning

It is a variant of conventional spinning. In this process the part diameter is the same as the blank diameter but the thickness of the spun part is reduced according to $t = t_0 \sin\alpha$. This process is also known as power spinning, flow turning, and hydrospinning. It is used for large axisymmetrical conical or curvilinear shapes such as rocket motor casings and missile nose cones.

Thinning is sometimes quantified by the Spinning reduction r:

$$r = \frac{t_o - t}{t_o}$$

Tube Spinning

Tube spinning is used to reduce the wall thickness and increase the length of a tube by means of a roller applied to the work over a cylindrical mandrel. Tube spinning is similar to shear spinning except that the starting workpiece is a tube rather than a flat disk. The operation can be performed by applying the roller against the work externally (using a cylindrical mandrel on the inside of the tube) or internally (using a die to surround the tube). It is also possible to form profiles in the walls of the cylinder by controlling the path of the roller as it moves tangentially along the wall. Spinning reduction for a tube spinning operation that produces a wall of uniform thickness can be determined as in shear spinning.

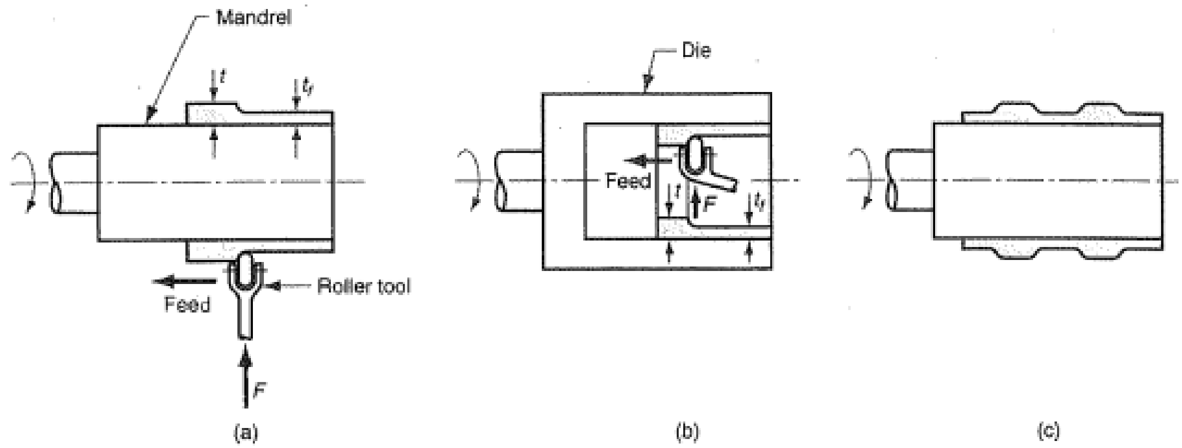
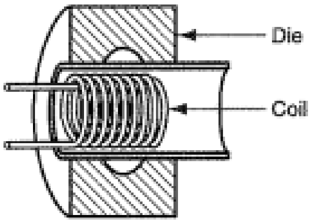


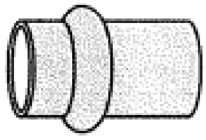
Fig : Tube spinning: (al external; (b) internal; and (c) profiling

High Energy Rate Forming

Several processes have been developed to form metals using large amounts of energy applied in a very short time. Owing to this feature, these operations are called higlp energy rate forming (HERF) processes. They include explosive forming, electrohydraulic forming, and electromagnetic forming.

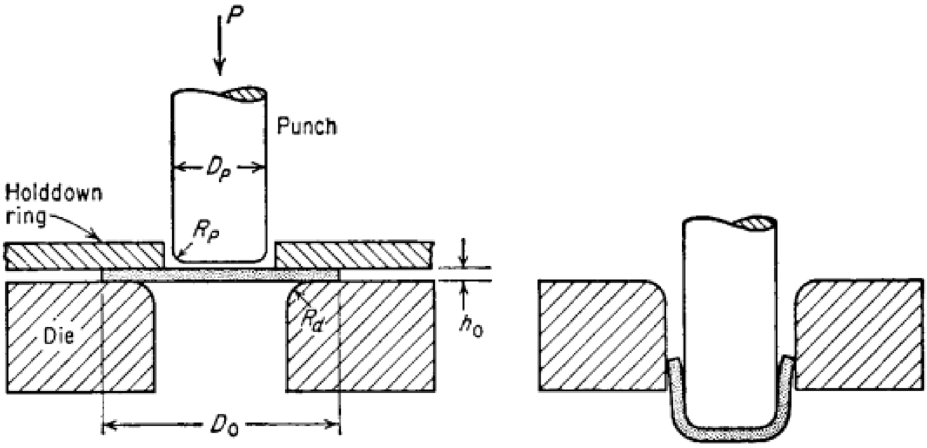
Explosive Forming





Deep Drawing

Deep drawing is the metalworking process used for shaping flat sheets into cup shaped articles such as bathtubs, shell cases, and automobile panels. This is done by placing a blank of appropriate size over a shaped die and pressing the metal into the die with a punch. Generally a clamping or hold down pressure is required to press the blank against the die to prevent wrinkling. This is best done by means of a blank holder or hold down ring in a double action press.



Drawability

The drawability of a metal is measured by the ratio of the initial blank diameter to the diameter of the cup drawn from the blank (usually approximated by the punch diameter). For a given material there is a limiting draw ratio (LDR), representing the largest blank that can be drawn through a die DP without tearing. The theoretical upper limit on LDR is

$$LDR \approx \left(\frac{D_o}{D_P}\right)_{\mathrm{Nas}} \approx e^{y}$$

where η is an efficiency term to account for frictional losses. If η = 1, then LDR = 2.7, while if η = 0.7, LDR = 2. Some of the practical considerations which affect drawability are:

• Die radius should be about 10 times sheet thickness. • Punch radius - a sharp radius leads to local thinning and tearing. • Clearance between punch and die-20 to 40 per cent greater than the sheet thickness •Lubricate die side to reduce friction in drawing.

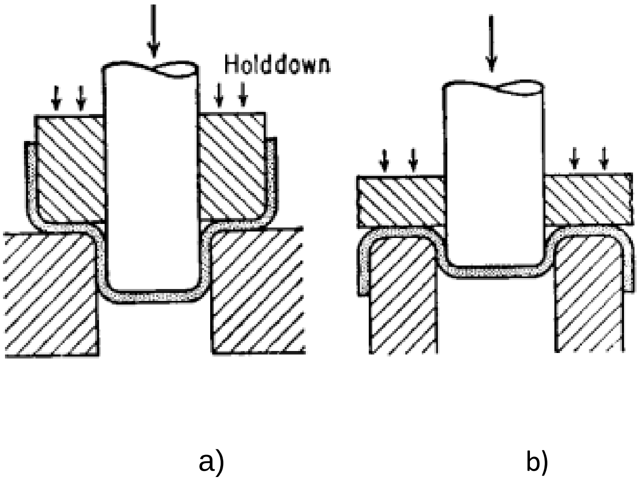
Redrawing

Since the average maximum reduction in deep drawing is about 50 percent, to make tall slender cups (such as cartridge cases and closed end tubes), it is necessary to use successive drawing operations. Reducing a cup or drawn part to a smaller diameter and increased height is known as redrawing.

The two basic methods of redrawing are direct, or regular redrawing and reverse, or indirect redrawing.

In direct redrawing the original outside surface of the cup remains the outside surface of the redrawn cup.

In reverse redrawing the cup is turned inside out so that the outside surface of the drawn cup becomes the inside surface of the redrawn shell.



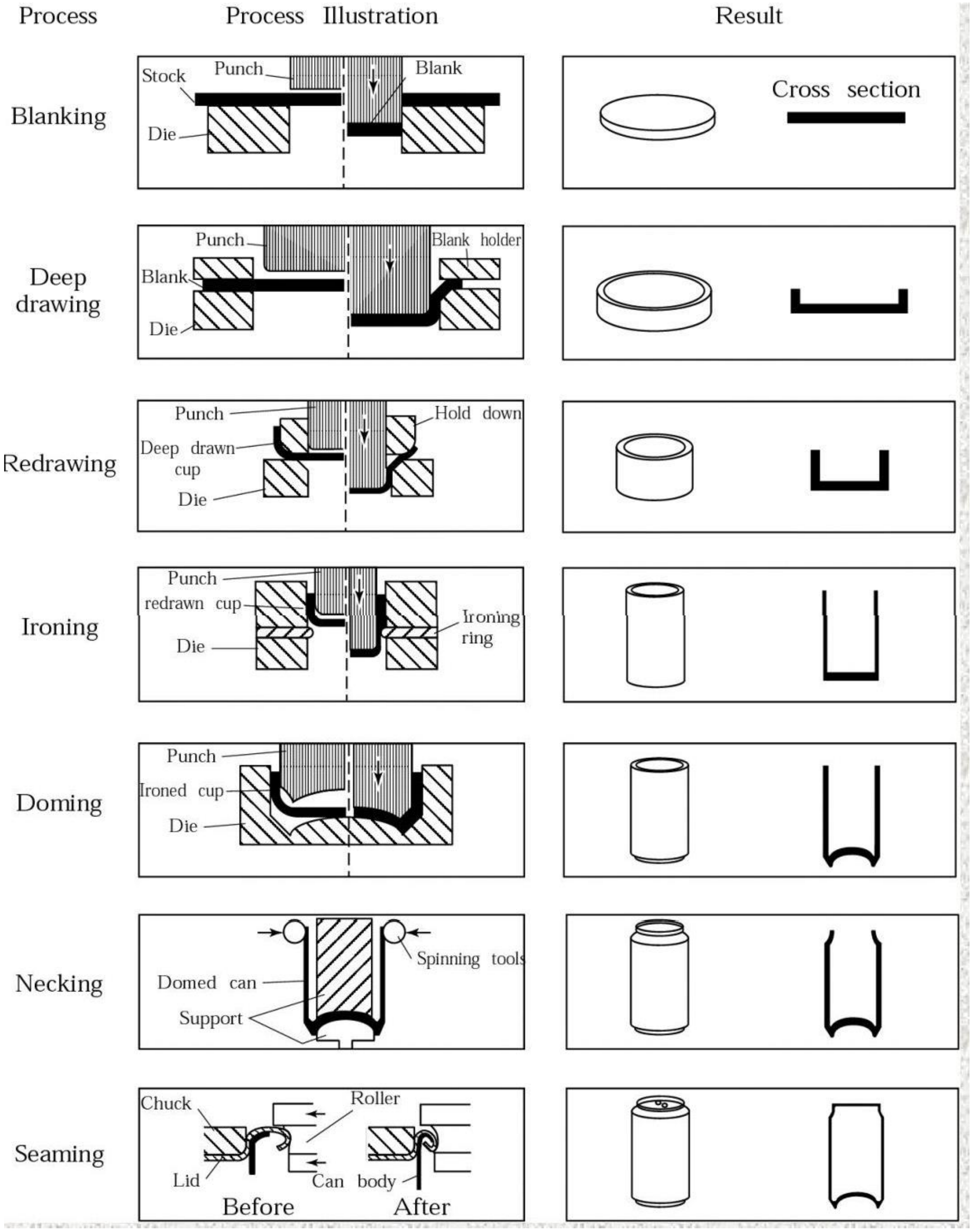
a) b)

Fig a) Direct redrawing b) Indirect redrawing

Ironing & sinking

Redrawing operations may also be classified into drawing with appreciable decrease in wall thickness, called ironing, and drawing with little change in wall thickness, called sinking. The ironing process is basically the same as tube drawing with a moving mandrel. The predominant stress in ironing is the radial compressive stress developed by the pressure of the punch and the die. Redrawing without reduction in wall thickness is basically the same as tube sinking or tube drawing without a mandrel. The predominant stresses are an axial tensile stress from the action of the punch and a circumferential compression from the drawing in of the metal.

The metal-forming processes involved in manufacturing a two-piece aluminum beverage can



During the drawing operation, the movement of the blank into the die cavity induces compressive circumferential (hoop) stresses in the flange, which tend to cause the flange to wrinkle during drawing. This phenomenon can be demonstrated simply by trying to force a circular piece of paper into a round cavity, such as a drinking glass. Wrinkling can be reduced or eliminated if a blank holder is loaded by a certain force. In order to improve performance, the magnitude of this force can be controlled as a function of punch travel.

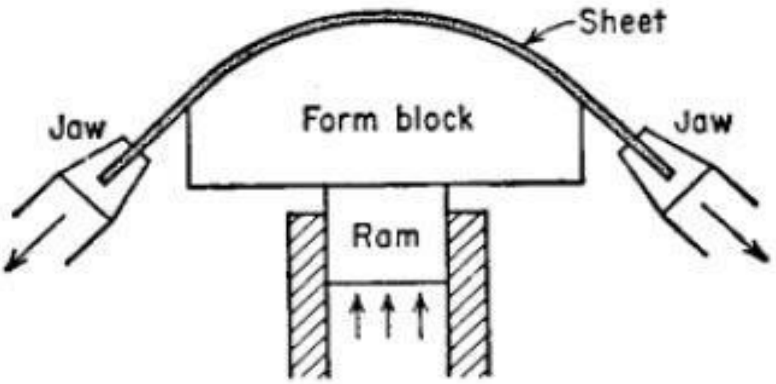
Maximum punch force

$$F_{Nas} = \pi D_p \quad T\,(UTS)\,\left[\left(\frac{D_0}{D_p}\right) - 0.7\right]$$

Force increases with increasing blank diameter, thickness, strength, and the ratio $\frac{D_0}{D_p}$. The wall of the cup is subjected principally to a longitudinal (vertical) tensile stress due to the punch force. Elongation under this stress causes the cup wall to become thinner and, if excessive, can cause tearing of the cup.

Stretch Forming

Stretch forming is the process of forming by the application of primarily tensile forces in such a way as to stretch the material over a tool or form block. Stretch forming is used most extensively in the aircraft industry to produce parts of large radius of curvature, frequently with double curvature. An important consideration is that springback is largely eliminated in stretch forming because the stress gradient is relatively uniform. On the other hand, because tensile stresses predominate, large deformations can be obtained by this process only in materials with appreciable ductility.

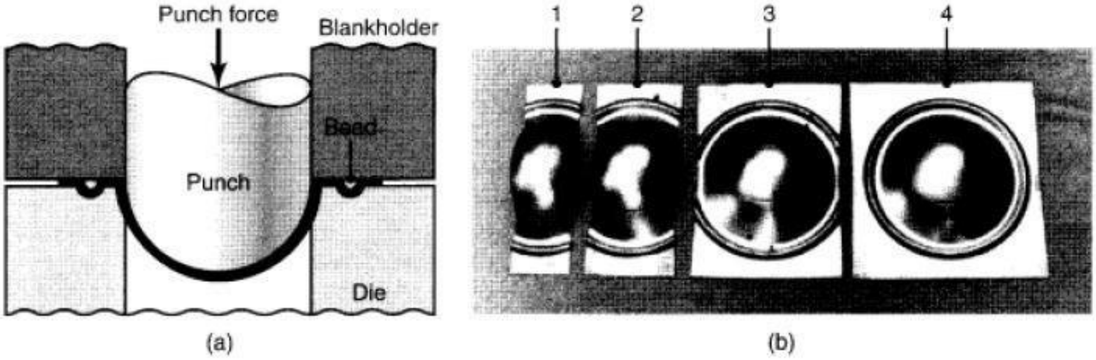


Formability Tests for Sheet Metals

Sheet-metal formability is defined as the ability of the sheet metal to undergo the desired shape change without failure, such as by necking, cracking, or tearing.

Cupping Tests

In the Erichsen test, the sheet specimen is clamped between two circular, flat dies and a steel ball or round punch is forced into the sheet until a crack begins to appear on the stretched specimen. The punch depth, d, at which failure occurs is a measure of the formability of the sheet.



(a) (b)

Fig . Erichsen test

Forming-limit Diagrams

A forming-limit diagram (FLD) for a particular metal is constructed by first marking the flat sheet with a grid pattern of circles, using chemical or photo- printing techniques. The blank then is stretched over a punch, and the deformation of the circles is observed and measured in regions where failure (necking and tearing) has occurred. After stretching circles deform into ellipses. By measuring the axes of the ellipse after deformation the local strain in two dimensions can be easily calculated. The results of such tests are usually presented in the form of a forming limit diagram.

On this diagram the primary strain causing the shape change is the major strain and the transverse strain is referred to as the minor strain. For each combination of major and minor strain the point at which necking begins is plotted, thus defining a region in which forming can be accomplished without necking and a region in which necking will occur (the fail region). It is important to note that if a minor strain is applied, the strain to necking is increased, allowing greater shape change to occur. Fig. indicates that compressive minor strain is more effective than a tensile minor strain for increasing the major strain that can occurred. After stretching circles deform into ellipses. By measuring the axes of the ellipse after deformation the local strain in two dimensions can be easily calculated. The results of such tests are usually presented in the form of a forming limit diagram.

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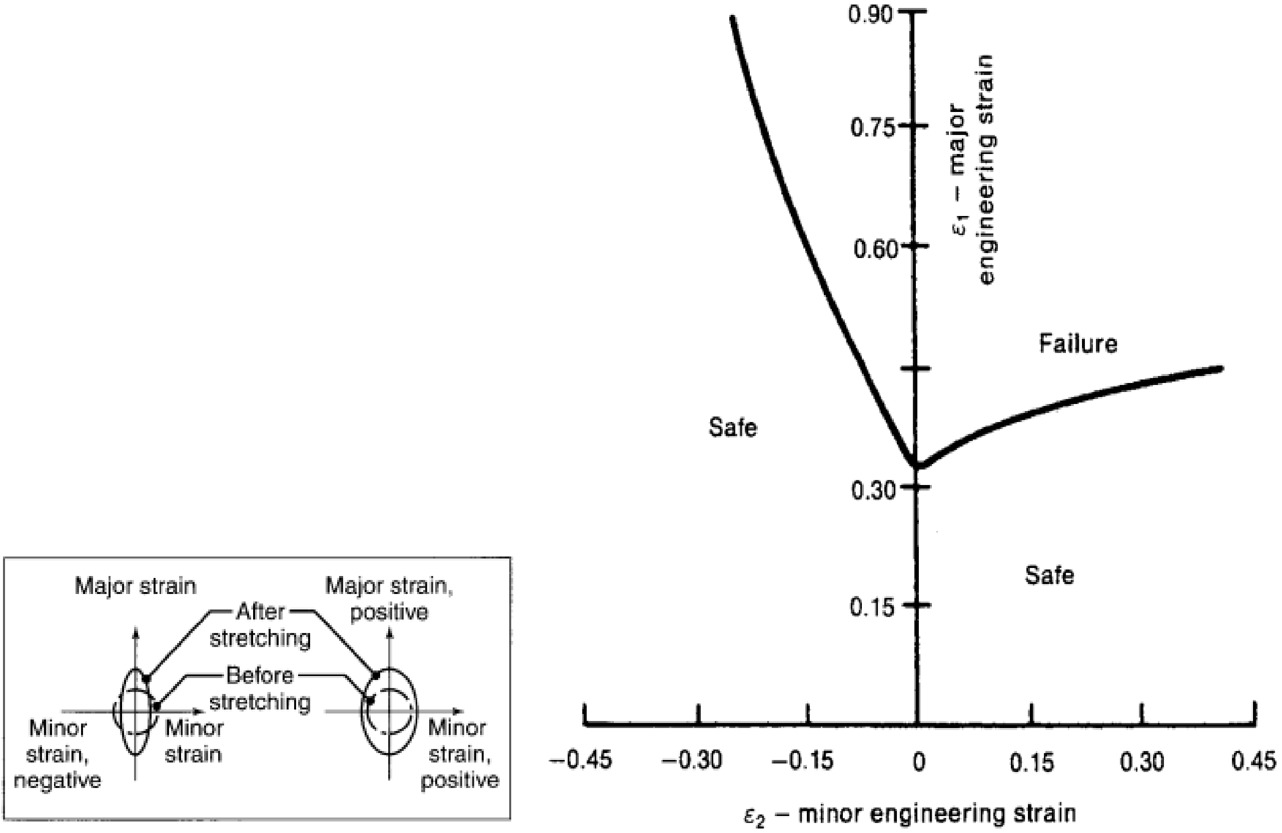


Fig (a) Strains in deformed circular grid patterns. (b) Forming-limit diagram for an aluminium killed steel

Fixture And Jig

Fixtures, being used in machine shop, are strong and rigid mechanical devices which enable easy, quick and consistently accurate locating, supporting and clamping, blanks against cutting tool(s) and result faster and accurate machining with consistent quality, functional ability and interchangeability.

Jig is a fixture with an additional feature of tool guidance.

Principles And Methods Of Locating, Supporting And Clamping Blanks And Tool Guidance In Jigs And Fixtures

The main functions of the jigs and fixtures are :

(a) easily, quickly, firmly and consistently accurately

- locating
- supporting and
- clamping

the blank (in the jig or fixture) in respect to the cutting tool(s)

(b) providing guidance to the slender cutting tools using proper bushes

Locating – principles and methods

For accurate machining, the workpiece is to be placed and held in correct position and orientation in the fixture (or jig). Any solid body may have maximum twelve degrees of freedom as indicated in Fig. By properly locating, supporting and clamping the blank its all degrees of freedom are to be arrested as typically shown in Fig.

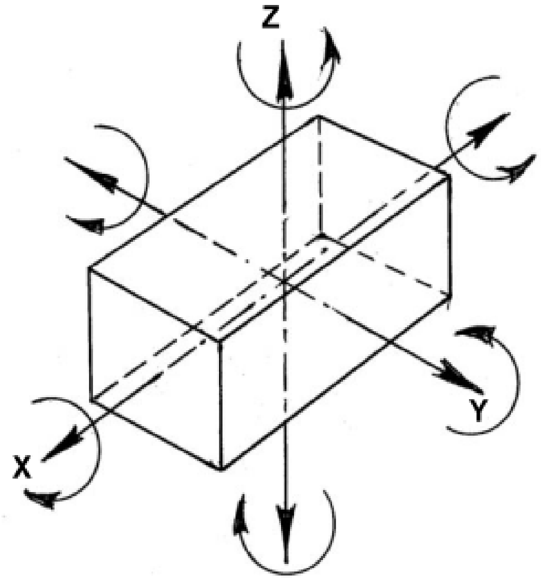


Fig. Possible degrees of freedom of a solid body

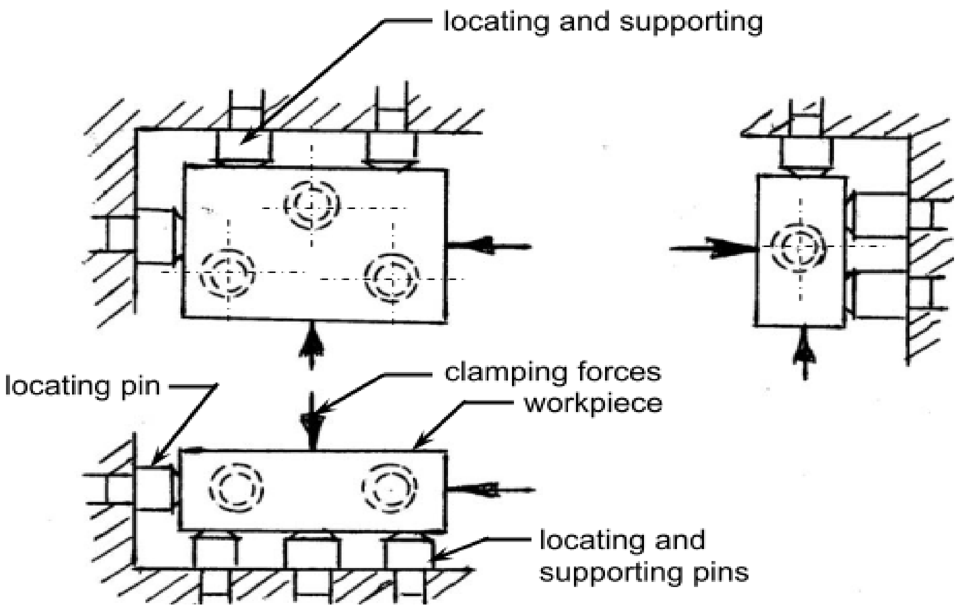


Fig. Arresting all degrees of freedom of a blank in a fixture.

principle of location

This 3-2-1 principle states that "a work piece will be completely confined when placed against three points in one plane, two points in another plane and one point in third plane if the planes are perpendicular to each other". Work piece should be supported on three buttons support for any holding device.

The three adjacent locating surfaces of the blank (work piece) are resting against 3, 2 and 1 pins respectively, which prevent 9 degrees of freedom. The rest three degrees of freedom are arrested by three external forces usually provided directly by clamping. Some of such forces may be attained by friction.

Principles of location

- One or more surfaces (preferably machined) and / or drilled / bored hole(s) are to be taken for reference
- The reference surfaces should be significant and important feature(s) based on which most of the dimensions are laid down
- Locating should be easy, quick and accurate
- In case of locating by pin, the pins and their mounting and contact points should be strong, rigid and hard
- A minimum of three point must be used to locate a horizontal flat surface
- The locating pins should be as far apart as feasible
- Vee block and cones should be used for self-locating solid and hollow cylindrical jobs as typically shown in Fig. 8.1.6
- Sight location is applicable to first – operation location of blank with irregular surfaces produced by casting, forging etc. as indicated in Fig. 8.1.7 when the bracket is first located on two edges to machine the bottom surface which will be used for subsequent locating.

- Adjustable locating pin(s) as indicated in Fig. 8.1.3 is to be used to accommodate limited part size variation

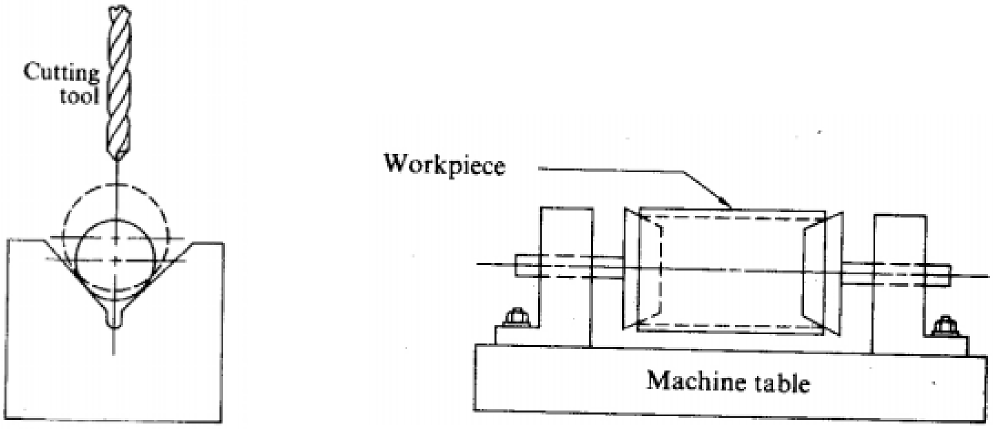
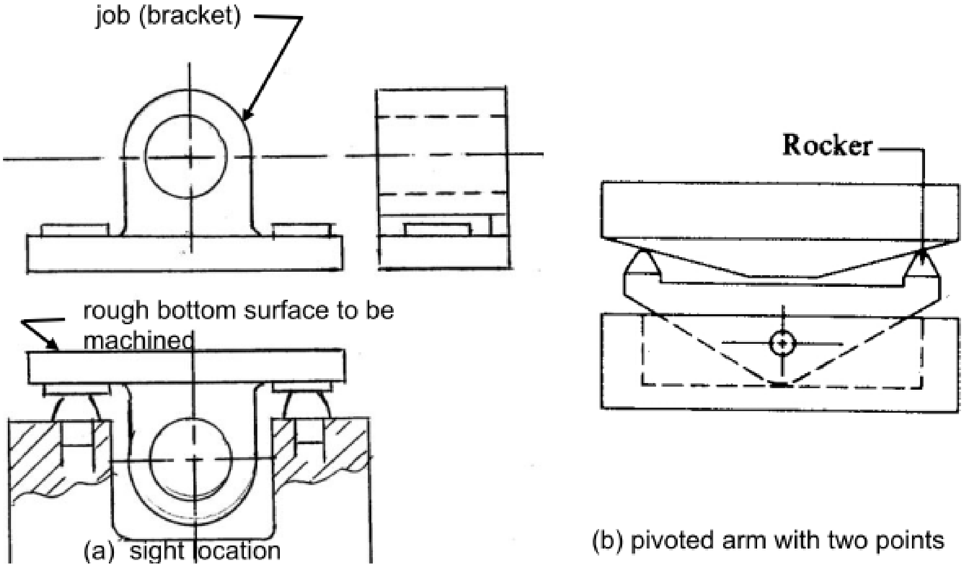


Fig : 8.1.6 Locating by Vee block and cone



(a) sight location

(b) pivoted arm with two points

Fig : 8.1.7 (a) Sight location and (b) location by pivoted points (equalizer)

Principles of clamping

- clamping need to be strong and rigid enough to hold the blank firmly during machining
- clamping should be easy, quick and consistently adequate
- clamping should be such that it is not affected by vibration, chatter or heavy pressure
- the way of clamping and unclamping should not hinder loading and unloading the blank in the jig or fixture
- the clamp and clamping force must not damage or deform the workpiece
- clamping operation should be very simple and quick acting when the jig or fixture is to be used more frequently and for large volume of work
- clamps, which move by slide or slip or tend to do so during applying clamping forces, should be avoided
- clamping system should comprise of less number of parts for ease of design, operation and maintenance
- the wearing parts should be hard or hardened and also be easily replaceable

- clamping force should act on heavy part(s) and against supporting and locating surfaces
- clamping force should be away from the machining thrust forces
- clamping method should be fool proof and safe
- clamping must be reliable but also inexpensive

Various methods of clamping

Clamping method and system are basically of two categories :

(a) general type without much consideration on speed of clamping operations

(b) quick acting types

(a)

- Screw operated strap clamps as typically shown in Fig. 8.1.17. The clamping end of the strap is pressed against a spring which enables quick unclamping

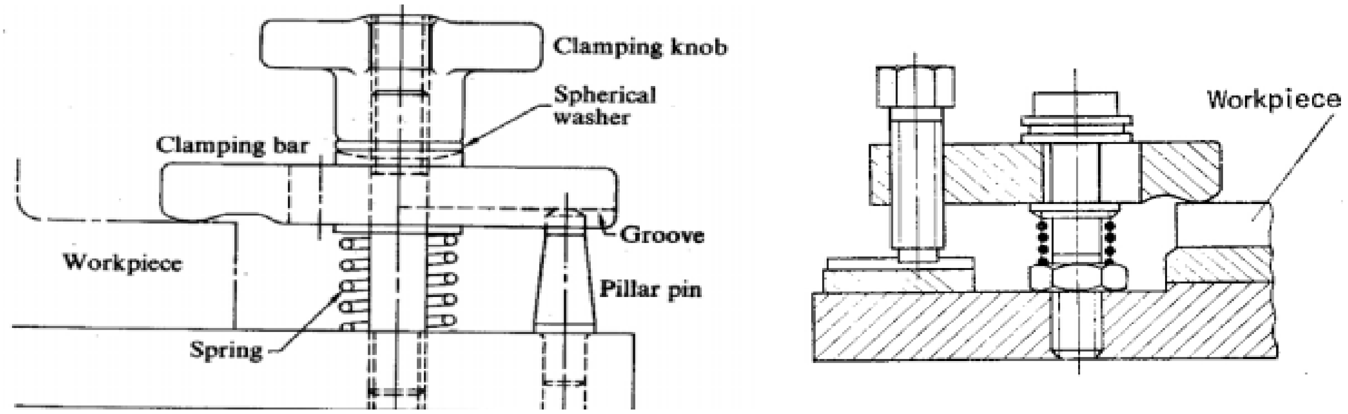
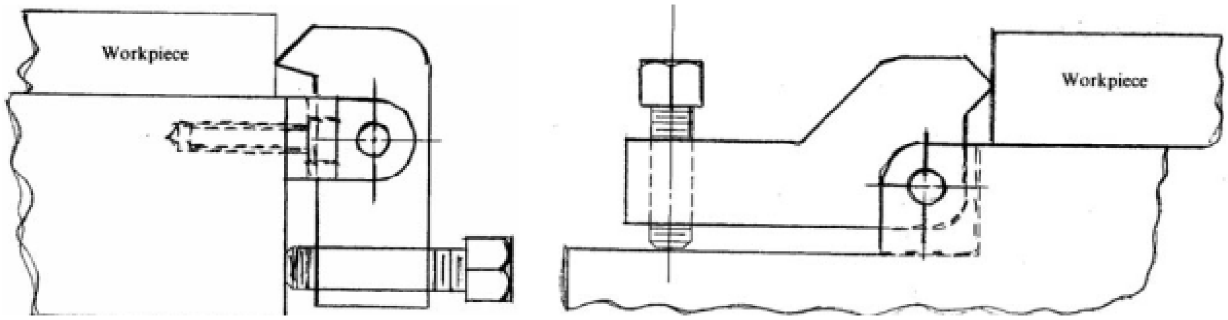
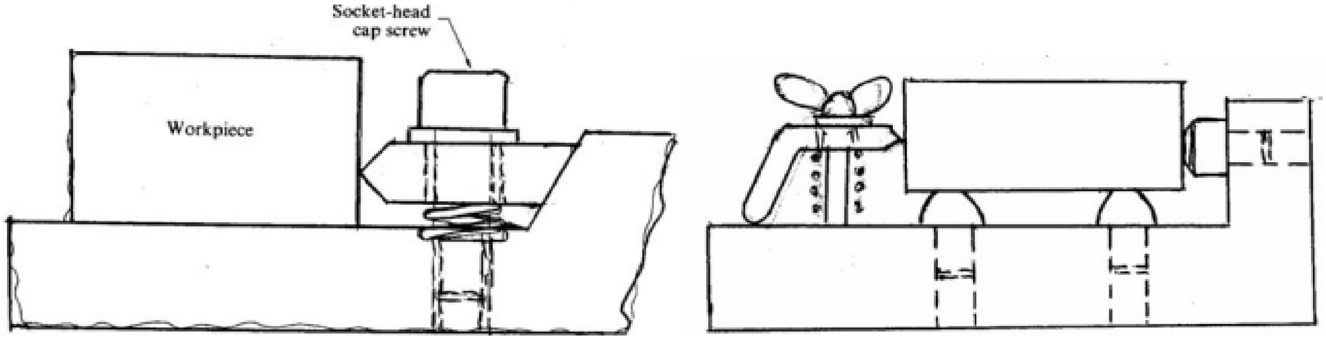


Fig : 8.1.17 Common strap type clamping

- Clamping from side for unobstructed through machining (like milling, planing and broaching) of the top surface. Some commonly used such clamping are shown in Fig. 8.1.18





- Clamping by swing plates : Such clamping, typically shown in Fig. 8.1.19, are simple and relatively quick in operation but is suitable for jobs of relatively smaller size, simpler shape and requiring lesser clamping forces.

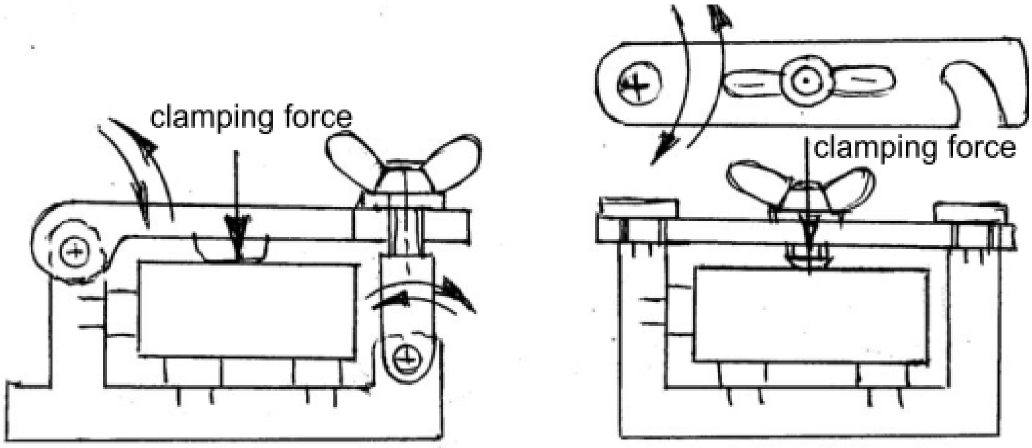


Fig. 8.1.19 Clamping by swing plates

(b) Quick clamping methods and systems

- Use of quick acting nut – a typical of such nut and its application is visualised schematically in Fig. 8.1.20

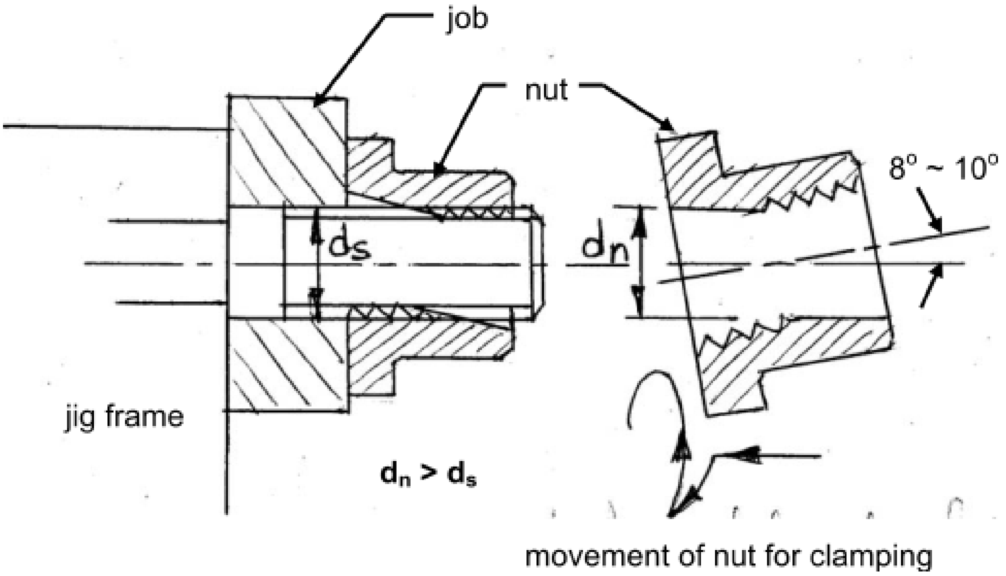
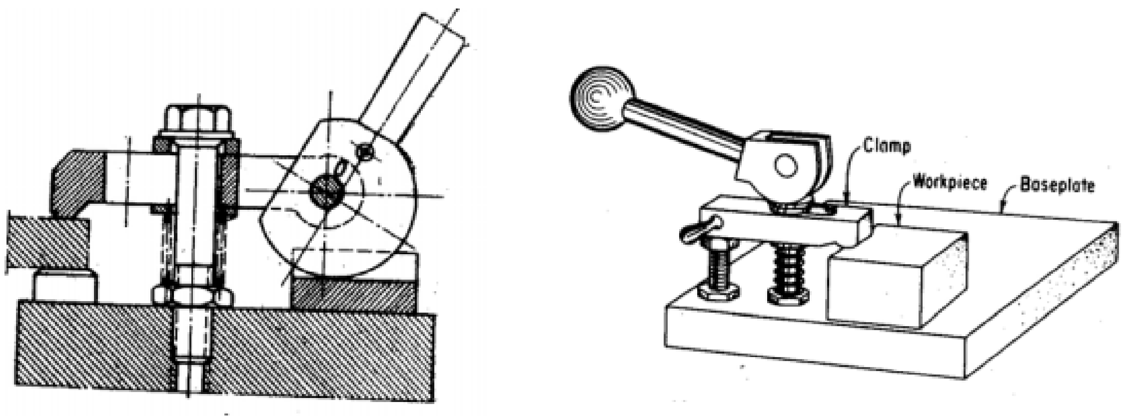


Fig. 8.1.20 Quick acting nut for rapid clamping

- Cam clamping : Quick clamping by cam is very effective and very simple in operation. Some popular methods and systems of clamping by cam are shown in Fig. 8.1.21 .The cam and screw type clamping system is used for clamping through some interior parts where other simple system will not have access.



(a) clamping by cam

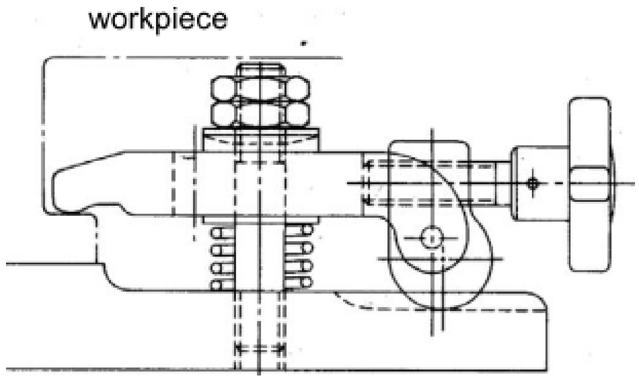


Fig. 8.1.21 Quick clamping by cams

(b) screw and cam clamping from distance

Summary of the principal characteristics, advantages and disadvantages of metal deformation processes

Process	Characteristics	Advantages	Disadvantages
Rolling	The squeezing of cast metals into more useful and handle able shapes such as plate, billet, bar, sheet and structural sections	• Improves and refines the metallurgical properties of the metal • Provides shapes that are more convenient to the user and nearer to the final required form • Excellent finish and accuracy with cold rolling	• poor surface finish and dimensional precision with hot rolling • During cooling may lock in unwanted internal stresses which can cause unexpected distortions later • Work hardening resulting from cold rolling creates a hard surface skin that may increase machining difficulties

Forging	The deforming of raw material into a shape as near as possible to the final required profile by imparting either impact (kinetic) or pressure energy	• Greatly reduces material wastage and can be a much more economical option than casting or machining from the solid • Impact strength and toughness are greatly enhanced, in part because of the beneficial grain flow pattern produced, which tends to follow the component's profile • Forgings are usually easy to weld • Allows one-piece components to be made which were previously fabricated assemblies	• Manually operated systems are potentially hazardous to operators • Only limited reshaping • Is possible when cold working, and there is significant danger of metal fracture if limits are exceeded • Tooling is expensive so large volume production is necessary to justify these costs. Also, forging presses are very expensive pieces of capital equipment
Extrusion	The pushing of metal through a hole in one end of a steel die, the profile of which determines the crosssectional shape of the lengths of extruded material produced	• Highly complex two dimensional shapes are easily produced • The die is readily changed so small batch sizes are economical • Advantageous grain flow along the direction of extrusion is produced • Dimensional accuracy and surface finish are usually good	• Steel is difficult to extrude owing to its high compressive strength and special lubricants are needed • Cold impact extrusion is severely limited in the degree of extrusion possible Three-dimensional shapes are not feasible

Cold drawing (thin rod, wire and tube drawing)	Similar principle to extrusion except that the metal is pulled through the hole in the die rather than being pushed through it	• Small batches are feasible owing to the ease of changing the drawing dies • Grain flow is in	• Severe limitations on the degree of draw possible in one step, so interstage annealing may be required • Because of the long lengths of product produced and the speeds that it is delivered from the die (up to 60 mph), special mechanical handling facilities must be provided
		the direction of drawing • Accuracy and finish are good • Surface hardness and material toughness can be modified by varying process parameters	
Sheet metal bending	The bending of ductile sheet metal into final component shape; often also involves metal shearing both before and after bending	• This is the only way to produce certain shapes such as car body panels • Little or no further metal working is usually required—surface protection coatings can even be provided precoated on the material stock • High production rates are possible when the process is mechanized	• Dies are usually extremely expensive, and are only economical for large-quantity production, typical of that found in the automotive and “white goods” industries • Complex three-dimensional shapes can be difficult to produce in one operation without the risk of metal failure • Bends that are too tight cause serious thinning of the material, and there is then a risk of metal splitting in these areas

Deep drawing	A sheet metal bending process used when sheet metal parts are deep in relation to their dimensions in the other two axes	• Accuracy and productivity are high when drawing operations are mechanized • Soft dies, using elastomers or fluid as the drawing interface and top die, make small batch production possible, specially for parts with large surface areas • However, the special presses used for this are expensive	• Because this is a cold working process there are severe limitations on the amount of draw possible in one step • Interstage annealing is frequently a necessary expense • Dies are very costly so large scale production is essential
Spinning, shear forming and flow turning	Cold working processes used for the manufacture of precision circular parts, up to 4m in diameter, from sheet metal/plate or preform	• Refined microstructure is produced, giving enhanced physical properties • With flow forming it is possible to vary component thickness as required • In shear forming only the area being formed is under stress, so greater deformation is possible than with deep drawing • Formers used in spinning are not expensive, and so provide an economic alternative to	• The metal blanks used in these processes must be capable of being rotated, i.e.not too large a diameter or mass • For all but the most basic shapes special lathe-type forming machines are necessary, usually CNC controlled • Considerable experience is needed if the part is not to fracture owing to excessive work hardening. • Stress relief is an expensive additional operation, but is frequently essential if the final part is to be substantially free of internal stresses

		deep drawing if	
		small batches are required	

MODULE 6

Definition of Welding

In its broadest context, welding is a process in which materials of the same fundamental type or class are brought together and caused to join (and become one) through the formation of primary (and, occasionally, secondary) chemical bonds under the combined action of heat and pressure.

Weldability

The weldability of a metal is usually defined as its capacity to be Welded into a specific structure that has certain properties and characteristics and will satisfactorily meet service requirements.

The Weld joint

Three distinct zones can be identified in a typical weld joint, as shown in Fig.

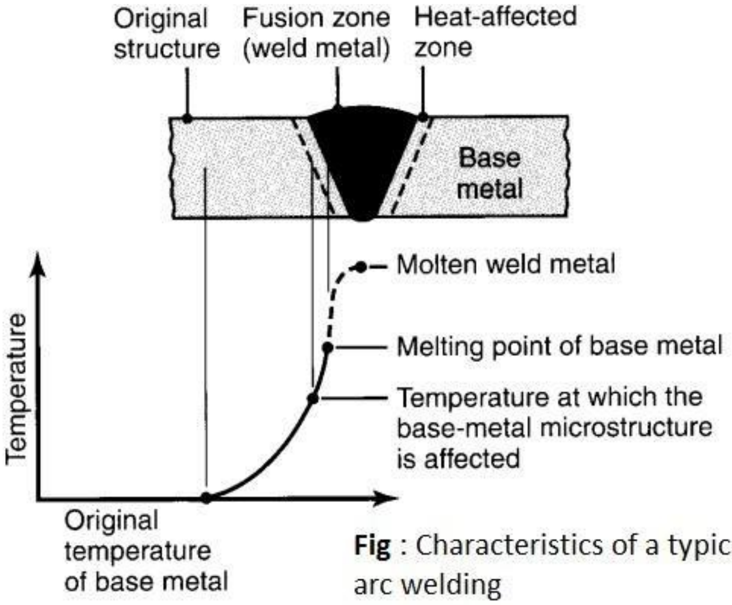


Fig : Characteristics of a typical fusion weld zone in oxyfuel-gas and arc welding

I. Base metal   2. Heat-affected zone   3. Weld metal

A joint produced without a filler metal is called ***autogenous***, and its weld zone is composed of the resolidified base metal. A joint made with a filler metal has a central zone called the weld metal and is composed of a mixture of the base and the filler metals.

Solidification of the Weld Metal

After the application of heat and the introduction of the filler metal (if any) into the weld zone, the weld joint is allowed to cool to ambient temperature. The solidification process is similar to that in casting and begins with the formation of columnar (dendritic) grains. These grains are relatively long and form parallel to the heat flow. Because metals are much better heat conductors than the surrounding air, the grains lie parallel to the plane of the two components being welded.

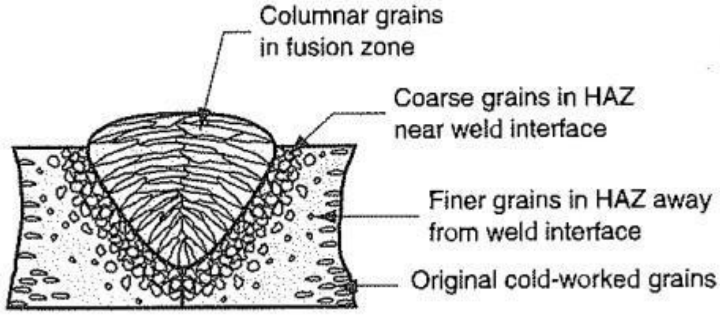


Fig : Typical grain structure for fusion welded joint

Grain structure and grain size depend on the specific metal alloy, the particular welding process employed, and the type of filler metal. Because it began in a molten state, the weld metal basically has a cast structure, and since it has cooled slowly, it has coarse grains. Consequently, this structure generally has low strength, toughness, and ductility. However, the proper selection of filler-metal composition or of heat treatments following welding can improve the mechanical properties of the joint.

The resulting structure depends on the particular alloy, its composition, and the thermal cycling to which the joint is subjected. For example, cooling rates may be controlled and reduced by pre/venting the general weld area prior to welding. Preheating is important, particularly for metals having high thermal conductivity, such as aluminum and copper. Without preheating, the heat produced during welding dissipates rapidly through the rest of the parts being joined.

Heat-affected Zone (HAZ)

The heat-affected zone (HAZ) is within the base metal itself. It has a microstructure different from that of the base metal prior to welding, because it has been temporarily subjected to elevated temperatures during welding. The portions of the base metal that are far enough away from the heat source do not undergo any microstructural changes during welding because of the far lower temperature to which they are subjected.

The properties and microstructure of the HAZ depend on (a) the rate of heat input and cooling and (b) the temperature to which this zone was raised. In addition to metallurgical factors (such as the original grain size, grain orientation, and degree of prior cold work), physical properties (such as the specific heat and thermal conductivity of the metals) influence the size and characteristics of the HAZ.

The heat applied during welding recrystallizes the elongated grains of the cold- worked base metal. On the one hand, grains that are away from the weld metal will recrystallize into fine, equiaxed grains. On the other hand, grains close to the weld metal have been subjected to elevated temperatures for a longer time. Consequently, the grains will grow in size (grain growth), and this region will be softer and have lower strength. Such a joint will be weakest at its HAZ.

Welding Defects

As a result of a history of thermal cycling and its attendant microstructural changes, a welded joint may develop various discontinuities. Welding discontinuities also can be caused by an inadequate or careless application of proper welding technologies or by poor operator training. The major discontinuities that affect weld quality are,

Porosity

Porosity in welds may be caused by

- Gases released during melting of the weld area, but trapped during solidification.
- Chemical reactions during welding.
- Contaminants.

Porosity in welds can be reduced by the following practices:

- Proper selection of electrodes and filler metals.
- Improved welding techniques, such as preheating the weld area or increasing the rate of heat input.
- Proper cleaning and the prevention of contaminants from entering the weld zone.
- Reduced welding speeds to allow time for gas to escape.

Slag Inclusions

Slug inclusions are compounds such as oxides, fluxes, and electrode coating materials that are trapped in the weld zone. If shielding gases are not effective during welding, contamination from the environment also may contribute to such inclusions. Welding conditions are important as well: With control of welding process parameters, the molten slag will float to the surface of the molten weld metal and thus will not become entrapped.

Slag inclusions can be prevented by the following practices:

- Cleaning the weld-bead surface by means of a wire brush (hand or power) or a chipper before the next layer is deposited.
- Providing sufficient shielding gas.
- Redesigning the joint to permit sufficient space for proper manipulation of the puddle of molten weld metal.

Incomplete Fusion and Penetration

Incomplete fusion produces poor weld beads, such as those shown in Fig. below.

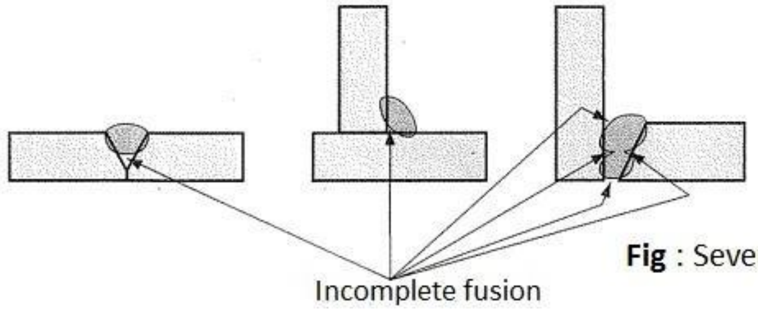


Fig : Several forms of incomplete fusion

A better weld can be obtained by the use of the following practices:

- Raising the temperature of the base metal.
- Cleaning the weld area before welding.
- Modifying the joint design and changing the type of electrode used.
- Providing sufficient shielding gas.

Incomplete penetration occurs when the depth of the welded joint is insufficient. Penetration can be improved by the following practices:

- Increasing the heatinput.
- Reducing the travel speed during the Welding.
- Modifying the jointdesign.
- Ensuring that the surfaces to be joined fit each other properly.

Weld Profile

Weld profile is important not only because of its effects onthe strength and appearance of the Weld, but also because it canindicate incomplete fusion or the presence of slag inclusions in multiple-layer welds.

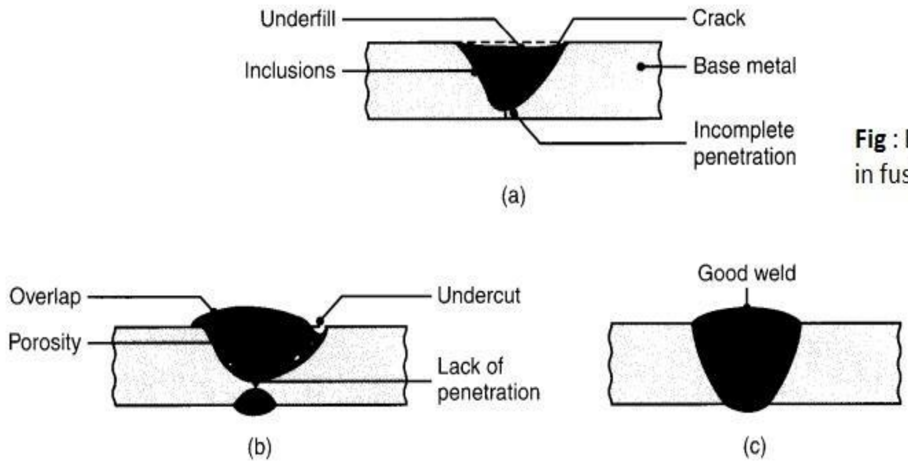


Fig : Examples of various defects in fusion weld

- ***Underfilling*** results When the joint is not filled with the proper amount of weld metal (Fig.a).
- ***Undercutting*** results from the melting away of the base metal and the consequent

generation of a groove in the shape of a sharp recess or notch (Fig.b). 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.

- ***Overlap*** is a surface discontinuity (Fig.b) usually caused by poor Welding practice or by the selection of improper materials. A good Weld is shown in Fig.¢

Cracks

Cracks may occur in various locations and directions in the Weld area. Typical types of cracks are longitudinal, transverse, crater, under bead, and toe cracks.

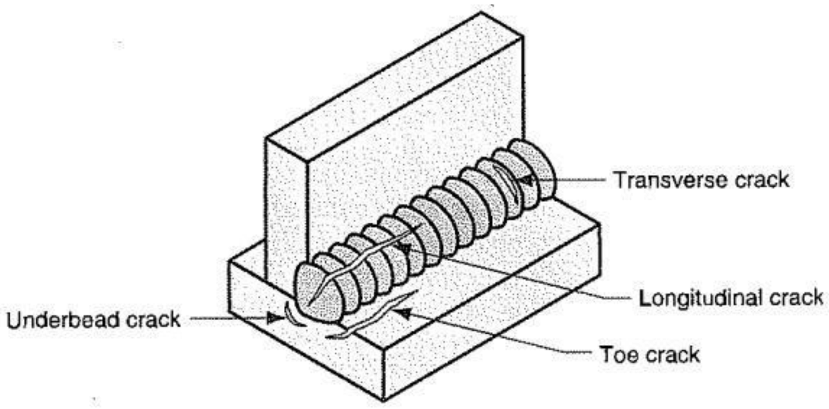


Fig : Various forms of welding cracks

Cracks generally result from a combination of the following factors:

- Temperature gradients that cause thermal stresses in the Weld zone.
- Variations in the composition of the Weld zone that cause different rates of contraction during cooling.
- Embrittlement of grain boundaries , caused by the segregation of such elements as sulfur to the grain boundaries and occurring when the solid-liquid boundary moves when the Weld metal begins to solidify.
- Hydrogen embrittlement.
- Inability of the weld metal to contract during cooling. This is a situation similar to hot tears that develop in castings and is related to excessive restraint of the workpiece during the welding operation.

The basic crack-prevention measures in welding are the following:

- Change the parameters, procedures, and sequence of the welding operation.
- Preheat the components to be welded.
- Avoid rapid cooling of the welded components.
- Modify the joint design to minimize stresses developed from shrinkage during cooling

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 inadvertently may touch the parts being welded at places other than the weld zone. (Such encounters are called arc strikes.) The surface discontinuities thereby produced may be objectionable for reasons of appearance or of subsequent use of the welded part.

Residual Stresses

Because of localized heating and cooling during welding, the expansion and contraction of the weld area causes residual stresses in the workpiece. Residual stresses can lead to 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, such as by machining or sawing.
- Reduced fatigue life of the welded structure.

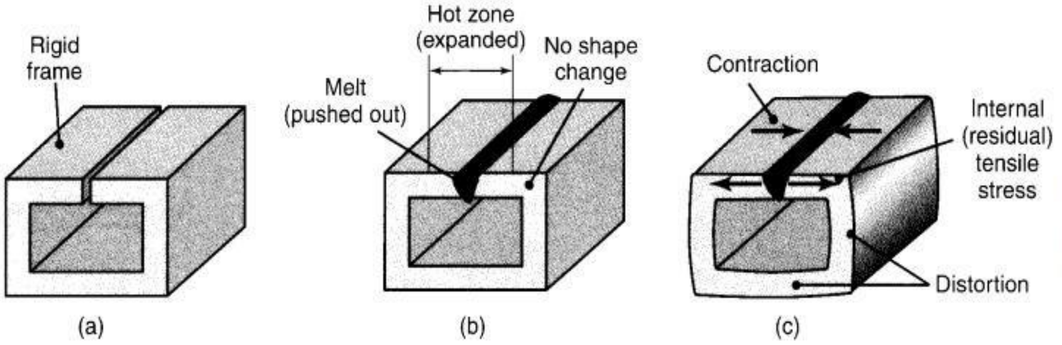


Fig : Distortion of a welded structure

Oxyfuel-gas Welding

Oxyfuel-gas welding (OFW) is a general term used to describe any welding process that uses a fuel gas combined with oxygen to produce a flame. The flame is the source of the heat that is used to melt the metals at the joint. The most common gas-welding process uses acetylene; the process is known as oxyacetylene-gas welding (OAW) and is typically used for structural metal fabrication and repair work.

OAW utilizes the heat generated by the combustion of acetylene gas (C_2H_2) in a mixture with oxygen. The heat is generated in accordance with a pair of chemical reactions. The primary combustion process, which occurs in the inner core of the flame, involves the following reaction:

$C_2H_2 + O_2 \rightarrow 2\,CO + H_2$ + Heat

This reaction dissociates the acetylene into carbon monoxide and hydrogen and produces about one-third of the total heat generated in the flame. The secondary combustion process is

$2\,CO + H_2 + 1.50_2 \rightarrow 2\,CO_2 + H_2 0$ + Heat.

This reaction consists of the further burning of both the hydrogen and the carbon monoxide and produces about two-thirds of the total heat. Note that the reaction also produces water vapor. The temperatures developed in the flame can reach 3300°C.

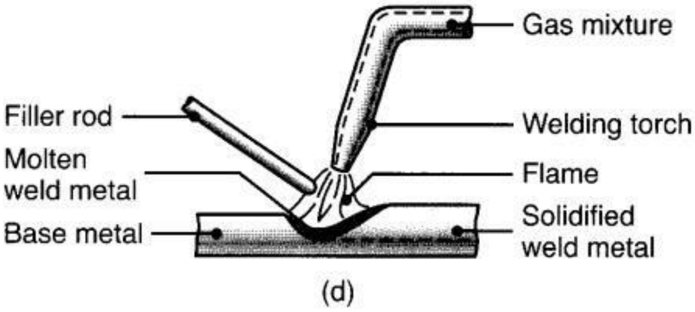
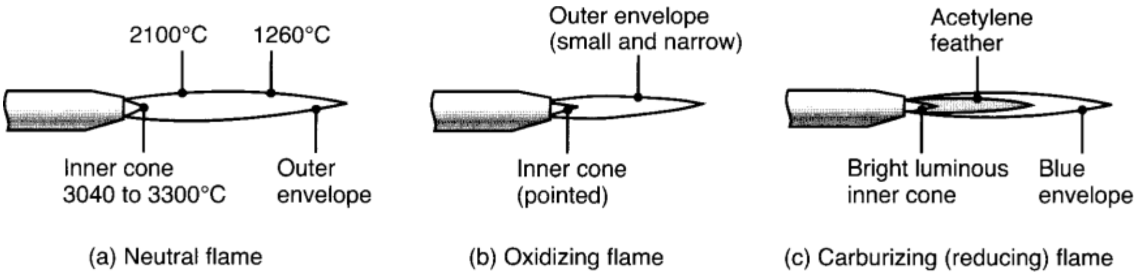


Fig : Principle of the oxyfuel-gas welding process.

Flame Types

The proportion of acetylene and oxygen in the gas mixture is an important factor in oxyfuel-gas welding. At a ratio of 1:1 (i.e., when there is no excess oxygen), the flame is considered to be neutral (Fig. a). With a greater oxygen supply, the flame can be harmful (especially for steels), because it oxidizes the metal. For this reason, a flame with excess oxygen is known as an oxidizing flame (Fig.b). Only in the welding of copper and copper-based alloys is an oxidizing flame desirable, because in those cases, a thin protective layer of slag (compounds of oxides) forms over the molten metal. If the oxygen is insufficient for full combustion, the flame is known as a reducing, or carburizing, flame (a flame having excess acetylene; Fig.c). The temperature of a reducing flame is lower; hence, such a flame is suitable for applications requiring low heat, such as brazing, soldering, and flame-hardening operations.



(a) Neutral flame (b) Oxidizing flame (c) Carburizing (reducing) flame

Welding Practice and Equipment

Oxyfuel-gas welding can be used with most ferrous and nonferrous metals for almost any workpiece thickness, but the relatively low heat input limits the process to thicknesses of less than 6 mm.

The equipment for oxyfuel-gas welding consists basically of a welding torch connected by hoses to high-pressure gas cylinders and equipped with pressure gages and regulators. Oxygen and acetylene cylinders have different threads, so the hoses cannot be connected to the wrong cylinders. The low equipment cost is an attractive feature of oxyfuel-gas welding. Although it can be mechanized, this operation is essentially manual and, hence, slow. However, it has the advantages of being portable, versatile, and economical for simple and low-quantity work.

Filler Metals

Filler metals are used to supply additional metal to the weld zone during welding. They are available as filler rods or wire and may be bare or coated with flux. The purpose of the flux is to retard oxidation of the surfaces of the parts being welded by generating a gaseous shield around the weld zone. The flux also helps to dissolve and remove oxides and other substances from the weld zone, thus contributing to the formation of a stronger joint. The slag developed (compounds of oxides, fluxes, and electrode-coating materials) protects the molten puddle of metal against oxidation as it cools.

Arc welding

Arc welding (AW) is a fusion-welding process in which coalescence of the metals is achieved by the heat from an electric arc between an electrode and the work.

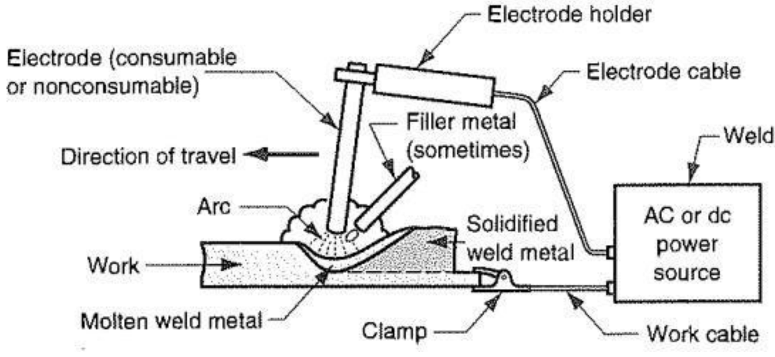


Fig : The basic configuration and electrical circuit of an arc-welding process

An electric arc is a discharge of electric current across a gap in a circuit. It is sustained by the presence of a thermally ionized column of gas (called a plasma) through which current flows. To initiate the arc in an AW process, the electrode is brought into contact with the work and then quickly separated from it by a short distance. The electric energy from the arc thus formed produces temperatures of 5500°C (10,000°F) or higher, sufficiently hot to melt any metal. A pool of molten metal, consisting of base metal(s) and filler metal (if one is used) is formed near the tip of the electrode. In most arc-welding processes, filler metal is added during the operation to increase the volume and strength of the weld joint. As the electrode is moved along thejoint, the molten weld pool solidifies in its wake.

General Technology of Arc Welding

Electrodes Electrodes used in AW processes are classified as consumable or nonconsumable. Consumable electrodes provide the source of the filler metal in arc welding.These electrodes are available in two principal forms: rods (also called sticks) and wire.Welding rods are typically 225-450 mm (9—18 in) long and 9.5 mm (3/8 in) or less in diameter. The problem with consumable welding rods, at least in production welding operations, is that they must be changed periodically, reducing arc time of the welder.Consumable weld wire has the advantage that it can be continuously fed into the weld pool from spools containing long lengths of wire, thus avoiding the frequent interruptions that occur when using welding sticks. In both rod and wire ‘forms, the electrode is consumed by the arc during the welding process and added to the weld joint as filler metal.

Nonconsumable electrodes are made of tungsten (or carbon, rarely), which resists melting by the arc. Despite its name, a nonconsumable electrode is gradually depleted during the welding process (vaporization is the principal mechanism), analogous to the gradual wearing of a cutting tool in a machining operation. For AW processes that utilize nonconsumable electrodes, any filler metal used in the operation must be supplied by means of a separate wire that is fed into the weld pool.

Arc Shielding At the high temperatures in arc welding, the metals being joined are very chemically reactive to oxygen, nitrogen, and hydrogen in the air. The mechanical properties of the weld joint can be seriously degraded by these reactions. Thus, some means to shield the arc from the surrounding air is provided in nearly all AW processes. Arc shielding is accomplished by covering the electrode tip, arc, and molten weld pool with a blanket of gas or flux, or both, which inhibit exposure of the weld metal to air.

Common shielding gases include argon and helium, both of which are inert. In the welding of ferrous metals with certain AW processes, oxygen and carbon dioxide are used, usually in combination with Ar and/or He, to produce an oxidizing atmosphere or to control weld shape.

A **flux** is a substance used to prevent the formation of oxides and other unwanted contaminants, or to dissolve them and facilitate removal. During welding, the flux melts and becomes a liquid slag, covering the operation and protecting the molten weld metal. The slag hardens upon cooling and must be removed later by chipping or brushing. Flux is usually formulated to serve several additional functions: (1) provide a protective atmosphere for welding, (2) stabilize the arc, and (3) reduce spattering.

The method of flux application differs for each process. The delivery techniques include (1) pouring granular flux onto the welding operation, (2) using a stick electrode coated with flux material in which the coating melts during welding to cover the operation, and (3) using tubular electrodes in which flux is contained in the core and released as the electrode is consumed.

Types of Welding Currents The three different types of current used for welding are alternating current (AC), direct-current electrode negative (DCEN), and directcurrent electrode positive (DCEP). The terms *DCEN* and *DCEP* have replaced the former terms *direct-current straight polarity (DCSP)* and *direct-current reverse polarity (DCRP)*. DCEN and DCSP are the same currents, and DCEP and DCRP are the same currents. Some electrodes can be used with only one type of current. Others can be used with two or more types of current. Each welding current has a different effect on the weld.

DCEN

In direct-current electrode negative, the electrode is negative, and the work is positive. The electrons are leaving the electrode and traveling across the arc to the surface of the metal being welded. This results in approximately one-third of the welding heat on the electrode and two-thirds on the metal being welded.

Consequently, DCSP results in deep penetrating, narrow welds, but with higher workpiece heat input.

DCEN welding current produces a high electrode melting rate.

DCEP

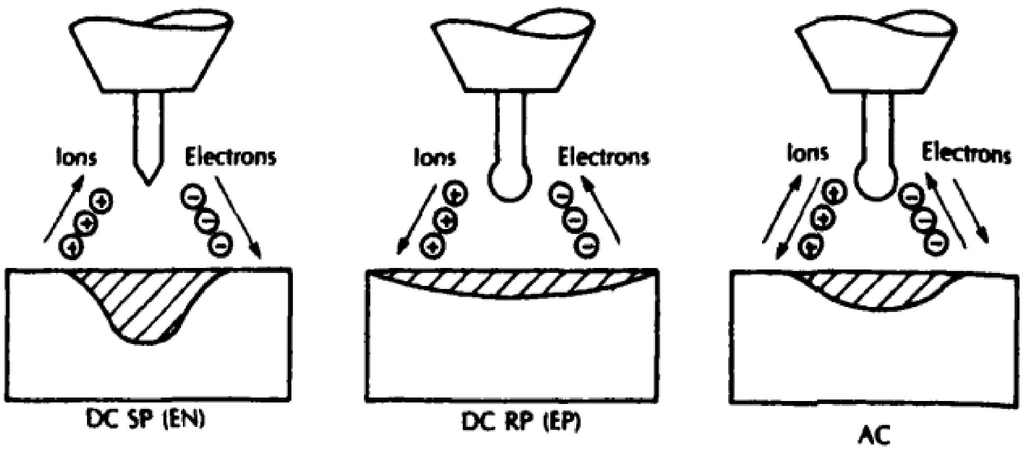
In direct-current electrode positive, the electrode is positive, and the work is negative. The electrons are leaving the surface of the metal being welded and traveling across the arc to the electrode. This results in approximately two-thirds of the welding heat on the electrode and one-third on the metal being welded.

In DCRP, on the other hand, the heating effect of the electrons is on the tungsten electrode rather than on the workpiece. Consequently, larger watercooled electrode holders are required, shallow welds are produced, and workpiece heat input can be kept low. This operating mode is good for welding thin sections or heat-sensitive metals and alloys. This mode also results in a scrubbing action on the workpiece by the large positive ions that strike its surface, removing oxide and cleaning the surface. This mode is thus preferred for welding metals and alloys that oxidize easily, such as aluminum or magnesium.

The DCSP mode is much more common with nonconsumable electrode arc processes than the DCRP mode.

AC

In alternating current, the electrons change direction every 1/120 of a second so that the electrode and work alternate from anode to cathode, Figure 3-8. The positive side of an electrode arc is called the anode, and the negative side is called the cathode. The rapid reversal of the current flow causes the welding heat to be evenly distributed on both the work and the electrode—that is, half on the work and half on the electrode. The even heating gives the weld bead a balance between penetration and buildup.



DC SP (EN)
No cleaning action
70% heat at work
30% heat at W
Excellent electrode current capacity

DC RP (EP)
Strong cleaning action
30% heat at work
70% heat at W
Poor electrode current capacity

AC
Cleaning every half-cycle
~50% heat at work
~50% heat at W
Good electrode current capacity

Types of Power Sources

Two types of electrical devices can be used to produce the low-voltage, high-amperage current combination that arc welding requires. One type uses electric motors or internal combustion engines to drive alternators or generators. The other type uses step-down transformers. Because transformer-type welding machines are quieter, are more energy efficient, require less maintenance, and are less expensive, they are now the industry standards. However, engine- powered generators are still widely used for portable welding.

Transformer-Type Welding Machines A welding transformer uses the alternating current (AC) supplied to the welding shop at a high voltage to produce the low voltage welding power. The heart of these welders is the step-down transformer. All transformers have the following three major components:

- Primary coil—the winding attached to the incoming electrical power

- Secondary coil—the winding that has the electrical current induced and is connected to the welding lead and work leads

- Core—made of laminated sheets of steel and used to concentrate the magnetic field produced in the primary winding into the secondary winding,

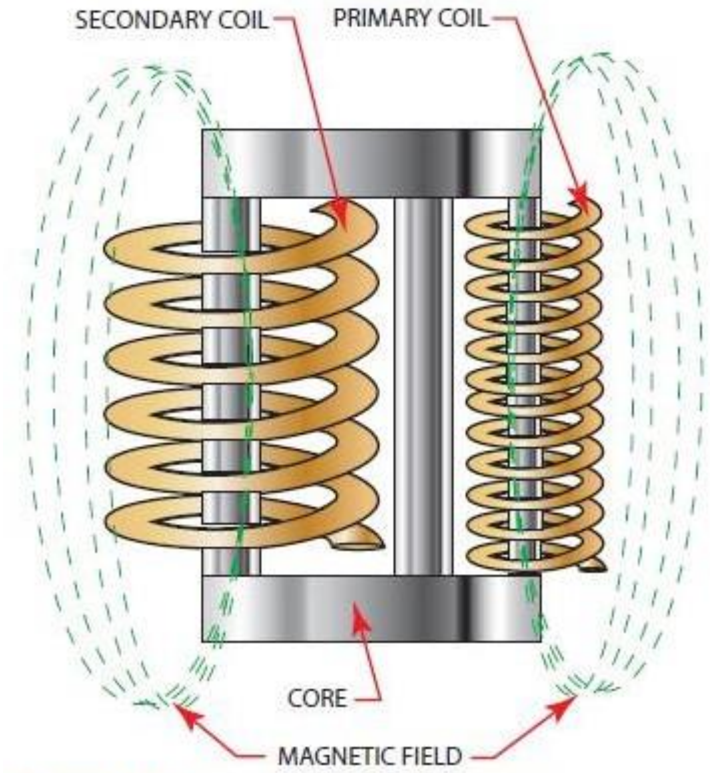


FIGURE 3-16 Parts of a step-down transformer.

Generator- and Alternator- Type Welders

Generators and alternators both produce welding electricity from a mechanical power source. Both devices have an armature that rotates and a stator that is stationary. As a wire moves through a magnetic force field, electrons in the wire are made to move, producing electricity.

In an alternator, magnetic lines of force rotate inside a coil of wire, **Figure 3-27.** An alternator can produce AC only. In a generator, a coil of wire rotates inside a magnetic field. A generator produces DC. It is possible for alternators to use diodes to change the AC to DC for welding. In generators, the welding current is produced on the armature and is picked up with brushes**.** In alternators, the welding current is produced on the stator, and only the small current for the electromagnetic force field goes across the brushes. Therefore, the brushes in an alternator are smaller and last longer. Alternators can be smaller in size and lighter in weight than generators and still produce the same amount of power.

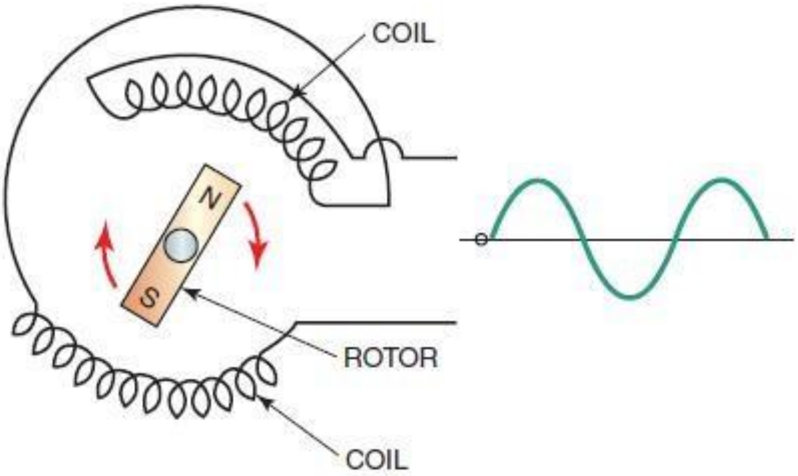


FIGURE 3-27 Schematic diagram of an alternator.
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AW Processes- Consumable Electrodes

Shielded Metal Arc Welding Shielded metal arc welding (**SMAW**) is an AW process that uses a consumable electrode consisting of a filler metal rod coated with chemicals that provide flux and shielding. The welding stick (SMAW is sometimes called stick welding) is typically 225-450 mm long and 2.5-95 mm in diameter. The filler metal used in the rod must be compatible with the metal to be welded, the composition usually being very close to that of the base metal. The coating consists of powdered cellulose (i.e., cotton and wood powders) mixed with oxides, carbonates, and other ingredients, held together by a silicate binder. Metal powders are also sometimes included in the coating to increase the amount of filler metal and to add alloying elements. The heat of the welding process melts the coating to provide a protective atmosphere and slag for the welding operation. It also helps to stabilize the arc and regulate the rate at which the electrode melts.

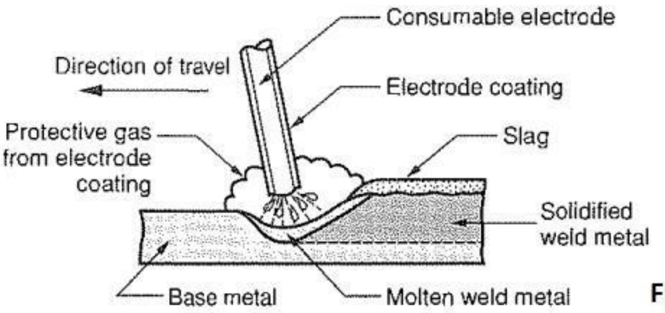


Fig : Shielded metal arc welding (SMAW).

During operation the bare metal end of the welding stick (opposite the welding tip) is clamped in an electrode holder that is connected to the power source. The holder has an insulated handle so that it can be held and manipulated by a human welder. Currents typically used in SMAW range between 30 and 300 A at voltages from 15 to 45 V. Selection of the proper power parameters depends on the metals being welded, electrode type and length, and depth of weld penetration required.

Shielded metal arc welding is usually performed manually. Common applications include construction, pipelines, machinery structures, shipbuilding, fabrication job shops, and repair work. It is preferred over oxyfuel welding for thicker sections-above 5 mm —because of its higher power density. The equipment is portable and low cost, making SMAW highly versatile and probably the most widely used of the AW processes. Base metals include steels, stainless steels, cast irons, and certain nonferrous alloys. It is not used or seldom used for aluminum and its alloys, copper alloys, and titanium.

A **disadvantage** of shielded metal arc welding as a production operation is the use of the consumable electrode stick. As the sticks are used up, they must periodically be changed. This reduces the arc time with this welding process. Another limitation is the current level that can be used. Because the electrode length varies during the operation and this length affects the resistance heating of the electrode, current levels must be maintained within a safe range or the coating will overheat and melt prematurely when starting a new welding stick. Some of the other AW processes overcome the limitations of welding stick length in SMAW by using a continuously fed wire electrode.

Gas Metal Arc Welding Gas metal arc welding (GMAW) or **Metal Inert Gas Welding (MIG)** is an AW process in which the electrode is a consumable bare metal wire, and shielding is accomplished by flooding the arc with a gas. The bare wire is fed continuously and automatically from a Spool through the welding gun, as illustrated in Figure . Wire diameters ranging from 0.8 to 6.5 mm are used in GMAW, the size depending on the thickness of the parts being joined and the desired deposition rate. Gases used for shielding include inert gases such as argon and helium, and active gases such as carbon dioxide. Selection of gases (and mixtures of gases) depends on the metal being welded, as well as other factors. Inert gases are used for welding aluminum alloys and stainless steels, while CO2 is commonly used for welding low and medium carbon steels. The combination of bare

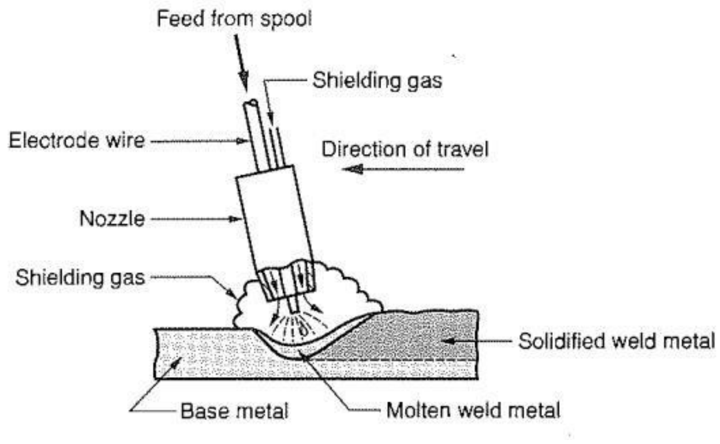


Fig : Gas metal arc welding (GMAW) or Metal Inert Gas Welding (MIG)

electrode wire and shielding gases eliminates the slag covering on the weld bead and thus precludes the need for manual grinding and cleaning of the slag. The GMAW process is therefore ideal for making multiple welding passes on the same joint.

The various metals on which GMAW is used and the variations of the process itself have given rise to a variety of names for gas metal arc welding. When the process was first introduced in the late 1940s, it was applied to the welding of aluminum using inert gas (argon) for arc shielding. The name applied to this process was **MIG welding** (for metal inert gas welding). When the same welding process was applied to steel, it was found that inert gases were expensive and CO_2; was used as a substitute. Hence the term **CO_2welding** was applied. Refinements in GMAW for steel welding have led to the use of gas mixtures, including CO_2 and argon, and even oxygen and argon.

GMAW is widely used in fabrication operations in factories for welding a variety of ferrous and nonferrous metals. Because it uses continuous weld wire rather than welding sticks, it has a significant advantage over SMAW in terms of arc time when performed manually. For the same reason, it also lends itself to automation of arc welding. The electrode stubs remaining after stick welding also wastes filler metal, so the utilization of electrode material is higher with GMAW. Other features of GMAW include elimination of slag removal (since no flux is used), higher deposition rates than SMAW, and good versatility.

Flux-Cored Arc Welding This arc welding process was developed in the early 19505 as an adaptation of shielded metal arc welding to overcome the limitations imposed by the use of stick electrodes.

Flux-cored arc welding (FCAW) is an arc-welding process in which the electrode is a continuous consumable tubing that contains flux and other ingredients in its core . Other ingredients

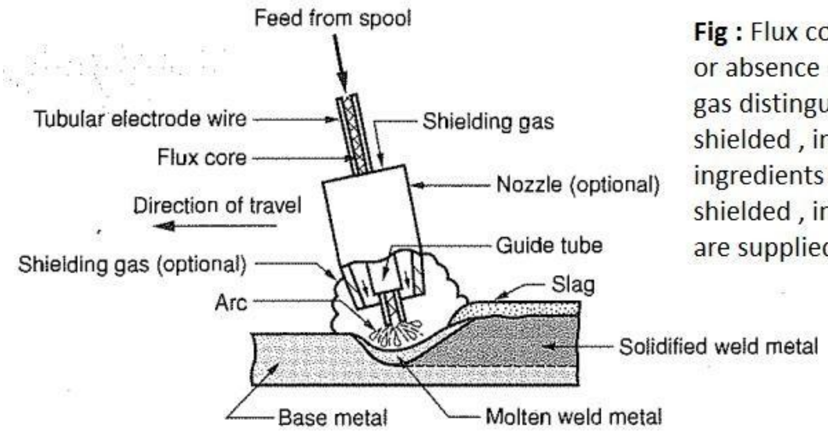


Fig : Flux cored arc welding .The presence or absence of externally supplied shielding gas distinguishes the two types (1) self shielded , in which the core provides the ingredients for shielding; and (2) gas shielded , in which external shielding gases are supplied.

may include deoxidizers and alloying elements. The tubular flux-cored “wire” is flexible and can therefore be supplied in the form of coils to be continuously fed through the arc-welding gun. There are two versions of FCAW:(1) **self-shielded** and (2) **gas shielded**. In the first version of FCAW to be developed, arcshielding was provided by a flux core, thus leading to the name **self-shielded flux cored arc welding**. The core in this form of FCAW includes not only fluxes but also ingredients that generate shielding gases for protecting the arc. The second version of FCAW, developed primarily for welding steels, obtains arc shielding from externally supplied gases, similar to gas metal arc welding. This version is called **gas-shielded flux cored arc welding**. Because it utilizes an electrode containing its own flux together with separate shielding gases, it might be considered a hybrid of SMAW and GMAW. Shielding gases typically employed are carbon dioxide for mild steels or mixtures of argon and carbon dioxide for stainless steels.

FCAW has advantages similar to GMAW, due to continuous feeding of the electrode. It is used primarily for welding steels and stainless steels over a wide stock thickness range. It is noted for its capability to produce very-high-quality weld joints that are smooth and uniform.

Eiectrogas Welding Electrogas welding (**EGW**) is an AW process that uses a continuous consumable electrode (either flux-cored wire or bare wire with externally supplied shielding gases) and molding shoes to contain the molten metal. The process is primarily applied to vertical butt welding, as in fig. When the flux-cored electrode wire is employed, no external gases are supplied, and the process can be considered a special application of self-shielded FCAW. When a bare electrode wire is used with shielding gases from an external source, it is considered a special case of GMAW. The molding shoes are water cooled to prevent their being added to the weld pool. Together with the edges of the parts being welded, the shoes form a container, almost like a mold cavity, into which the molten metal from the electrode and base parts is gradually added. The process is performed automatically, with a moving weld head to travel vertically upward to fill the cavity in a single pass.

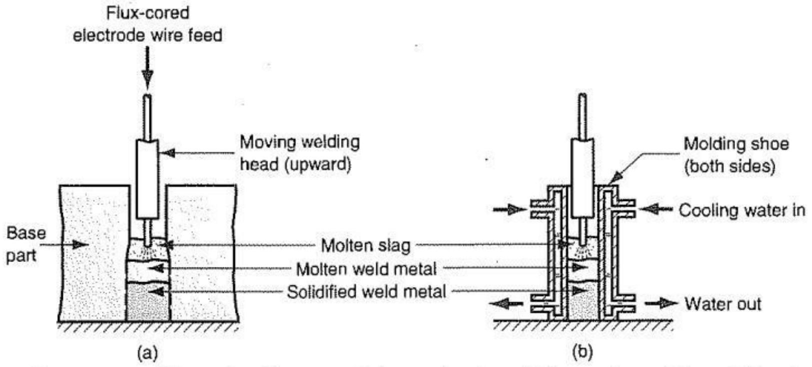


Fig : Electrogas welding using flux- cored electrode wire: (a) front View with molding shoe removed for clarity, and (b) side view showing molding shoes on both sides.

Principal applications of electrogas welding are steels (low and medium-carbon,low-alloy, and certain stainless steels) in the construction of large storage tanks and in shipbuilding. Stock thicknesses from 12 to 75 mm are within the capacity of EGW. In addition to butt welding, it can also be used for fillet and groove welds, always in a vertical orientation. Specially designed molding shoes must sometimes be fabricated for the joint shapes involved.

Submerged Arc Welding This process, developed during the 1930s, was one of the first AW processes to be automated. Submerged arc welding (SAW) is an arc-welding process that uses a continuous, consumable bare wire electrode, and arc shielding is provided by a cover of granular flux. The electrode wire is fed automatically from a coil into the arc. The flux is introduced into the joint slightly ahead of the weld arc by gravity from a hopper, as shown in Figure. The blanket of granular flux completely submerges the welding operation, preventing sparks, spatter, and radiation that are so hazardous in other AW processes. Thus, the welding operator in SAW need not wear the somewhat cumbersome face shield required in the other operations (safety glasses and protective gloves, of course, are required). The portion of the flux closest to the arc is melted, mixing with the molten weld metal to remove impurities and then solidifying on top of the weld joint to form a glass like slag. The slag and unfused flux granules on top provide good protection from the atmosphere and good thermal insulation for the weld area, resulting in relatively slow cooling and a high-quality weld joint, noted for toughness and ductility.

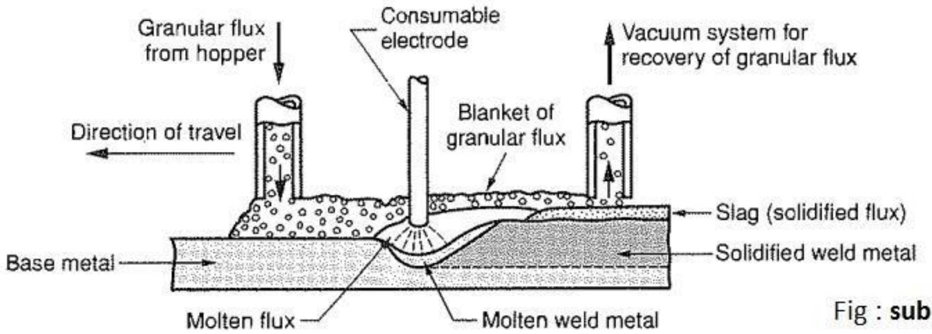


Fig : **submerged arc welding**

Submerged arc welding is widely used in steel fabrication for structural shapes (e.g.welded I- beams); longitudinal and circumferential seams for large diameter pipes, tanks, and pressure vessels; and welded components for heavy machinery. In these kinds of applications, steel plates of 25-mm thickness and heavier are routinely welded by this process. Low-carbon, low-alloy, and stainless steels can be readily welded by SAW; but not high-carbon steels, tool steels, and most nonferrous metals. Because of the gravity feed of the granular fiux, the parts must always be in a horizontal orientation, and a backup plate is often required beneath the joint during the welding operation.

AW Processes---Non-consumable Electrodes

Gas Tungsten Arc Welding Gas tungsten arc welding **(GTAW)** is an AW process that uses a non consumable tungsten electrode and an inert gas for arc shielding. The term TIG welding (tungsten inert gas welding) is often applied to this process (in Europe, WIG welding is the term--the chemical symbol for tungsten is W, for Wolfram). The GTAW process can be implemented with or without a filler metal. When a filler metal is used, it is added to the weld pool from a separate rod or wire, being melted by the heat of the arc rather than transferred across the arc as in the consumable electrode AW processes. Tungsten is a good electrode material due to its high melting point of 3410°C. Typical shielding gases include argon, helium, or a mixture of these gas elements.

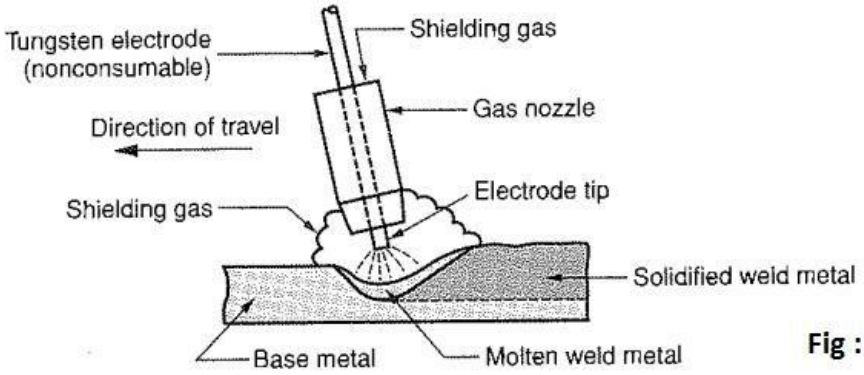


Fig : Gas tungten arc welding

GTAW is applicable to nearly all metals in a wide range of stock thicknesses. It can also be used for joining various combinations of dissimilar metals. Its most common applications are for aluminum and stainless steel. Cast irons, wrought irons, lead, and of course tungsten are difficult to weld by GTAW. In steel welding applications, GTAW is generally slower and more costly than the consumable electrode AW processes, except when thin sections are involved and very-high-quality welds are required. When thin sheets are TIG welded to close tolerances, filler metal is usually not added. The process can be performed manually or by machine and automated methods for all joint types. Advantages of GTAW in the applications to which it is suited include high-quality welds, no weld spatter because no filler metal is transferred across the arc, and little or no postweld cleaning because no flux is used.

Plasma Arc Welding Plasma arc welding (**PAW**) is a special form of gas tungsten arc welding in which a constricted plasma arc is directed at the weld area. In PAW, a tungsten electrode is contained in a specially designed nozzle that focuses a high-velocity stream of inert gas (e,g., argon or argon- hydrogen mixtures) into the region of the arc to form a high-velocity, intensely hot plasma arc stream. Argon, argon-hydrogen, and helium are also used as the arc-shielding gases.

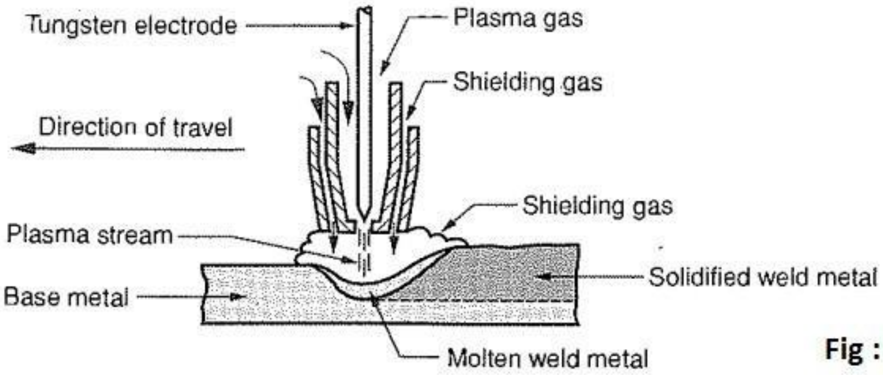


Fig : Plasma arc welding

Temperatures in plasma arc welding reach 28,000°C or greater, hot enough to melt any known metal. The reason why temperatures are so high in PAW (significantly higher than those in GTAW) derives from the constriction of the arc. Although the typical power levels used in PAW are below those used in GTAW the power is highly concentrated to produce a plasma jet of small diameter and very high power density.

Plasma arc welding was introduced around 1960 but was slow to catch on. In recent years its use is increasing as a substitute for GTAW in applications such as automobile subassemblies, metal cabinets, door and window frames, and home appliances. Owing to the special features of PAW, its advantages in these applications include good arc stability, better penetration control than most other AW processes, high travel speeds, and excellent Weld quality. The process can be used to weld almost any metal, including tungsten. D1fficult to weld metals with PAW include bronze, cast irons, lead, and magnesium. Other limitations include high equipment cost and larger torch size than other AW operations, which tends to restrict access in some joint configurations.

The plasma in PAW is created by the low-volume flow of argon through the inner orifice of the PAW torch. A high-frequency pilot arc established between the permanent tungsten electrode and the inner nozzle ionizes the orifice gas and ignites the primary arc to the work piece. When the work piece is connected electrically to the welding torch such that it is of opposite polarity to the permanent electrode, the plasma is drawn to the work piece electrically, and the plasma generation is referred to as operating in the transferred arc mode. When the work piece is not connected electrically to the torch, and the plasma is simply forced to the work piece by the force of the inert gas, the plasma generation is referred to as operating in the **nontransferred mode** (see Figure.). The transferred arc mode is usually employed for welding or cutting, while the no transferred arc mode is usually employed for thermal spraying. Concentric flow of inert gas from an outer gas nozzle provides shielding to the arc and the weld in PAW. This shielding gas can be argon, helium, or argon mixed with helium or hydrogen to obtain subtle differences in arc characteristics.

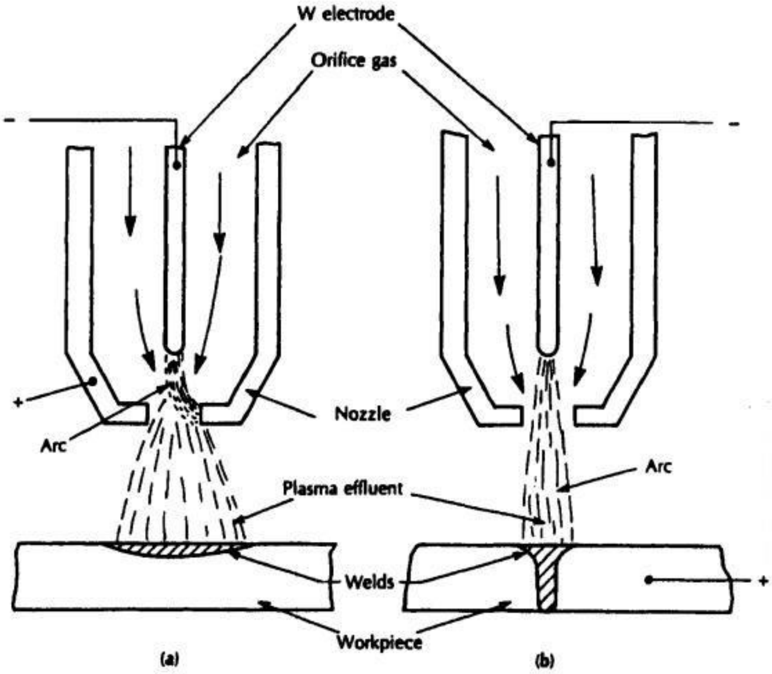


Fig : Schematic comparison of the (a) **nontransferred** and (b) **transferred arc** modes of plasma generation.

Electroslag Welding. The electroslag welding (ESW) process is not a true arc welding process. The energy for melting the base metal and filler is provided by a molten bath of slag that is resistance heated by the welding current. An arc is employed only to melt the flux initially, after being struck at the bottom of the joint. Welds are produced in the vertical up direction (and, occasionally, in horizontal fillets), with the joint edges being melted and fused by molten weld filler metal contained in the joint by water-cooled dams or shoes, as shown in Figure.

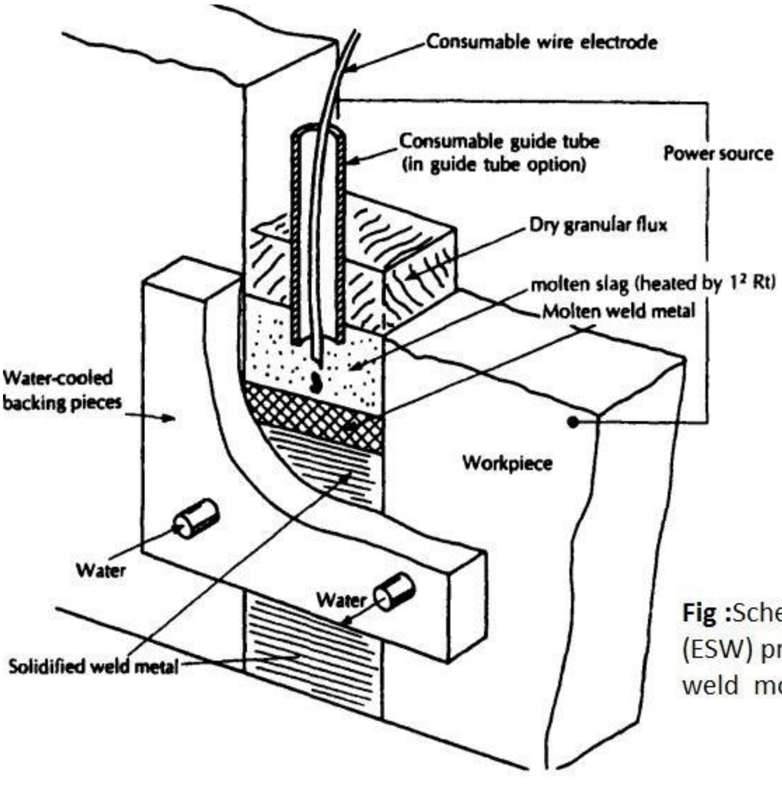


Fig : Schematic of the electroslag welding (ESW) process, including torch, weld, weld mold, and electrical hookup

Consumable – workpiece welding

Stud arc welding or Stud welding (SW)

Stud welding (SW) is a specialized AW process for joining studs or similar components to base parts. A typical SW operation is illustrated in Figure, in which shielding is obtained by the use of a ceramic ferrule. To begin with, the stud is chucked in a special weld gun that automatically controls the timing and power parameters of the steps shown in the sequence. The worker must only position the gun at the proper location against the base workpart to which the stud will be attached and pull the trigger. SW applications include threaded fasteners for attaching handles to cookware, heat radiation fins on machinery, and similar assembly situations. In high-production operations, stud welding usually has advantages over rivets, manually arc-welded attachments, and drilled and tapped holes.

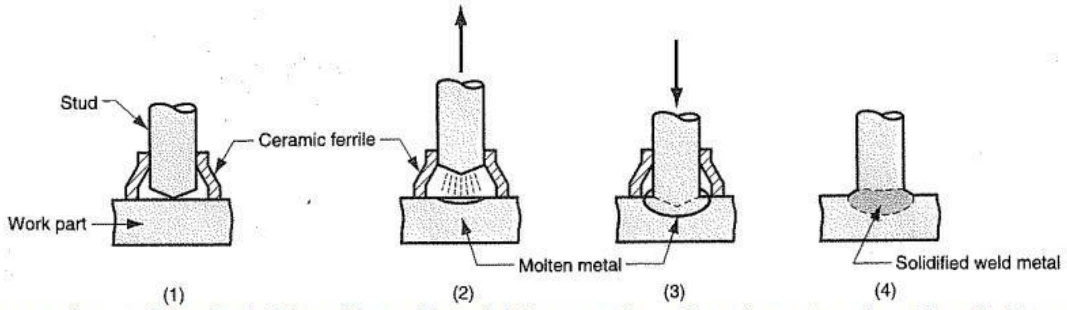


Fig : Stud arc welding (SW): (1) stud is positioned; (2) current flows from the gun, and stud is pulled from base to establish arc and create a molten pool; (3) stud is plunged into molten pool; and (4) ceramic ferrule is removed after solidification.

Capacitor - discharge stud welding

In attaching smaller (2-6 mm – diameter) studs , the energy stored in a condenser is used for heating. Discharge takes place just before or during approach to the surface. The intense localise heat allows the joining of widely differing cross sections and of dissimilar materials. Timing and motion control are critical. Studs can be welded to thin sheets , even to those coated with paint or PTFE on the other side, allowing the fastening of instrument panels , nameplates and auto trim.

The term **percussion welding (PEW)** is used to describe capacitor discharge welding applied to joining wires to terminals and other flat surfaces.

SOLID - STATE WELDING

In solid state-welding, coalescence of the part surfaces is achieved by (1) pressure alone, or (2) heat and pressure. For some solid - state processes, time is also a factor. If both heat and pressure are used, the amount of heat by itself is not sufficient to cause melting of the work surfaces. In other words, fusion of the parts would not occur using only the heat that is externally applied in these processes. In some cases, the combination of heat and pressure, or the particular manner in which pressure alone is applied, generates sufficient energy to cause localised melting of the faying surfaces. Filler metal is not added in solid –state welding.

General Considerations in Solid-State Welding

In most of the solid-state processes, a metallurgical bond is created with little or no melting of the base metals. To metallurgically bond two similar or dissimilar metals, the two metals must be brought into intimate contact so that their cohesive atomic forces attract each other. In normal physical contact between two surfaces, such intimate contact is prohibited by the presence of chemical films, gases, oils, and so on. In order for atomic bonding to succeed, these films and other substances must be removed. In fusion welding (as well as other joining processes such as brazing and soldering), the films are dissolved or burned away by high temperatures, and atomic bonding is established by the melting and solidification of the metals in these processes. But in solid-state welding, the films and other contaminants must be removed by other means to allow metallurgical bonding to take place. In some cases, a thorough cleaning of the surfaces is done just before the welding process; while in other cases, the cleaning action is accomplished as an integral part of bringing the part surfaces together. To summarize, the essential ingredients for a successful solid-state weld are that the two surfaces must be very clean, and they must be brought into very close physical contact with each other to permit atomic bonding.

Welding processes that do not involve melting have several advantages over fusion- welding processes. If no melting occurs, then there is no heat-affected zone, and so the metal surrounding the joint retains its original properties. Many of these processes produce welded joints that comprise the entire contact interface between the two parts, rather than at distinct spots or seams, as in most fusion-welding operations. Also, some of these processes are quite applicable to bonding dissimilar metals, without concerns about relative thermal expansions, conductivities, and other problems that usually arise when dissimilar metals are melted and then solidified during joining.

Solid State-Welding Processes

Forge Welding Forge welding is of historic significance in the development of manufacturing technology. The process dates from about 1000 b.c., when blacksmiths of the ancient world learned to join two pieces of metal .Forge welding is a welding process in which the components to be joined are heated to hot working temperatures and then forged together by hammer or other means.

Considerable skill was required by the craftsmen who practiced it in order to achieve a good weld by present-day standards.

Cold Welding Cold welding (CW) is a solid-state welding process accomplished by applying high pressure between clean contacting surfaces at room temperature. The faying surfaces must be exceptionally clean for CW to work, and cleaning is usually done by degreasing and wire brushing immediately before joining. Also, at least one of the metals to be welded, and preferably both, must be very ductile and free of work hardening. Metals such as soft aluminum and copper can be readily cold welded. The applied compression forces in the process result in cold working of the metal parts, reducing thickness by as much as 50%; but they also cause localized plastic deformation at the contacting surfaces, resulting in coalescence. For small parts, the forces may be applied by simple hand operated tools. For heavier work, powered presses are required to exert the necessary force. No heat is applied from external sources in CW, but the deformation process raises the temperature of the work somewhat. Applications of CW include making electrical connections.

Roll Welding Roll welding is a variation of either forge welding or cold welding, depending on whether external heating of the work parts is accomplished prior to the process. Roll welding (ROW) is a solid-state welding process in which pressure sufficient to cause coalescence is applied by means of rolls, either with or without external application of heat. If no external heat is supplied, the process is called cold roll welding; if heat is supplied, the term hot roll welding is used. Applications of roll welding include cladding stainless steel to mild or low alloy steel for corrosion resistance, making bimetallic strips for measuring temperature, and producing “sandwich” coins for the U.S. mint.

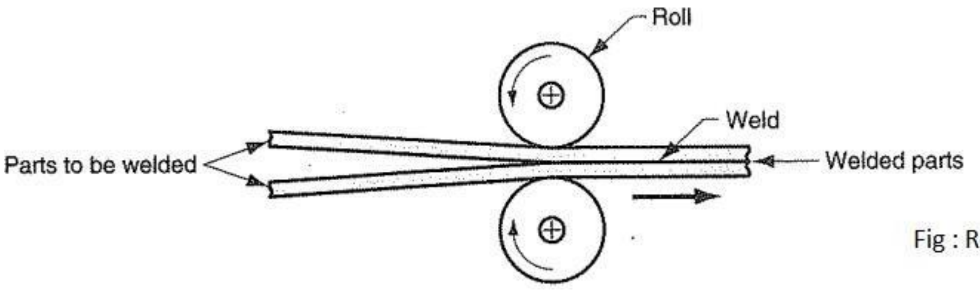


Fig : Roll welding (ROW)

Hot Pressure Welding Hotpressure welding (**HPW**) is another variation of forge welding in which coalescence occurs from the application of heat and pressure sufficient to cause considerable deformation of the base metals. The deformation disrupts the surface oxide film, thus leaving clean metal to establish a good bond between the two parts. Time must be allowed for diffusion to occur across the laying surfaces. The operation is usually carried out in a vacuum chamber or in the presence of a shielding medium. Principal applications of **HPW** are in the aerospace industry.

Diffusion Welding Diffusion welding (DFW) is a solid-state welding process that results from the application of heat and pressure, usually in a controlled atmosphere, with sufficient time allowed for diffusion and coalescence to occur. Temperatures are well below the melting points of the metals (about 0.5 T_m is the maximum), and plastic deformation at the surfaces is minimal. The primary mechanism of coalescence is solid-state diffusion, which involves migration of atoms across the interface between contacting surfaces. Applications of DFW include the joining of high-strength and refractory metals in the aerospace and nuclear industries. The process is used to join both similar and dissimilar metals, and in the latter case a tiller layer of a different metal is often sandwiched between the two base metals to promote diffusion. The time for diffusion to occur between, the faying surfaces can be significant, requiring more than an hour in some applications.

Explosion Welding Explosion welding (EXW) is a solid-state welding process in which rapid coalescence of two metallic surfaces is caused by the energy of a detonated explosive. It is commonly used to bond two dissimilar metals, in particular to clad one metal on top of a base metal over large areas. Applications include production of corrosion-resistant sheet and plate stock for making processing equipment in the chemical and petroleum industries. The term explosion cladding is used in this context. No filler metal is used in EXW, and no external heat is applied. Also, no diffusion occurs during the process (the time is too short). The nature of the bond is metallurgical, in many cases combined with a mechanical interlocking that results from a rippled or wavy interface between the metals.

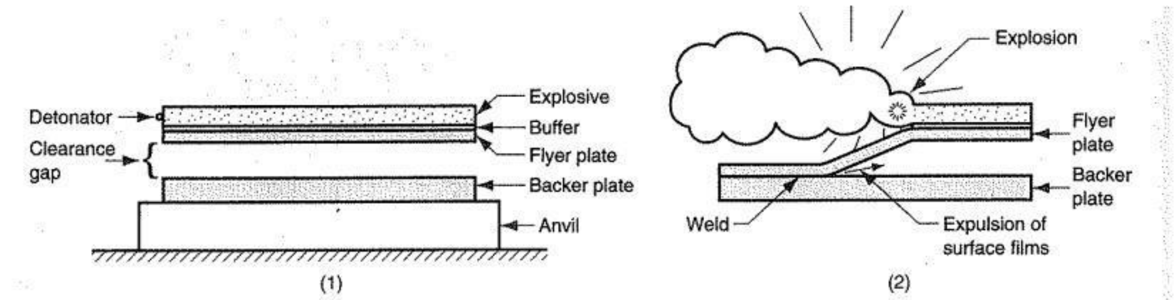


Fig : explosion welding (EXW): (1) setup in the parallel Configuration, and (2) during detonation of the explosive charge.

Friction Welding Friction welding is a widely used commercial process, amenable to automated production methods. Friction welding (FRW) is a solid-state welding process in which coalescence is achieved by frictional heat combined with pressure. The friction is induced by mechanical rubbing between the two surfaces, usually by rotation of one part relative to theother, to raise the temperature at the joint interface to the hot working range for the metals involved. Then the parts are driven toward each other with sufficient force to form a metallurgical bond. The axial compression force upsets the parts, and a flash is produced by the material displaced. Any surface films that may have been on the contacting surfaces are expunged during the process. The flash must be subsequently trimmed (c.g., by turning) to provide a smooth surface in the weld region. When properly carried out, no melting occurs at the faying surfaces. No filler metal, flux, or shielding gases are normally used.

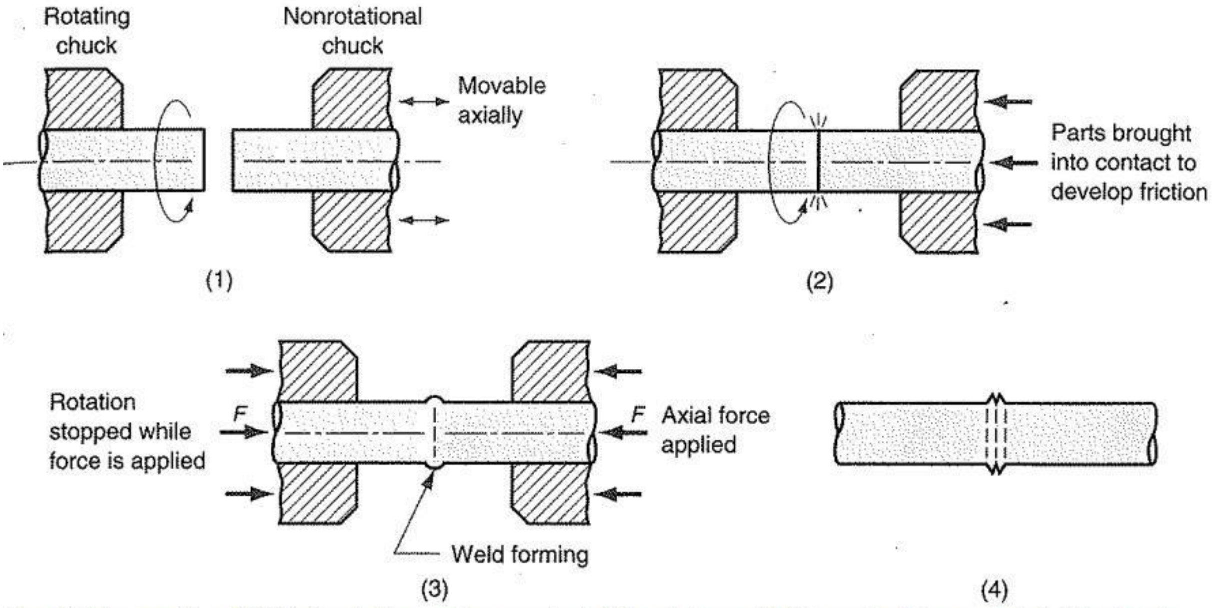


Fig : Friction welding (FRW): [ll rotating part, no contact; (2) parts brought into contact to generate friction heal; (3) rotation stopped and axial pressure applied; and (4) weld created.

Ultrasonic Welding Ultrasonic welding (USW) is a solid-state welding process in which two components are held together under modest clamping force, and oscillatory shear stresses of ultrasonic frequency are applied to the interface to cause coalescence.The oscillatory motion between the two parts breaks down any surface films to allow intimate contact and strong metallurgical bonding between the surfaces. Although heating of the contacting surfaces occurs due to interfacial rubbing and plastic deformation, the resulting temperatures are well below the melting point. No filler metals, fluxes, or shielding gases are required in USW.

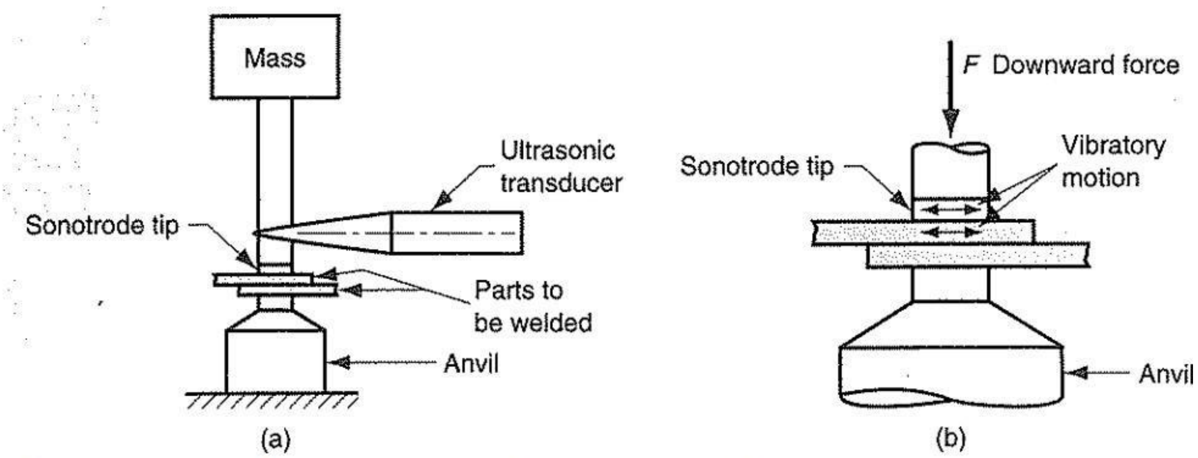


Fig : Ultrasonic welding (USW): a) general setup for a lap loint; and b) closeup of weld area.

RESISTANCE WELDING

Resistance welding (RW) is a group of fusion-welding processes that uses a combination of heat and pressure to accomplish coalescence, the heat being generated by electricai resistance to current flow at the junction to be welded. The principal components in resistance welding are shown in Figure for a resistance spot welding operation, the most widely used process in the group. The components include workparts to be welded (usually sheet metal parts), two opposing electrodes, a means of applying pressure to squeeze the parts between the electrodes, and an AC power supply from which a controlled current can be applied. The operation results in a fused zone betweenthe two parts, called a weld nugget in spot welding.

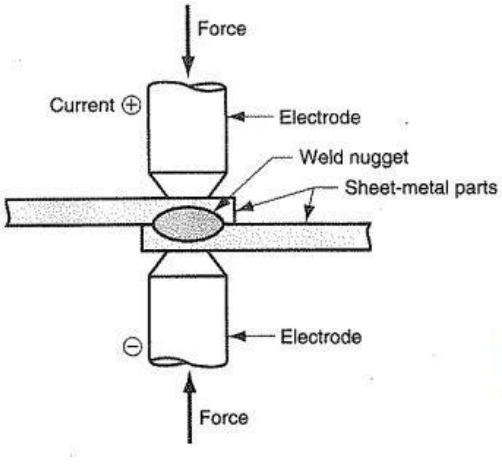


Fig : Resistance welding showing the components in spot welding, the predominant process in the RW group.

By comparison to arc welding, resistance welding uses no shielding gases, flux, or filler metal; and the electrodes that conduct electrical power to the process are nonconsumable. RW is classified as fusion welding because the applied heat almost always causes melting of the 'faying surfaces. However, there are exceptions. Some welding operations based on resistance heating use temperatures below the melting points of the base metals, so fusion does not occur.

Resistance spot welding (RSW) is an RW process in which fusion of the laying surfaces of a lap joint is achieved at one location by opposing electrodes. The process is used to join sheet-metal parts of thickness 3 min or less, using a series of spot welds, in situations where an airtight assembly is not required. The size and shape of the weld spot is determined by the electrode tip, the most common

electrode shape being round, but hexagonal, square, and other shapes are also used. The resulting weld nugget is typically 5-10 mm in diameter, with a heat-affected zone extending slightly beyond the nugget into the base metals. If the weld is made properly, its strength will be comparable to that of the surrounding metal.

Materials used for RSW electrodes consist of two main groups: (1) copper-based alloys and (2) refractory metal compositions such as copper and tungsten combinations. The second group is noted for superior wear resistance. As in most manufacturing processes, the tooling in spot welding gradually wears out as it is used. Whenever practical, the electrodes are designed with internal passageways for water cooling.

Resistance Seam Welding In resistance scam welding (RSEW), the stick-shaped electrodes in spot welding are replaced by rotating wheels, as shown in Figure , and a series of overlapping spot welds are made along the lap joint. The process is capable of producing air tight joints, and its industrial applications include the production of gasoline tanks, automobile mufflers, and various other fabricated sheet metal containers. Technically, RSEW is the same as spot welding, except that the wheel electrodes introduce certain complexities. Since the operation is usually carried out continuously, rather than discretely, the seams should be along a straight or uniformly curved line. Sharp corners and similar discontinuities are difficult to deal with. Also, warping of the parts becomes more of a factor in resistance seam welding, and well-designed fixtures are required to hold the work in position and minimize distortion.

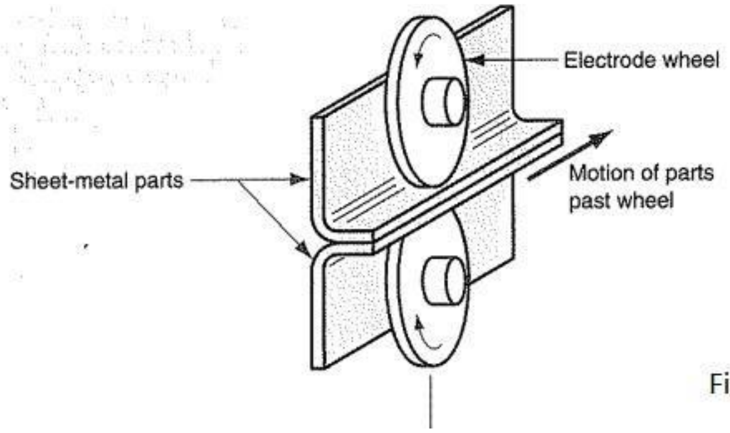


Fig : Resistance seam welding (RSEW).

Resistance Projection Welding Resistance projection welding (RPW) is an RW process in which coalescence occurs at one or more relatively small contact points on the parts. These contact points are determined by the design of the parts to be joined, and may consist of projections, embossments, or localized intersections of the parts. Refer Fig;

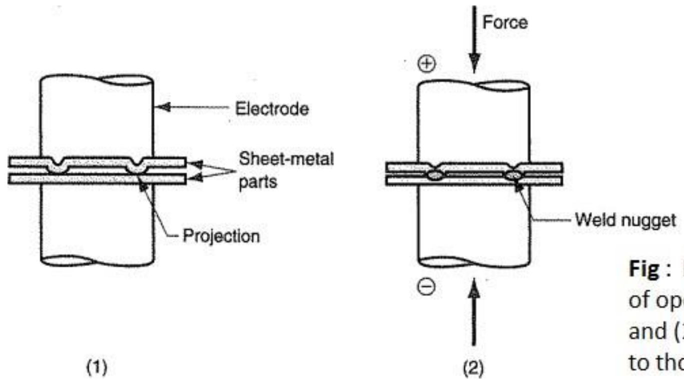


Fig : Resistance projection welding (RPW): (1) at start of operation,contact between parts is at projections; and (2) when current is applied, weld nuggets similar to those in spot welding are formed at the projections.

The part on top has been fabricated with two embossed points to contact the other part at the start of the process. It might he argued that the embossing operation increases the cost of the part, but this increase may be more than offset by savings in welding cost.

In **flash welding (FW),** normally used for butt joints, the two surfaces to be joined are brought into contact or near contact and electric current is applied to heat the surfaces to the melting point, after which the surfaces are forced together to form the weld. The two steps are outlined in Figure.

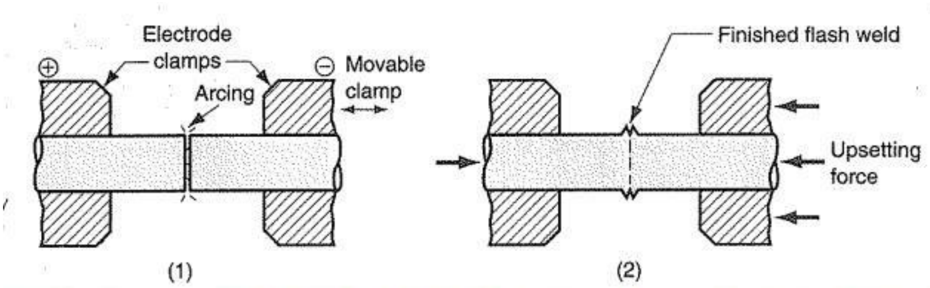


Fig : Flash welding (FW): (1) heating by electrical resistance; and (2)upsettingwpads are forced together.

In addition to resistance heating, some arcing occurs (called **flashing**, hence the name of the welding process), depending on the extent of contact between the faying surfaces, so flash welding is sometimes classified in the arc welding group. Current is usually stopped during upsetting. Some metal, as well as contaminants on the surfaces, is squeezed out of the joint and must be subsequently machined to provide a joint of uniform size.

Upset welding (UW) is similar to flash welding except that in UW the faying surfaces are pressed together during heating and upsetting. In flash welding, the heating and pressing steps are separated during the cycle. Heating in UW is accomplished entirely by electrical resistance at the contacting surfaces; no arcing occurs. When the faying surfaces have been heated to a suitable temperature below the melting point, the force pressing the parts together is increased to cause upsetting and coalescence in the contact region. Thus, upset welding is not a fusionwvelding process in the same sense as the other welding processes we have discussed. Applications of UW are similar" to those of flash welding: joining ends of wire, pipes, tubes, and so on.

Percussion welding (PEW) is also similar to flash welding, except that the duration of the weld cycle is extremely short, typically lasting only il~1O ms. Fast heating is accomplished by rapid discharge of electrical energy between the two surfaces to be joined, followed immediately by percussion of one part against the other to form the weld. The heating is very localized, making this process attractive for electronic applications in which the dimensions are very small and nearby components may be sensitive to heat.

BRAZING

Brazing is a joining process in which a filler metal is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. No melting of the base metals occurs in brazing; only the filler melts. In brazing the filler metal (also called the brazing metal), has a melting temperature (liquidus) that is above 450°C (840°F) but below the melting point (solidus) of the base meta1(s) to be joined. If the joint is properly designed and the brazing operation has been properly performed, the brazed joint will be stronger than the filler metal out of which it has been formed upon solidification. This rather remarkable result is due to the small part clearances used in brazing, the metallurgical bonding that occurs between base and filler metals, and the geometric constrictions that are imposed on the joint by the base parts.

Brazing has several **advantages** compared to welding: (1) any metals can be joined, including dissimilar metals; (2) certain brazing methods can be performed quickly and consistently, thus permitting high cycle rates and automated production; (3) some methods allow multiple joints to be brazed simultaneously; (4) brazing can be applied to join thin walled parts that cannot be welded; (5) in general, less heat and power are required than in fusion welding-; (6) problems with. the heat affected zone (HAZ) in the base metal near the joint are reduced; and (7) joint areas that are inaccessible by many welding processes can be brazed, since capillary action draws the molten filler metal into the joint.

Disadvantages and limitations of brazing include (1) joint strength is generally less than that of a welded joint; (2) although strength of a good brazed joint is greater than that of the filler metal, it is likely to be less than that of the base metals; (3) high service temperatures may weaken a brazed joint; and (4) the color of the metal in the brazed joint may not match the color of the base metal parts, a possible aesthetic disadvantage.

Brazing as a production process is widely used in a variety of industries, including automotive (e.g., joining tubes and pipes), electrical equipment (e.g., joining wires and cables), cutting tools (e.g., brazing cemented carbide inserts to shanks), and jewelry making. In addition, the chemical processing industry and plumbing and heating contractors join metal pipes and tubes by brazing. The process is used extensively for repair and maintenance work in nearly all industries.

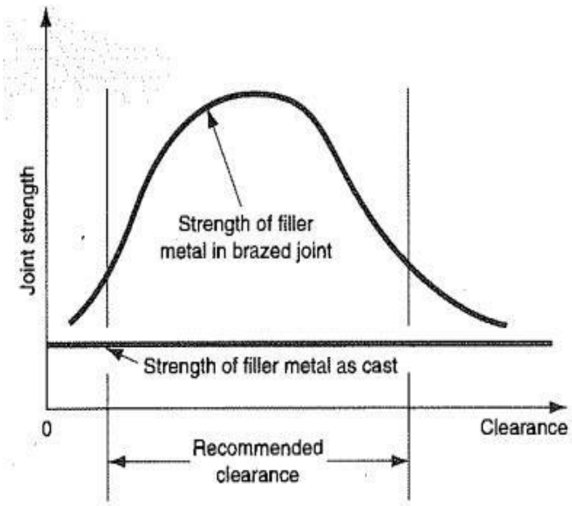


Fig : Joint strength as function of joint clearance

Filler metals and Fluxes

Common filler metals used in brazing are listed in Table along with the principal base metals on which they are typically used.

TABLE Common filler metals used in brazing and the base metals on which they are used.

Filler Metal	Typical Composition	Approximate Brazing Temperature °C	Approximate Brazing Temperature °F	Base Metals
Aluminum and silicon	90 Al, 10 Si	600	1100	Aluminum
Copper	99.9 Cu	1120	2050	Nickel copper
Copper and phosphorous	95 Cu, 5 P	850	1550	Copper
Copper and zinc	60 Cu, 40 Zn	925	1700	Steels, cast irons, nickel
Gold and silver	80 Au, 20 Ag	950	1750	Stainless steel, nickel alloys
Nickel alloys	Ni, Cr, others	1120	2050	Stainless steel, nickel alloys
Silver alloys	Ag, Cu, Zn, Cd	730	1350	Titanium, Monel, Inconel, tool steel, nickel

To qualify as a brazing metal, the following characteristics are needed: (1) melting temperature must be compatible with the base metal, (2) surface tension in the liquid phase must be low for good wettability, (3) fluidity of the molten metal must be high for penetration into the interface, (4) the metal must be capable of being brazed into a joint of adequate strength for the application, and (5) chemical and physical interactions with base metal (e.g., galvanic reaction) must be avoided.

Brazing fluxes serve a similar purpose as in welding; they dissolve, combine with, and otherwise inhibit the formation of oxides and other unwanted byproducts in the brazing process. Use of a flux does not substitute for the cleaning steps described above. Characteristics of a good flux include (1) low melting temperature, (2) low viscosity so that it can be displaced by the filler metal, (3) facilitates wetting, and (4) protects the joint until solidification of the filler metal. The flux should also be easy to remove after brazing. Common ingredients for brazing fluxes include borax, borates, fluorides, and chlorides. Wetting agents are also included in the mix to reduce surface tension of the molten filler metal and to improve wettability. Forms of flux include powders, pastes, and slurries.

Brazing Methods

Torch Brazing In torch brazing, flux is applied to the part surfaces and a torch is used to direct a flame against the work in the vicinity of the joint. A reducing flame is typically used to inhibit oxidation. After the workpart joint areas have been heated to a suitable temperature, filler wire is added to the joint, usually in wire or rod form. Fuels used in torch brazing include acetylene, propane, and other gases, with air or oxygen. The selection of the mixture depends on heating requirements of the job. Torch brazing is often performed manually, and skilled workers must be employed to control the flame, manipulate the hand-held torches, and properly judge the temperatures; repair work is a common application. The method can also be used in mechanized production operations, in which parts and brazing metal are loaded onto a conveyor or indexing table and passed under one or more torches.

Furnace Brazing Furnace brazing uses a furnace to supply heat for brazing and is best suited to medium and high production. In medium production, usually in batches, the component parts and brazing metal are loaded into the furnace, heated to brazing temperature, and "then cooled and removed. High-production operations use flow~through furnaces, in which parts are placed on a conveyor and are transported through the various heating and cooling sections. Temperature and atmosphere control are important in furnace brazing; the atmosphere must be neutral or reducing. Vacuum furnaces are sometimes used. Depending on the atmosphere and metals being brazed, the need for a flux may be eliminated.

induction Brazing Induction brazing utilizes heat from electrical resistance to a high frequency current induced in the work. The parts are preloaded with filler metal and placed in a high-frequency AC field—-the parts do not directly contact the induction coil. Frequencies range from 5 kHz to 5 MHz. High frequency power sources tend to provide surface heating, while lower frequencies cause deeper heat penetration into the work and are appropriate for heavier sections. The process can be used to meet low- to high~production requirements.

Resistance Brazing Heat to melt the filler metal in this process is obtained by resistance to flow of electrical current through the parts. As distinguished from induction brazing, the parts are directly connected to the electrical circuit in resistance brazing. The equipment is similar to that used in resistance welding, except that a tower power level is required for brazing. The parts with filler metal preplaced are held between electrodes while pressure and current are applied. Both induction and resistance brazing achieve rapid heating cycles and are used for relatively small parts. Induction brazing seems to be the more widely used of the two processes.

Dip Brazing In dip brazing, either a molten salt bath or a molten metal bath accomplishes heating. In both methods, assembled parts are immersed in the baths contained in a heating pot. Solidification occurs when the parts are removed from the bath. In the salt bath method, the molten mixture contains fluxing ingredients and the filler metal is preloaded onto the assembly. In the metal bath method, the molten filler metal is the heating medium; it is drawn by capillary action into the joint during submersion. A flux cover is maintained on the surface of the molten metal bath. Dip brazing achieves fast heating cycles and can be used to braze many joints on a single part or on multiple parts simultaneously.

infrared Brazing This method uses heat from a high-intensity infrared lamp. Some IR lamps are capable of generating up to 5000 W of radiant heat energy, which can be directed at the workparts for brazing. The process is slower than most of the other processes reviewed above, and is generally limited to thin sections.

Braze Welding This process differs from the other brazing processes in the type of joint to which it is applied. As pictured in Figure 32.6, braze welding is used for filling a more conventional weld joint, such as the V-joint shown. A greater quantity of filler metal is deposited than in brazing, and no capillary action occurs. In braze welding, the joint consists entirely of filler metal; the base metal does not melt and is therefore not fused into the joint as in a conventional "fusion welding process. The principal application of braze welding is repair work.

SOLDERING

Soldering is similar to brazing and can be defined as a joining process in which a filler metal with melting point (liquidus) not exceeding 450°C (840°F) is melted and distributed by capillary action between the faying surfaces of the metal parts being joined. As in brazing, no melting of the base metals occurs, but the filter metal wets and combines with the base metal to form a metallurgical bond. Details of soldering are similar to those of brazing, and many of the heating methods are the same. Surfaces to be soldered must be precleaned so they are free of oxides, oils, and so on. An appropriate flux must be applied to the faying surfaces, and the surfaces are heated. Filler metal, called solder, is added to the joint, which distributes itself between the closely fitting parts.

Advantages attributed to soldering include (1) low energy input relative to brazing and fusion welding, (2) variety of heating methods available, (3) good electrical and thermal conductivity in the joint, (4) capability to make air—tight and liquid-tight seams for containers, and (5) easy to repair and rework.

The biggest **disadvantages** of soldering are (1) low joint strength unless reinforced by mechanically means and (2) possible weakening or melting of the joint in elevated temperature service.

Solders and Fluxes

Solders and fluxes are the materials used in soldering. Both are critically important in the joining process.

Solders Most solders are alloys of tin and lead, since both metals have low melting points . Their alloys possess a range of liquidus and solidus temperatures to achieve good control of the soldering process for a variety of applications. Lead is poisonous and its percentage is minimized in most solder compositions. Tin is chemically active at soldering temperatures and promotes the wetting action required for successful joining.

Soldering Fluxes Soldering fluxes should do the following: (1) be molten at soldering temperatures, (2) remove oxide films and tarnish from the base part surfaces, (3) prevent oxidation during heating, (4) promote wetting of the faying surfaces, (5) be readily displaced by the molten solder during the process, and (6) leave a residue that is noncorrosive and nonconductive.

Soldering fluxes can be classified as organic or inorganic. **Organic fluxes** are made of either rosin (i.e., natural rosin such as gum wood, which is not water-soluble) or water- soluble ingredients (e.g., alcohols, organic acids, and halogenated salts). The water soluble type facilitates cleanup after soldering. Organic fluxes are most commonly used for electrical and electronics connections. They tend to be chemically reactive at elevated soldering temperatures but relatively noncorrosive atroom temperatures. **Inorganic fluxes** consist of inorganic acids (e.g., muriatic acid) and salts (e.g., combinations of ZIIIC and ammonium chlorides) and are used to achieve rapid and active fiuxing where oxide films are problem.

Soldering Methods

These methods include torch soldering, furnace soldering, induction soldering, resistance soldering, dip soldering, and infrared soldering. There are other soldering methods, not used in brazing, that should be described here. These methods are band soldering, wave soldering, and reflow soldering.

Hand Soldering Hand soldering is performed manually using a hot soldering iron. A bit, made of copper, is the working end of a soldering iron. Its functions are (1) to deliver heat to the parts being soldered, (2) to melt the solder, (3) to convey molten solder to the joint, and (4) to withdraw excess solder. Most modern soldering irons are heated by electrical resistance.

Wave Soldering Wave soldering is a mechanized technique that allows multiple lead wires to be soldered to a printed circuit board (PCB) as it passes over a wave of molten solder. The typical setup is one in which a PCB, on which electronic components have been placed with their lead wires extending through the holes in the board, is loaded onto a conveyor for transport through the wave soldering equipment. The conveyor supports the PCB on its sides, so that its underside is exposed to the processing steps, which consist of the following: (1) flux is applied using any of several methods, including foaming, spraying, or brushing; (2) preheating (using light bulbs, heating coils, and infrared devices) to evaporate solvents, activate the flux, and raise the temperature of the assembly; and (3) wave soldering, in which the liquid solder is pumped from a molten bath through a slit onto the bottom of the board to make the soldering connections between the lead wires and the metal circuit on the board.

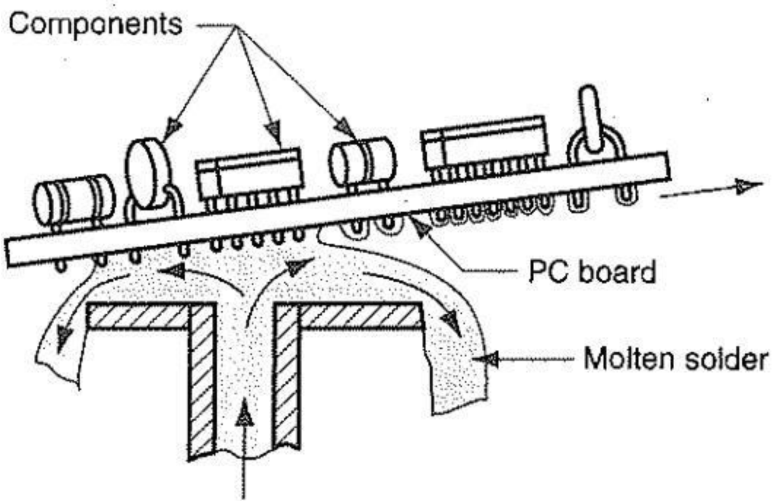


Fig : Wave soldering, in which molten solder is delivered up through a narrow slot onto the underside of a printed circuit board to connect the component lead wires.

Reflow Soldering This process is also widely used in electronics to assemble surface mount components to printed circuit boards. In the process, a solder paste consisting of solder powders in a flux binder is applied to spots on the board where electrical contacts are to be made between surface mount components and the copper circuit. The components are then placed on the paste spots, and the board is heated to melt the solder, forming mechanical and electrical bonds between the component leads and the copper on the circuit board.

APPENDIX I

CONTENT BEYOND THE SUBJECT

APPENDIX I

CNC Machine

In a CNC machine, all the numerical functions are controlled by the computer. The computer stores the programs which are required to operate the machine.

The computer also gives the display of various parameters of the machine-like spindle speed, feed rate etc. It consists of electronic instrumentation to measure the output.

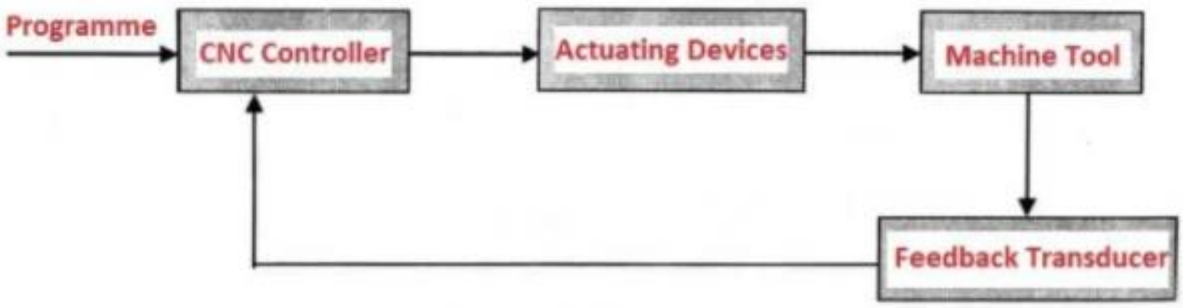
CNC stands for computer numerical control. It is a machine controlled by a computer. Its external appearance is similar to that of an NC machine. Tape or Computer Keyboard or Tutor Keyboard is used as input media for CNC machines. For NC machines tape is to be fit repeat to produce repeated jobs.

But for CNC machine tape is fit once and the program is stored in the memory and can be run repeatedly to produce repeated jobs. CNC or computer numerical control is an NC system that employs a dedicated microcomputer as a machine control unit.

The presence of a microprocessor, RAM memory, ROM memory, input and output devices have increased the level of automation in NC systems. CNC Machine is designed to perform multiple operations in a faster way which increase the flexibility of the machine.

Basic CNC Concept

A CNC system can be described in terms of three major elements:



Concept of CNC

1. Hardware,
2. Software and
3. Information.

1. Hardware:

A Hardware includes microprocessors that affect control system functions and peripheral devices for data communication, machine tool status monitoring and machine tool interfacing.

2. Software:

The software includes programs that are performed by system microprocessors and there are different types of software associated with CNC.

3. Information:

Information about the dynamic characteristics of the machine and many other information related to the process. When any of these deceptive components fail, the diagnostics subsystem will automatically separate the faulty component from the system and activate the unnecessary component in place of the damaged one so that the newly installed component can perform its task.

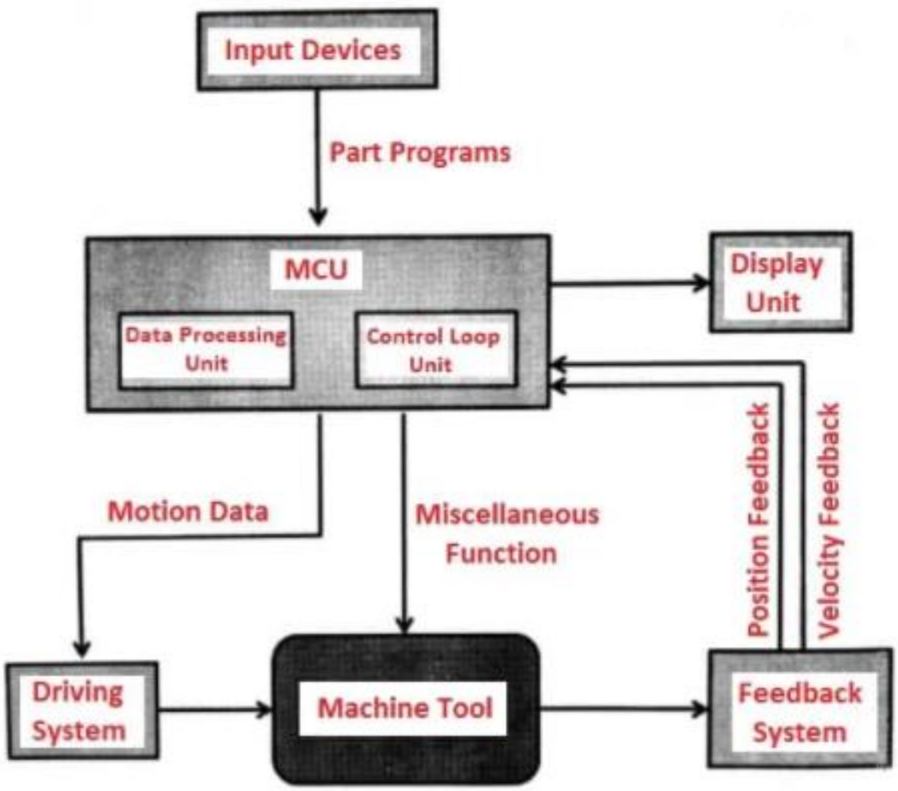
Features of CNC Machine

The feature of CNC machines are as follows:

- Part program input may be through the keyboard.
- The part program is entered into the computer and stored in the memory. Then it is used again and again.
- The entered part program can be edited for any errors or design changes.
- A graphical display of the cutter path and shape of the finished work is possible before actually running the program (simulation).
- Tool wear compensation is possible.
- Able to get machine utilization information's like the number of components produced, time per component, time for setting the job etc.,
- The sub-program facility is also possible for repetitive machining sequences.

Basic Elements of the CNC Machine

The main parts of the CNC machine are:



Basic Elements of CNC Machine

1. Input devices
2. Machine control unit (MCU)
3. Machine tool
4. Driving system
5. Feedback system
6. Display uni

1. Input Devices:

These are devices that are used to input the part program into a CNC machine. There are three generally used input devices and these are punch tape reader, magnetic tape reader and computer via RS-232-C communication.

2. Machine Control Unit (MCU):

Machine control unit called the heart of the CNC machine. It performs all the control functions of the CNC machine, there are various tasks performed by MCU are

- It reads the coded instructions given in it.
- Machine control unit decodes the coded instruction.
- This axis implements interpolation (linear, circular and helical) to generate motion commands.
- Machine control unit feeds the axis motion command to the amplifier circuit to drive the axis mechanism.
- It takes a feedback signal of position and speed for each drive axis.
- It implements the auxiliary control functions such as coolant or spindle on/off and tool change.

3. Machine Tool:

A CNC machine tool always has a sliding table and a spindle to control the position and speed. The table of the machine is controlled in the X and Y-axis direction and the spindle is controlled in the Z-axis direction.

4. Driving System:

The driving system of a CNC machine include of an amplifier circuit, drive motors and ball lead screws. The MCU supplies the signals (ie, of position and speed) of each axis to the amplifier circuits. The control signals are then augmented (increased) to actuate the drive motors. And the actuated drive motors rotate the ball lead screw to put in a position the machine table.

5. Feedback System:

The feedback system has the transducers that act as sensors. It is also called a measuring system. It consists of position and speed transducers that continuously monitor the position and speed of the cutting tool located at any given moment.

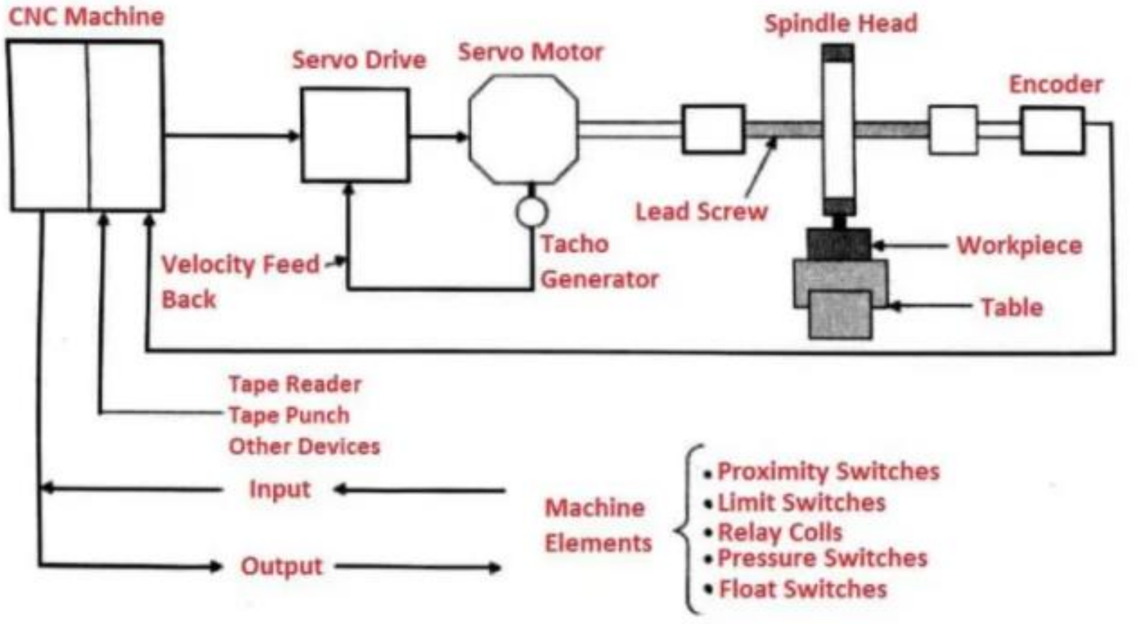
The MCU receives signals from transducers and it uses the difference in reference signals and feedback signals to generate control signals to correct position and speed errors.

6. Display Unit:

The monitor is employed to display programs, commands and other useful data of the CNC machine.

How CNC Machine Works?

The figure shows the **CNC machine working**:



CNC Machine Tool

First, the part program is entered into the MCU of the CNC.

The MCU processes all the data and according to the program prepared, it prepares all the motion commands and gives it to the driving system.

The drive system acts as motion commands sent by the MCU. The drive system manages the motion and velocity of the machine tool.

The feedback system records the position and velocity measurements of the machine tool and gives a feedback signal to the MCU.

In the MCU, the feedback signals are compared with reference signals and if errors occur, it corrects it and sends new signals to the machine tool to be corrected.

The display unit is used to see all the programs, commands, and other data. It works like the eye of the machine.

Working Principle of CNC Machine

It consists of two separate controls, a CNC controller that doses the function of program decoding interpolation, diagnostics machine actuation, etc. Another is the programmable logic controller (PLC), which dose spindle on-off, coolant on-off, turret operation etc.

Slides are transferred via their own feed drive (AC or DC) servomotors or ball screws and nut drives. The feed drive controllers the feed drive motors. Suitable transducers have been fitted to either the table or the motor, which measures the slide position.

Also, the position is monitored and checked through the feedback transducers to ensure the accuracy of positioning. The spindle is provided with stepped motors of AC or DC. A suitable control is used to vary is the speed of the spindle motor. A suitable feedback device connected to the shaft monitors the speed. This is how the **CNC machine works.**

Advantages of CNC Machine

Following are the advantages of CNC machine:

1. CNC machine can produce jobs with highest accuracy and precision than any other manual machine. It eliminates human errors.
2. It can be operated for 24 hours of a day. Higher flexibility also.
3. The parts manufactured by it have the same accuracy. There is no variety in parts manufactured by CNC machines.
4. A highly skilled operator is not needed to run a CNC machine.
5. A semi-skilled operator can also operate accurately and more precisely.
6. Operators can easily make changes and improvements and reduce the delay time and Reduce inspection cost.
7. It has the capability to produce a complex design with high accuracy in minimum possible time with minimum wastage.
8. Modern design software allows the designer to emulate the creator of his idea.
9. And this removes the need for making a prototype or model a saves time and money.
10. Fewer workers are required to operate a CNC machine and save labour cost.
11. It is suitable for batch production.
12. It requires less space for its operations

13. More operational safety.

Disadvantages of CNC Machine

Following are the disadvantages of CNC Machine:

1. The cost of a CNC machine is much higher than a manually operated machine.
2. The initial cost is high.
3. The parts of the CNC machines are costly.
4. Maintenance costs are significantly higher in the case of CNC.
5. It does not eliminate the need for costly tools.
6. CNC machine requires skilled programmers.
7. It is not suitable for small scale production
8. Maintenance cost is more.

Applications of CNC Machines

Almost every manufacturing industry uses CNC machines. With an increase in the competitive environment and demands, the demand for CNC usage has increased to a greater extent. The machine tools that come with the CNC are late, mills shaper welding etc.

The industries which are using CNC machines are the automotive industry, metal removal industry, fabricating metals industry, electrical discharge machining industry, wood industry etc.

The following parts are normally done in practice on CNC machines

1. Aerospace equipment.
2. Automobile parts.
3. Complex shapes.
4. Electronic industry uses CNC e.g. Printed circuit board.
5. Electrical industry uses CNC e.g. Coil winding.
6. For small to medium batch quantity.
7. Where the set-ups are very large.
8. It used where tool storage is a problem.

9. Where much metal needs to be removed.
10. When the part geometry is so complex.
11. The operations are very complex.
12. For parts subjected to regularly design changes.
13. When the inspection is required 100%.
14. It used when the lead time does not permit the conventional tooling manufacture.
15. When the machining time is very less as compared to down.
16. Where tool storage is a problem.
17. Where repetitive operations are required on the work