Module of Introduction Manufacturing Engineering

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The works is support by NORHED-II NORAD INDMEET Project (grant nr. 62862)

October, 2023
Jimma, Ethiopia

Chapter One

1. Manufacturing Engineering

Instructional Objectives

At the end of this Topic, the Reader/Students would be able to:-

i. Define the "manufacturing " from the aspect of Manufacturing Engineering
ii. Identify the role of "manufacturing"
iii. Define with examples the concept of "manufacturing"
iv. List the main classifications of the manufacturing processes
v. State the main purposes of "manufacturing processes"
vi. Describe the basic concept of advance manufacturing process that is " computer Aid manufacturing"
vii. Describe the basic concept of "manufacturing system"
viii. Define the concept of "production Development".

1.1 Basic Introduction to Manufacturing Engineering

Manufacturing is derived from the Latin word manufactus, means made by hand. In modern context it involves making products from raw material by using various processes, by making use of hand tools, machinery or even computers. Manufacturing Engineering, in its application to engineering industries, shows how the different problems related to development of various machines may be solved by a study of physical, chemical and other laws governing the manufacturing process.

The study of manufacturing reveals those parameters which can be most efficiently being influenced to increase production and raise its accuracy. The grows of manufacturing technology is depending on the progress and prosperity of human civilization are governed and judged mainly by improvement and maintenance of standard of living through availability or production of ample and quality goods and services for men's material welfare (MMW) in all respects. The successful creation of men's material welfare (MMW) depends mainly on.

- Availability of natural resources (NR)
- Exertion of human effort (HE); both physical and mental
- Development and use of power tools and machines (Tools)

This can be depicted in a simple form, $MMW = NR(HE)^{TOOLS}$ where, NR: refers to air, water, heat and light, plants and animals and solid and liquid minerals.

TOOLS: refers to power plants, chemical plants, steel plants, and machine tools etc. which magnify human capability. This clearly indicates the important roles of the components; NR, HE and TOOLS on achieving MMW and progress of civilization.

Manufacturing Defined from Technological Definition; it's the application of physical and chemical processes to alter the geometry, properties, and appearance of a starting material to make parts or products for a given application. Accomplished by combination of machinery, tools, power, and manual labors as shown in the following Fig.1.1

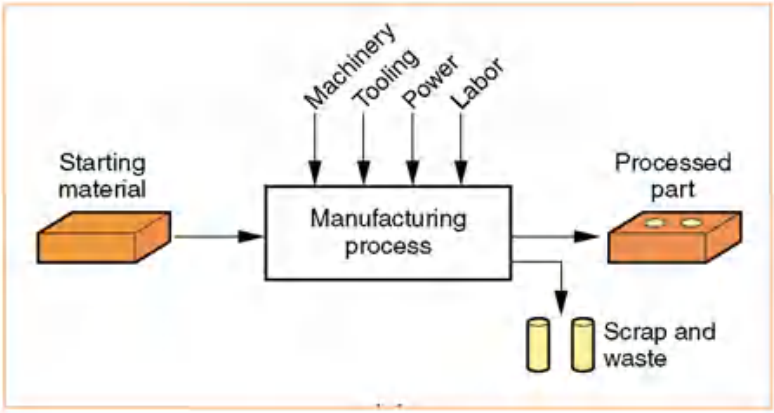


Fig.1.1 Over view of manufacturing process

Manufacturing Defined from Economic Definition; it's the transformation of materials into items of greater value by means of one or more processing and/or assembly operations.

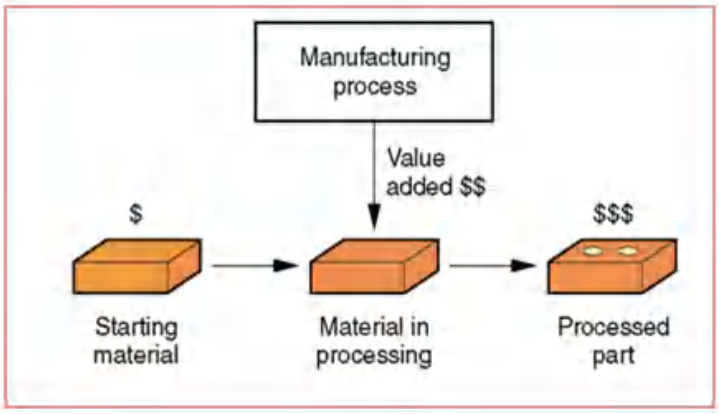


Fig.1.2 Purpose of Manufacturing

Manufacturing Engineering Cover Two Domains:-

(a) Production Management, Its mainly refers to planning, coordination and control of the entire manufacturing in most profitable way with maximum satisfaction to the customers by best utilization of the available resources like man, machine, materials and money.

The most significant and ultimate objective, i.e., "Increase in Profit, Pr", can be attained by:

I. Reducing the overall manufacturing cost, Cm
II. Increase in revenue, R by increasing quality and reliability of the products
III. Enhancement of saleable production.

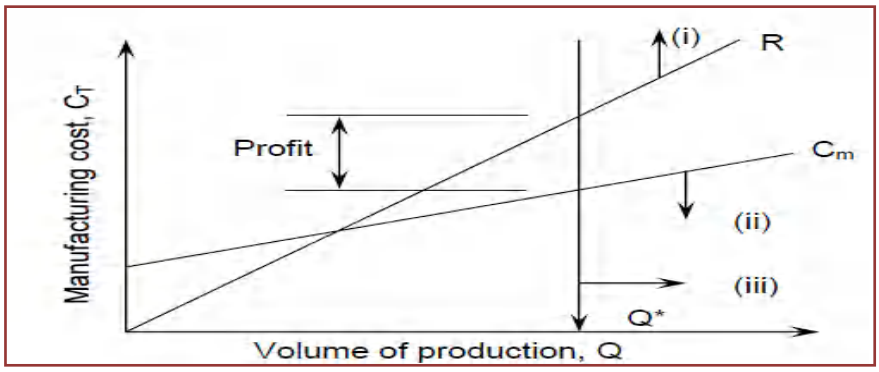


Fig. 1.3 Strategies of increasing profit in manufacturing process.

(b) Manufacturing Process

Manufacturing process is that part of the production process which is directly concerned with the change of form or dimensions of the part being produced. It does not include the transportation, handling or storage of parts.

1.1 Classification of Manufacturing Processes

For producing a product materials are needed. So that it is important to know the characteristics of the available engineering materials. Raw materials used in manufacturing process: - products, tools, machines and equipments in factories or may be some industries their manufacturing process start from extracting the ores. Ore is a process of converting mined metal into a molten form for reducing or refining processes in foundries. This molten metal is poured into moulds for producing commercial casting which is called ingots. Such ingots are then processed in rolling mills or machining to obtain the required materials in form of bloom, billets, slabs and rods. These forms of materials are further subjected to various manufacturing processes to get usable shapes and sizes in various manufacturing workshops. The processes may be classified into two major groups as primary shaping processes and secondary processes.

1.1.2 Primary Shaping

Primary shaping processes are manufacturing of a product from an amorphous material. Some processes produce finished products or articles into its usual form whereas others do not, and require further working to finish component to the desired shape and size. Some of the important primaries shaping processes are:-

- Casting (Solidification Processes) - starting material is a heated liquid that solidifies to form part geometry
- Powder metallurgy- powder metallurgical process.
- Metal forming (Deformation Processes) - starting material is a ductile solid that is deformed.
- Regenerative manufacturing- Production of solid products in layer by layer from raw materials in different form:- • liquid – e.g., Stereo lithography
  • Powder – e.g., Selective Sintering
  • Sheet – e.g., LOM (laminated object manufacturing)
  • Wire – e.g., FDM. (Fused Deposition Modeling).

1.1.3 Secondary or Machining Processes

As large number of components require further processing after the primary processes. These components are subjected to one or more number of machining operations in machine shop and Surface processing operations (clean, treat, coat, or deposit material onto the exterior surface of the work) to obtain the desired shape and dimensional accuracy. Thus, the jobs undergoing these operations are the roughly finished products received through primary shaping processes. The process of removing the undesired or unwanted material from the workpiece or job or component to produce a required shape using a cutting tool is known as machining. This can be done by a manual process or by using a machine called machine tool (traditional machines namely lathe, milling machine, drilling, shaper, planner, slotter).

In many cases these operations are performed on rods, bars and flat surfaces in machine shops. These secondary processes are mainly required for achieving dimensional accuracy and a very high degree of surface finish. The secondary processes require the use of one or more machine tools, various single or multi-point cutting tools (cutters), job holding devices, marking and measuring instruments, testing devices and gauges etc. for getting desired dimensional control and required degree of surface finish on the workpieces. The example of parts produced by machining processes includes hand tools machine tools instruments, automobile parts, nuts, bolts and gears etc. Lot of material is wasted as scrap in the secondary or machining process. Some of the common secondary or machining processes are: - Conventional machining processes namely Lathe, Milling, Drilling, Boring, Planning, CNC machining (precision machines) and Unconventional machining processes namely machining with Numerical Control (NC) machines tools or Computer Numerical Control (CNC) machines tools use ECM, LBM, AJM, USM setups etc.

1.2 Metal Forming Processes

Forming processes encompasses a wide variety of techniques, which make use of suitable force, pressure or stresses, like compression, tension and shear or their combination to cause a permanent deformation of the raw material to impart required shape. These processes are also known as mechanical working processes and are mainly classified into two major categories i.e., hot working processes and cold working processes. In these processes, no material is removed; however it is deformed and displaced using suitable stresses like compression, tension, and shear or combined stresses to cause plastic deformation of the materials to produce required shapes. Some of the important metals forming processes are:-

Hot working Processes (1) Forging, (2) Rolling, (3) Hot spinning, (4) Extrusion, (5) Hot drawing and (6) Hot spinning.

Cold working processes (1) Cold forging, (2) Cold rolling, (3) Cold heading, (4) Cold drawing, (5) Wire drawing,(6) Stretch forming, (7) Sheet metal working processes such as piercing, punching, lancing, notching, coining, squeezing, deep drawing, bending etc.

1.3 Joining Processes

Many products observed in day-to-day life, are commonly made by putting many parts together may be in subassembly. For example, the ball pen consists of a body, refill, barrel, cap, and refill operating mechanism. All these parts are put together to form the product as a pen. More than 800 parts are put together to make various subassemblies and final assembly of car or aero-plane. A complete machine tool may also require assembling more than 100 parts in various sub assemble or final assembly. The process of putting the parts together to form the product, which performs the desired function, is called assembly. An assemblage of parts may require some parts to be joined together using various joining processes. But assembly should not be confused with the joining process. Most of the products cannot be manufactured as single unit they are manufactured as different components using one or more of the above manufacturing processes, and these components are assembled to get the desired product. Joining processes are widely used in fabrication and assembly work. In these process two or more pieces of metal parts are joined together to produce desired shape and size of the product. The joining processes are carried out by fusing, pressing, rubbing, riveting, screwing or any other means of assembling. Temporary, semi-permanent or permanent type of fastening to make a good joint is generally created by these processes. Temporary joining of components can be achieved by use of nuts, screws and bolts. Some of the important and common joining processes are: (1) Welding (plastic or fusion), (2) Brazing, (3) Soldering, (4) Riveting, (5) Screwing, (6) Press fitting, (7) Sintering, (8) Adhesive bonding, (9) Shrink fitting, (10) Explosive welding, (11) Diffusion welding, (12) Keys and cotters joints, (13) Coupling and (14) Nut and bolt joints.

1.4 Surface Finishing Processes

Surface finishing processes are utilized for imparting intended surface finish on the surface of a job. By imparting a surface finishing process, dimension of part is not changed functionally; either a very negligible amount of material is removed from the certain material is added to the surface of the job. These processes should not be misunderstood as metal removing processes in any case as they are primarily intended to provide a good surface finish or a decorative or protective coating on to the metal surface. Surface cleaning process also called as a surface finishing process. Some of the commonly used surface finishing processes are:-(1) Honing, (2) Lapping, (3) Super finishing, (4) Belt grinding, (5) Polishing, (6) Tumbling, (7) Organic finishes, (8) Sanding, (9) deburring, (10) Electroplating, (11) Buffing, (12) Metal spraying, (13) Painting, (14) Inorganic coating, (15) Anodizing, (16) Sheradising, (17) Parkerizing, (18) Galvanizing, (19) Plastic coating, (20) Sand coating, (21) Anodizing and (22) Sand blasting.

1.5 Processes Effecting Change in Properties

Processes effecting change in properties are generally employed to provide certain specific properties to the metal work pieces for making them suitable for particular operations or use. Some important material properties like hardening, softening and grain refinement are needed to jobs and hence are imparted by heat treatment. Heat treatments affect the physical properties and also make a marked change in the internal structure of the metal. Similarly the metal forming processes effect on the physical properties of work pieces. Similarly shot peening process,

imparts fatigue resistance to work pieces. A few such commonly used processes are given as under :(1) Annealing, (2) Normalizing, (3) Hardening, (4) Case hardening, (5) Flame hardening, (6) Tempering, (7) Shot peeing, (8) Grain refining and (9) Age hardening.

1.6 Product Simplification and Standardization

The technique of simplification and standardization of product is closely inter-related that leads to higher efficiency in production, better quality and reduced production cost. Simplification is a process of determining limited number of grades, types and sizes of a components or products or parts in order to achieve better quality control, minimize waste, simplify production and, thus, reduce cost of production. By eliminating unnecessary varieties, sizes and designs, simplification leads to manufacture identical components or products for interchangeability and maintenance purposes of assembly of parts. Standardization is the important step towards interchangeable manufacture, increased output and higher economy. The technique of standardization comprises of determining optimal manufacturing processes, identifying the best possible engineering material, and allied techniques for the manufacture of a product.

1.7 Inspection and Quality Control

A product is manufactured to perform desired functions. It must have a specified dimension such as length, width, height, diameter and surface smoothness to perform or accomplish its intended function. It means that each product requires a defined size, shape and other characteristics as per the design specifications. For manufacturing the product to the specified size, the dimensions should be measured and checked during and after the manufacturing process. It involves measuring the size, smoothness and other features, in addition to their checking. These activities are called measurement and inspection respectively. In the era of globalization, every manufacturer must pay sufficient attention towards maintaining quality because it is another important requirement or function of a production unit. If a manufacturing concern wants to survive for longer time and to maintain its reputation among the users, it should under all condition apply enough efforts not only to keep up the standard of quality of its products once established but to improve upon the same from time to time.

1.8 Computer Aided Manufacturing (CAM)

The computer aided manufacturing implies manufacturing itself, aided or controlled by computers. In a wider sense, it denotes all the activities in the manufacturing environment like use of computers in inventory control, project management, material requirement planning, data acquisition, testing and quality control. Improved reliability in view of the better manufacturing methods and controls at the manufacturing stage, the products thus manufactured as well as of the manufacturing system would be highly reliable. Since most of the components of a CAM system would include integrated diagnostics and monitoring facilities, they would require less maintenance compared to the conventional manufacturing methods. Because of the Computer Numerical Control (CNC) machines used in production and the part programs being made by the stored geometry from the design stage, the scrap level would be reduced to the minimum possible and almost no rework would be necessary. Since all the information and controlling functions are attempted with the help of the computer, a better management control on the

manufacturing activity is possible. All the above advantages when properly translated, would mean a lower total cost and consequently, higher final earnings. Therefore any manufacturing activity in a production unit (job shop production or mass scale manufacture) can get the benefits of Computer Aided Manufacturing. However, better results can be obtained when the design and manufacturing activities are properly integrated. Also, when there is a large variety of products or minor changes required in the existing production programme, CAM can easily manage the necessary changes or alterations. Following are the main advantages of using CAM.

The integration of CAD and CAM systems is called Computer Integrated Manufacturing (CIM) system. The role of computer in manufacturing may be in two major groups namely computer monitoring and control of the manufacturing process and manufacturing support applications, which deal essentially with the preparations for act of manufacturing and post manufacture operations. Computers are used in controlling machine tools and other material handling equipments.

1.9 **Manufacturing System**

Manufacturing basically implies making of goods or articles and providing services to meet the needs of mankind. It creates value by useful application of physical and mental-labor in the process. It is a chain of interrelated activities of production process and other support services activities of an manufacturing environment such as order processing, product design, design and manufacturing of tools, die, mould, jigs, fixtures and gauges, selection of material, planning, managing and maintaining control of the processes, production, and reliable quality of processed product in a systematic and sequential manner with proper coordination, cooperation and integration of the whole manufacturing system that will lead to economical production and effective marketing of proposed product in the minimum possible time. It is, therefore, evident that manufacturing today is not a one man activity as it was in the initial stages, wherein all the physical and mental inputs were applied by a single craftsman. These days it has become totally a team work which consists of several components interacting together in a dynamic manner. This entire domain of manufacturing is known as Manufacturing System, which takes the required inputs and delivers the products for the customer. It is, therefore, evident that manufacturing today is not a one man activity as it was in the preliminary stages, wherein all the physical and mental inputs were provided by a single workman. Today it is a team work which consists of several components interacting together in a dynamic manner to provide the required physical and mental inputs at appropriate stages to impart desired results. This entire domain of manufacturing is known as Manufacturing System, which takes the required inputs and delivers the products for the customer. Manufacturing activities in a manufacturing system jointly contribute towards economic and qualitatively acceptable production of desired articles in minimum possible time. As per the need of the customer, the products are identified and their demands are determined roughly for market forecast by considering present and future competition.

The real manufacturing or production activity is carried out on the shop. The layout of the shop floor has a significant influence on the tools required to be coordinated in order to an economical and high quality production of various components. It should be such that it ensures timely

movement of raw materials, dies moulds, jigs and fixtures and finished components, adequate safety to men, material and machinery, enables timely inspection and quality control and minimizes handling time for material and parts, etc. During actual manufacturing a lot of different activities are called management function. Various engineers play an important role in the organizational function of a manufacturing concern. They are required to ensure proper movement of the material, tools and parts as per their specialized jobs in industry.

1.10 Product Development

A product development has to go through the following concepts:- (1)Product specifications,(2) Conceptual design ,(3) Ergonomics and aesthetics,(4) Standards), (5) Detailed design,(6) Prototype development,(7)Testing,(8) Simulation,(9) Design for manufacture,(10) Design for assembly,(11) Drafting.

Exercises

1. What should be the aims and objectives in manufacturing engineering of any product?
2. Justify “Machining/manufacturing is a value addition process”.
3. Why even a battery operated pencil sharpener cannot be accepted as a machine tool?
4. Why is making profit must for any industry?
5. How do you classify the manufacturing processes?
6. Distinguish between ‘primary’ and ‘secondary’ processes?
7. Discuss primary shaping processes. Give also a brief account of the primary shaping processes.
8. Explain the secondary or machining processes. Give also a brief account of these processes.
9. Describe and name the types of joining processes, surface finishing operations and the processes employed for changing the properties of manufactured components.
10. Explain the term ‘Manufacturing System’. What all it encompasses and how an integrated approach is made for making an economical and competitive product?
11. Explain the terms CAD, CAM, NC, CAD/CAM, FMS and CIM?
12. Briefly explain the conventional process of the product cycle in the conventional manufacturing environment.

Chapter Two

2. **Material-Removal Processes and Machines**

Metal cutting or material-removal processes are also known as machining processes. Machining processes (turning, milling, drilling and etc.) are the most widespread metal shaping process in mechanical manufacturing industry. Machining processes are commonly carried out in machine shops or tool room for machining cylindrical or flat jobs to a desired shape, size and finish on a rough block of job material with the help of a wedge shaped tool. The cutting tool is constrained to move relative to the job in such a way that a layer of metal is removed in the form of a chip. General metal cutting operations are shown in Fig. 2.1. These machining processes are performed on metal cutting machines, more commonly termed as machine tools using various types of cutting Tools (single or multi-point). A machine tool is a power driven metal cutting machine which assist in managing the needed relative motion between cutting tool and the job that changes the size and shape of the job material. In metal cutting (machining) process, working motion is imparted to the workpiece and cutting tool by the mechanisms of machine tool so that the work and tool travel relative to each other and machine the workpiece material in the form of shavings (or swarf) known as chips.

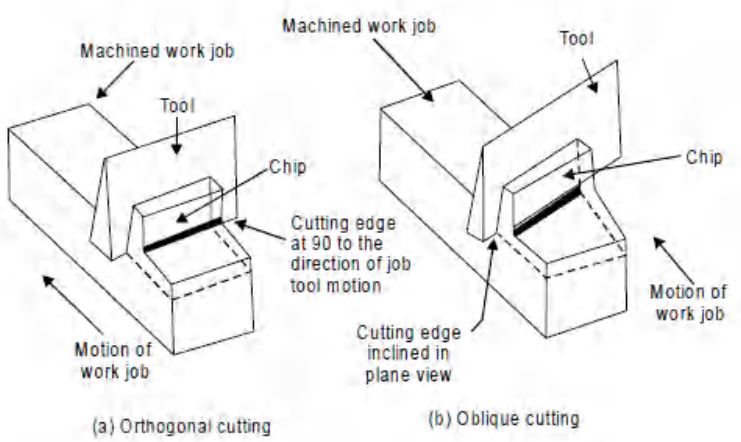


Figure : General cutting process with chip information

The machine is involve various kinds of machines tools commonly named as lathe, shaper, planer, slotter, drilling, milling and grinding machines etc. The machining jobs are mainly of two types namely cylindrical and flats or prismatic. Cylindrical jobs are generally machined using lathe, milling, drilling and cylindrical grinding whereas prismatic jobs are machined using shaper, planner, milling, drilling and surface grinding.

In the worldwide investment metal-machining holds steady or continues to increase year by year, the only exception being in the worst of recessions. The wealth of nations can be judged by these investments.

Whether machine tools are small or large inexpensive or extremely expensive they can be group into six major classifications are based upon the operations performed by the machines to shape metal. These basic operations include the following:-

- Drilling and boring (including reaming and tapping, turning and milling)
- Planning (including shaping broaching)
- Grinding (including shaping and lapping)
- Metal forming(including shearing, stamping, pressing and forging)

In addition into the basic metal shaping operations newer metal shaping operations have been developed during the past two decades. That employs the various characteristics of chemicals, electricity, and magnetism, liquids, explosive, light and sound.

Whether a machine tool is simple or complex, it performs one or more of these operations. Variations of the six basic operations are machine tools that combine two or more operations, as in lathe, boring, drilling; end milling machine and shearing press; or a combination milling and planning machine.

2.1 Introduction Lathe machine

Lathe is one of the most versatile and widely used machine tools all over the world. It is commonly known as the mother of all other machine tool. The main function of a lathe is to remove metal from a job to give it the required shape and size. The job is secure1y and rigid1y held in the chuck or in between centers on the lathe machine and then turn it against a single point cutting tool which wi1l remove meta1 from the job in the form of chips. Fig. 2.1.1 shows the working principle of lathe. An engine lathe is the most basic and simplest form of the lathe. It derives its name from the early lathes, which obtained their power from engines. Besides the simple turning operation as described above, lathe can be used to carry out other operations also, such as drilling, reaming, boring, taper turning, knurling, screw-thread cutting, grinding etc. operations such as cutting, knurling, drilling, or deformation with tools that are applied to the work-piece to create an object which has symmetry about an axis of rotation.

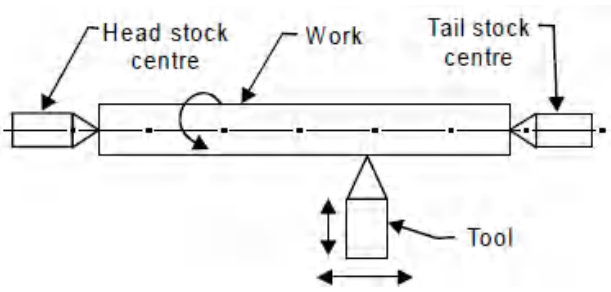


Fig. 2.1.1 Working principal of lathe machine

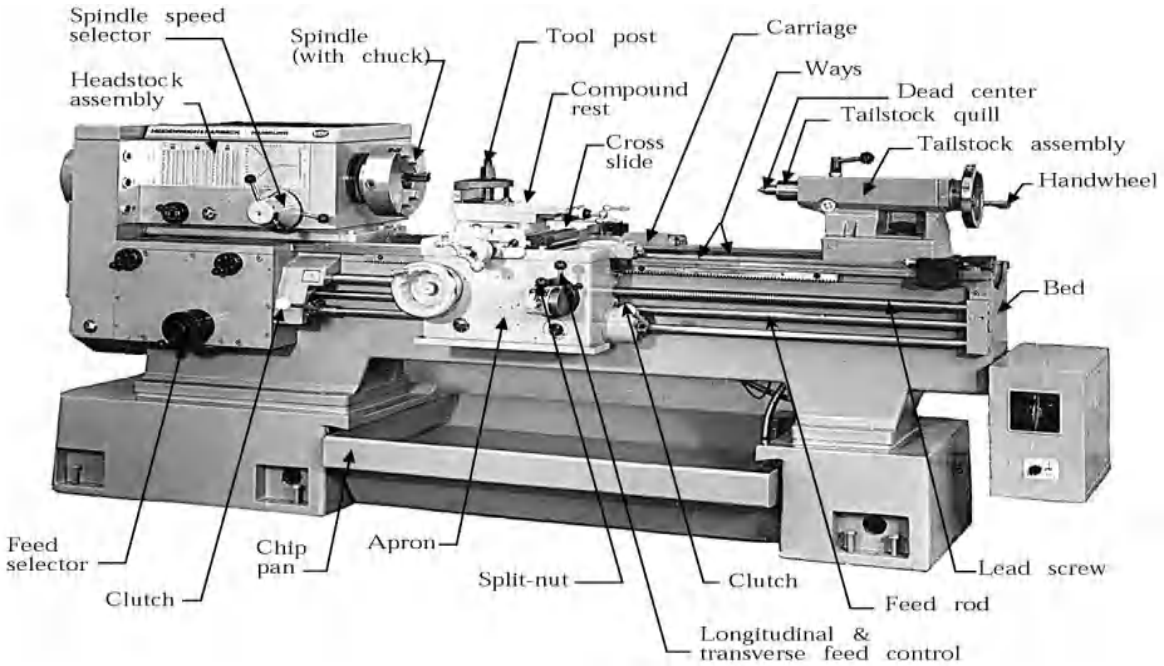


Fig.2.1.2 Component Description

A). Types of Lathe

Lathes are manufactured in a variety of types and sizes, from very small bench lathes used for precision work to huge lathes used for turning large steel shafts. But the principle of operation and function of all types of lathes is same. The different types of lathes are:

1. Speed lathe
    a) Wood working
    b) Spinning
    c) Centering
    d) Po1ishing
2. Centre or engine lathe
    (a) Be1t drive
    (b) Individual motor drive
    (c) Gear head lathe
3. Bench lathe
4. Tool room Lathe
5. Capstan and Turret 1athe
6. Special purpose lathe
    (a) Whee1 lathe
    (b) Gap bed lathe
    (c) Dup1icating lathe
    (d) T-lathe
7. Automatic lathe
    (a) Some of common lathes are described as under.

B). Construction of Lathe Machine

A simple lathe comprises of a bed made of grey cast iron on which headstock, tailstock, carriage and other components of lathe are mounted. Fig. 2.1.3 shows the different parts of engine lathe or central lathe. The major parts of lathe machine are given as under:-

1. Bed
2. Head stock
3. Tailstock

4. Carriage
5. Feed mechanism

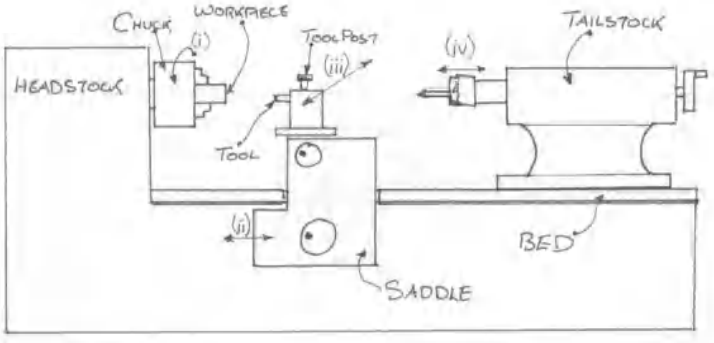


Fig.2.1.3 main components of lathe machine

Bed

The bed of a lathe machine is the base on which all other parts of lathe are mounted. It is massive and rigid single piece casting made to support other active parts of lathe. On left end of the bed, headstock of lathe machine is located while on right side tailstock is located. The carriage of the machine rests over the bed and slides on it. On the top of the bed there are two sets of guideways-innerways and outerways. The innerways provide sliding surfaces for the tailstock and the outerways for the carriage. The guideways of the lathe bed may be flat and inverted V shape. Generally cast iron alloyed with nickel and chromium material is used for manufacturing of the lathe bed.

Head Stock

The main function of headstock is to transmit power to the different parts of a lathe. It comprises of the headstock casting to accommodate all the parts within it including gear train arrangement. The main spindle is adjusted in it, which possesses live centre to which the work can be attached. It supports the work and revolves with the work, fitted into the main spindle of the headstock. The cone pulley is also attached with this arrangement, which is used to get various spindle speed through electric motor. The back gear arrangement is used for obtaining a wide range of slower speeds. Some gears called change wheels are used to produce different velocity ratio required for thread cutting.

Tail Stock

Fig. 2.1.4 shows the tail stock of central lathe, which is commonly used for the objective of primarily giving an outer bearing and support the circular job being turned on centers. Tail stock can be easily set or adjusted for alignment or non-alignment with respect to the spindle centre and carries a centre called dead centre for supporting one end of the work. Both live and dead centers have 60° conical points to fit centre holes in the circular job, the other end tapering to allow for good fitting into the spindles. The dead centre can be mounted in ball bearing so that it rotates with the job avoiding friction of the job with dead centre as it important to hold heavy jobs.

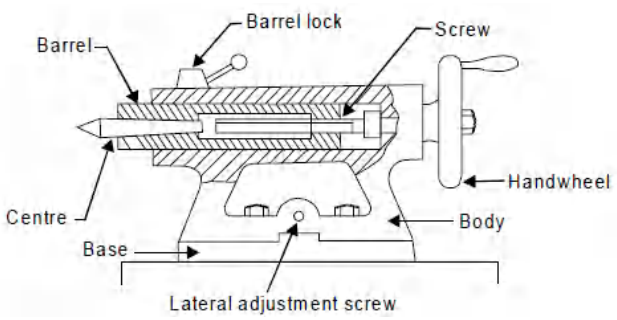


Fig. 2.1.4 Tail stock of central lathe.

Carriage

Carriage is mounted on the outer guide ways of lathe bed and it can move in a direction parallel to the spindle axis. It comprises of important parts such as apron, cross-slide, saddle, compound rest, and tool post. The lower part of the carriage is termed the apron in which there are gears to constitute apron mechanism for adjusting the direction of the feed using clutch mechanism and the split half nut for automatic feed. The cross-slide is basically mounted on the carriage, which generally travels at right angles to the spindle axis. On the cross-slide, a saddle is mounted in which the compound rest is adjusted which can rotate and fix to any desired angle. The compound rest slide is actuated by a screw, which rotates in a nut fixed to the saddle.

Feed Mechanism

Feed mechanism is the combination of different units through which motion of headstock spindle is transmitted to the carriage of lathe machine. Following units play role in feed mechanism of a lathe machine:-

1. End of bed gearing
2. Feed gear box
3. Lead screw and feed rod
4. Apron mechanism

The gearing at the end of bed transmits the rotary motion of headstock spindle to the feed gear box. Through the feed gear box the motion is further transmitted either to the feed shaft or lead screw, depending on whether the lathe machine is being used for plain turning or screw cutting. The feed gear box contains a number of different sizes of gears. The feed gear box provides a means to alter the rate of feed, and the ration between revolutions of the headstock spindle and the movement of carriage for thread cutting by changing the speed of rotation of the feed rod or lead screw. The apron is fitted to the saddle. It contains gears and clutches to transmit motion from the feed rod to the carriage, and the half nut which engages with the lead screw during cutting threads.

C). Accessories and Attachments of Lathe

There are many lathe accessories provided by the lathe manufacturer along with the lathe, which support the lathe operations. The important lathe accessories include centers, catch plates and carriers, chucks, collets, face plates, angle plates, mandrels, and rests. These are used either for holding and supporting the work or for holding the tool. Attachments are additional equipments provided by the lathe manufacturer along with the lathe, which can be used for specific operations. The lathe attachment include stops, ball turning rests, thread chasing dials, milling attachment, grinding attachment, gear cutting attachment, turret attachment and crank pin turning attachments and taper turning attachment.

Lathe centers

The most common method of holding the job in a lathe is between the two centers generally known as live centre (head stock centre) and dead centre (tailstock centre). They are made of very hard materials to resist deflection and wear and they are used to hold and support the cylindrical jobs.

Carriers or driving dog and catch plates

These are used to drive a job when it is held between two centers. Carriers or driving dogs are attached to the end of the job by a setscrew. A use of lathe dog for holding and supporting the job is shown in Fig. 21.6. Catch plates are either screwed or bolted to the nose of the headstock spindle. A projecting pin from the catch plate or carrier fits into the slot provided in either of them. This imparts a positive drive between the lathe spindle and job.

Chucks

Chuck is one of the most important devices for holding and rotating a job in a lathe. It is basically attached to the headstock spindle of the lathe. The internal threads in the chuck fit on to the external threads on the spindle nose. Short, cylindrical, hol1ow objects or those of irregular shapes, which cannot be conveniently mounted between centers, are easily and rigidly held in a chuck. Jobs of short length and large diameter or of irregular shape, which cannot be conveniently mounted between centers, are held quickly and rigidly in a chuck.
There are a number of types of lathe chucks, e.g.

1. Three jaws or universal
2. Four jaw independent chuck
3. Magnetic chuck
4. Collet chuck
5. Air or hydraulic chuck operated chuck
6. Combination chuck
7. Drill chuck.

Face plates
Face plates are employed for holding jobs, which cannot be conveniently held between centers or by chucks. A face plate possesses the radial, plain and T slots for holding jobs or work-pieces by bolts and clamps. Face plates consist of a circular disc bored out and threaded to fit the nose of the lathe spindle. They are heavily constructed and have strong thick ribs on the back. They have slots cut into them, therefore nuts, bolts, clamps and angles are used to hold the jobs on the face plate. They are accurately machined and ground.

Angle plates
Angle plate is a cast iron plate having two faces machined to make them absolutely at right angles to each other. Holes and slots are provided on both faces so that it may be clamped on a faceplate and can hold the job or workpiece on the other face by bolts and clamps. The plates are used in conjunction with a face plate when the holding surface of the job should be kept horizontal.

Mandrels
A mandrel is a device used for holding and rotating a hollow job that has been previously drilled or bored. The job revolves with the mandrel, which is mounted between two centers.
It is rotated by the lathe dog and the catch plate and it drives the work by friction. Different types of mandrels are employed according to specific requirements. It is hardened and tempered steel shaft or bar with 60° centers, so that it can be mounted between centers. It holds and locates a part from its center hole. The mandrel is always rotated with the help of a lathe dog; it is never placed in a chuck for turning the job. A mandrel unlike an arbor is a job holding device rather than a cutting tool holder. A bush can be faced and turned by holding the same on a mandrel between centers. It is generally used in order to machine the entire length of a hollow job.

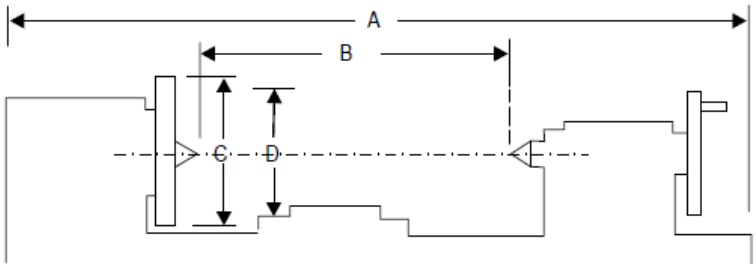
Rests
A rest is a lathe device, which supports a long slender job, when it is turned between centers or by a chuck, at some intermediate point to prevent bending of the job due to its own weight and vibration set up due to the cutting force that acts on it. The two types of rests commonly used for supporting a long job in an engine lathe are the steady or centre rest and the follower rest.

D) Specification of Lathe
The size of a lathe is generally specified by the following means:

(a) Swing or maximum diameter that can be rotated over the bed ways
(b) Maximum length of the job that can be held between head stock and tail stock centres
(c) Bed length, which may include head stock length also

(d) Maximum diameter of the bar that can pass through spindle or collect chuck of capstan lathe.

Fig. 2.1.5 illustrates the elements involved in specifications of a lathe. The following data also contributes to specify a common lathe machine.



A - Length of bed.
B - Distance between centres.
C - Diameter of the work that can be turned over the ways.
D - Diameter of the work that can be turned over the cross slide.

Fig. 2.1.5 Specifications of a lathe

Lathe Operations

For performing the various machining operations in a lathe, the job is being supported and driven by anyone of the following methods.

1. Job is held and driven by chuck with the other end supported on the tail stock centre.
2. Job is held between centers and driven by carriers and catch plates.
3. Job is held on a mandrel, which is supported between centers and driven by carriers and catch plates.
4. Job is held and driven by a chuck or a faceplate or an angle plate.

The above methods for holding the job can be classified under two headings namely job held between centers and job held by a chuck or any other fixture. The various important lathe operations are depicted through Fig. 2.1.8. The operations performed in a lathe can be understood by three major categories.

(a) Operations, which can be performed in a lathe either by holding the workpiece between centers or by a chuck

(b) Operations which are performed by holding the work by a chuck or a faceplate or an angle plate

(c) Operations which are performed by using special lathe attachments .

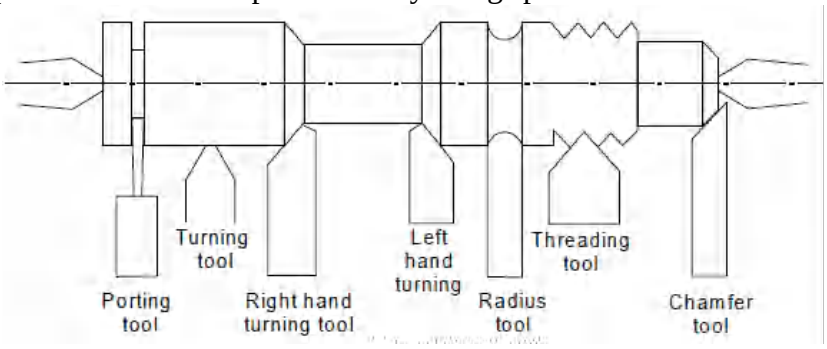


Fig. 2.1.8 some Lathe operation

E). Cutting Speed

Cutting speed for lathe work may be defined as the rate in meters per minute at which the surface of the job moves past the cutting tool. Machining at a correct cutting speed is highly important for good tool life and efficient cutting. Too slow cutting speeds reduce productivity and increase manufacturing costs whereas too high cutting speeds result in overheating of the tool and premature failure of the cutting edge of the tool. The following factors affect the cutting speed:

(i) Kind of material being cut,

(ii) Cutting tool material,
(iii) Shape of cutting tool,
(iv) Rigidity of machine tool and the job piece and
(v) Type of cutting fluid being used.

Calculation of cutting speed Cs, in meters per minute

$$Cs = ((22/7) \times D \times N)) /1000$$

Where D is diameter of job in mm and N is in RPM

FEED

Feed is defined as the distance that a tool advances into the work during one revolution of the headstock spindle. It is usually given as a linear movement per revolution of the spindle or job. During turning a job on the center lathe, the saddle and the tool post move along the bed of the lathe for a particular feed for cutting along the length of the rotating job.

2.3 Shaper, Planer and Slotter

Shaper

Shaper is a reciprocating type of machine tool in which the ram moves the cutting tool backwards and forwards in a straight line. The basic components of shaper are shown in Fig. 2.3.1. It is intended primarily to produce flat surfaces. These surfaces may be horizontal, vertical, or inclined. In general, the shaper can produce any surface composed of straight-line elements. The principal of shaping operation is shown in Fig. 2.3.2 (a, b).

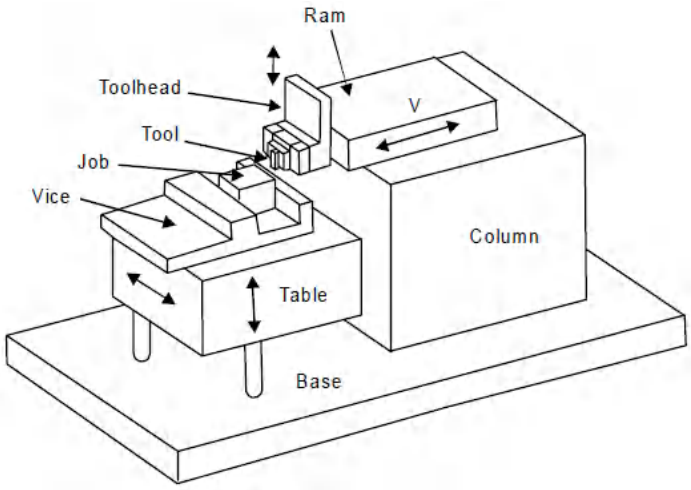


Fig. 2.3.1 Principal components of a shaper

Working Principle of Shaper

A single point cutting tool is held in the tool holder, which is mounted on the ram. The workpiece is rigidly held in a vice or clamped directly on the table. The table may be supported at the outer end. The ram reciprocates and thus cutting tool held in tool holder moves forward and backward over the workpiece. In a standard shaper, cutting of material takes place during the forward stroke of the ram. The backward stroke remains idle and no cutting takes place during this stroke. The feed is given to the workpiece and depth of cut is adjusted by moving the tool downward towards the workpiece. The time taken during the idle stroke is less as compared to forward cutting stroke and this is obtained by quick return mechanism.

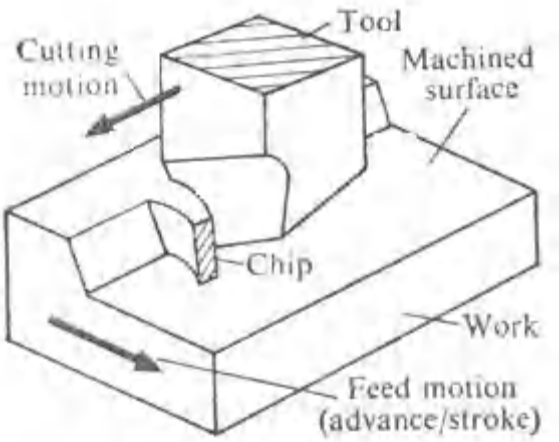


Fig. 2.3.2 Working principal of shaping machine

Types of Shapers

Shapers are classified under the following headings:

1. According to the type of mechanism used for giving reciprocating motion to the ram
    a) Crank type
    b) Geared type
    c) Hydraulic type
2. According to the type of design of the table:
    a) Standard shaper
    b) Universal shaper
3. According to the position and travel of ram:
    a) Horizontal type
    b) Vertical type
    c) Traveling head type
4. According to the type of cutting stroke:
    a) Push type
    b) Draw type.

Specification of a Shaper

The size of a shaper is specified by the maximum length of stroke or cut it can make. Usually the size of shaper ranges from 175 to 900 mm. Besides the length of stroke, other particulars, such as the type of drive (belt drive or individual motor drive), floor space required, weight of the machine, cutting to return stroke ratio, number and amount of feed, power input etc. are also sometimes required for complete specification of a shaper.

Shaper Mechanism

In a shaper, rotary motion of the drive is converted into reciprocating motion of the ram by the mechanism housed within the column or the machine. In a standard shaper metal is removed in the forward cutting stroke, while the return stroke goes idle and no metal is removed during this period as shown in Fig. 2.3.4. The shaper mechanism is so designed that it moves the ram holding the tool at a comparatively slower speed during forward cutting stroke, whereas during the return stroke it allow the ram to move at a faster speed to reduce the idle return time. This mechanism is known as quick return mechanism. The reciprocating movement of the ram and the quick return mechanism of the machine are generally obtained by anyone of the following methods:

1) Crank and slotted link mechanism
2) Whitworth quick return mechanism, and
3) Hydraulic shaper mechanism

The crank and slotted link mechanism is discussed as under.

Crank and Slotted Link Mechanism

In crank and slotted link mechanism (Fig. 2.3.3), the pinion receives its motion from an individual motor or overhead line shaft and transmits the motion or power to the bull gear. Bull gear is a large gear mounted within the column. Speed of the bull gear may be changed by different combination of gearing or by simply shifting the belt on the step cone pulley. A radial slide is bolted to the centre of the bull gear. This radial slide carries a sliding block into which the crank pin is fitted. Rotation of the bull gear will cause the bush pin to revolve at a uniform speed. Sliding block, which is mounted upon the crank pin is fitted within the slotted link. This slotted link is also known as the rocker arm. It is pivoted at its bottom end attached to the frame of the column. The upper end of the rocker arm is forked and connected to the ram block by a pin. With the rotation of bull gear, crank pin will rotate on the crank pin circle, and simultaneously move up and down the slot in the slotted link giving it a rocking movement, which is communicated to the ram. Thus the rotary motion of the bull gear is converted to reciprocating motion of the ram.

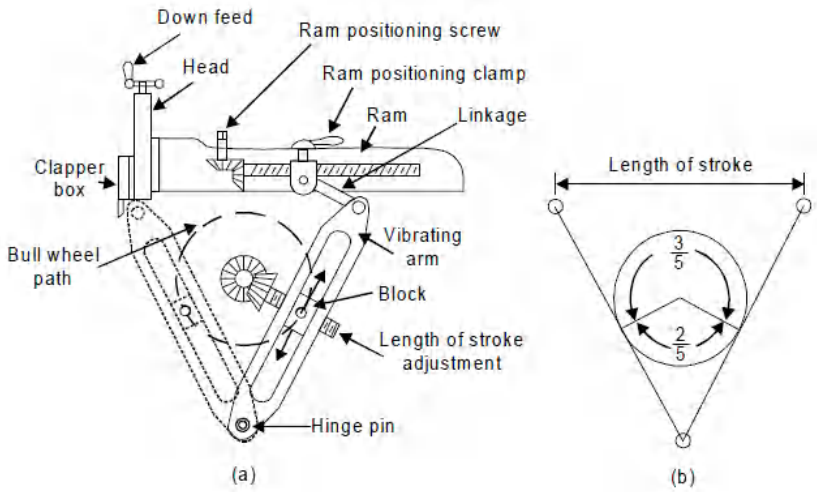


Fig. 2.3.3 Crank and slotted link mechanism

Surfaces Produced on Shaper

1. Horizontal plain surface
2. Vertical plain surface
3. Inclined surface
4. Grooved surface
5. Slotted surface
6. Stepped surface

Planer

Like a shaper, planer is used primarily to produce horizontal, vertical or inclined flat surfaces by a single point cutting tool. But it is used for machining large and heavy workpieces that cannot be accommodated on the table of a shaper. In addition to machining large work, the planer is frequently used to machine multiple small parts held in line on the platen. Planer is mainly of two kinds namely open housing planer and double housing planer. The principle parts of the open housing planer are shown in Fig 2.3.4(a). The principle parts of the double housing planer are shown in Fig 2.3.4(b). The bigger job is fixed with help of the grooves on the base of the planer and is accurately guided as it travels back and forth. Cutting tools are held in tool heads of double housing planer and the work piece is clamped onto the worktable as shown in Fig. 2.3.4(b). The worktable rides on the gin tool heads that can travel

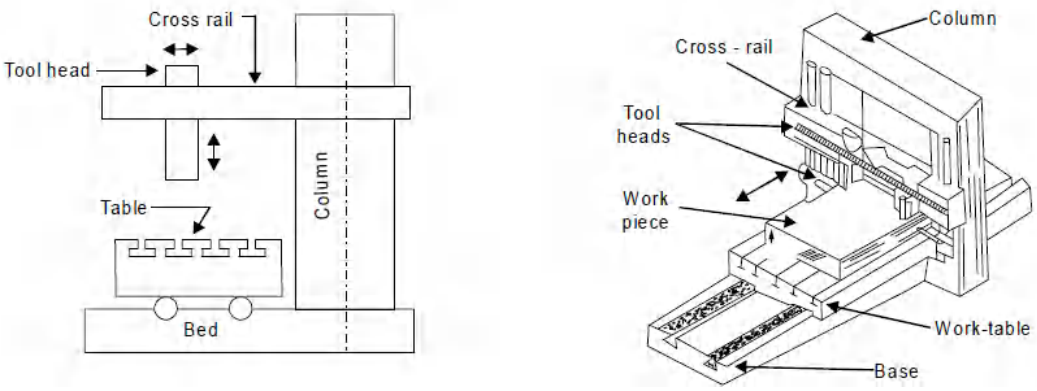


Fig. 2.3.4 Principle parts of double housing planer

from side to side i.e., in a direction at right angle to the direction of motion of the worktable. Tool heads are mounted on a horizontal cross rail that can be moved up and down. Cutting is achieved by applying the linear primary motion to the workpiece (motion X) and feeding the tool at right angles to this motion (motion Y and Z). The primary motion of the worktable is normally accomplished by a rack and pinion drive using a variable speed motor. As with the shaper, the tool posts are mounted on clapper boxes to prevent interference between the tools and work-piece on the return stroke and the feed motion is intermittent. The size of a standard planer is specified by the size of the largest solid that can reciprocate under the tool. In addition to this, some other parameters such as table size (length and width), type of drive, number of speeds and feeds available, power input, weight of the machine, floor space required etc. may be required to specify a planer completely.

Working Principal of Planer

Fig. 2.3.5 depicts the working principle of a planer. In a planer, the work which is supported on the table reciprocates past the stationary cutting tool and the feed is imparted by the lateral movement of the tool. The tool is clamped in the tool holder and work on the table. Like shaper, the planner is equipped with clapper box to raise the tool in idle stroke. The different mechanisms used to give reciprocating motion to the table are following-

1. Reversible motor drive
2. Open and cross belt drive
3. Hydraulic drive

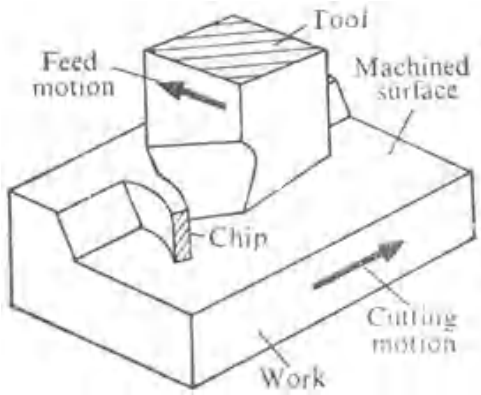


Fig. 2.3.5 Working principle of a planer

Types of Planers

Planers may be classified in a number of ways, but according to general construction,these are the following types:

1. Double housing planer
2. Open side planer

3. Pit planer
4. Edge or plate type planer
5. Divided table planer

Difference Between Shaper and Planer

The difference between shaper and planner is given in Table 2.3.1.

Table 2.3.1 Difference between shaper and planer

S.No.	Shaper	Planer
1.	The work is held stationary cutting tool on the ram is moved back and forth across the work	In a planer, the tool is stationary and the workpiece travels back and forth under the tool
2.	It is used for shaping much smaller jobs	A planer is meant for much larger jobs than can be undertaken on a shaper. Jobs as large as 6 meter wide and twice as long can be machined on a planer.
3.	A shaper is a light machine	It is a heavy duty machine.
4.	Shaper can employ light cuts and finer feed	Planer can employ heavier cuts and coarse feed,
5.	A shaper uses one cutting tool at a time	Several tools can cut simultaneously on a planer
6.	The shaper is driven using quick-return link mechanism	The drive on the planer table is either by gears or by hydraulic means
7.	It is less rigid and less robust	Because of better rigidity of planer, as compared to that of a shaper, planer can give more accuracy on machined surfaces.

Slotter

The slotter or slotting machine is also a reciprocating type of machine tool similar to a shaper or a planer. It may be considered as a vertical shaper. The chief difference between a shaper and a slotter is the direction of the cutting action. The machine operates in a manner similar to the shaper, however, the tool moves vertically rather than in a horizontal direction. The job is held stationary. The slotter has a vertical ram and a hand or power operated rotary table.

Principle Parts of A Slotter

Fig. 2.3.6 shows a slotter and its various parts. The main parts of a slotter are discussed as under:

Bed or Base

It is made up of cast iron. It supports column, tables, ram, driving mechanism etc. The top of the bed carries horizontal ways along which the worktable can traverse.

Table

It holds the work piece and is adjustable in longitudinal and cross-wise directions. The table can be rotated about its centre.

Hand wheels

They are provided for rotating the table and for longitudinal and cross traverse.

Column is the vertical member

They are made up of cast iron and it houses the driving mechanism. The vertical front face of the column is accurately finished for providing ways along which the ram moves up and down.

Ram

It is provided to reciprocate vertically up and down. At its bottom, it carries the cutting tool. It is similar to the ram of a shaper; but it is more massive and moves vertically, at right angle to the worktable, instead of having the horizontal motion of a shaper:

Cross-slide

It can be moved parallel to the face of the column. The circular work-table is mounted on the top of the cross-slide.

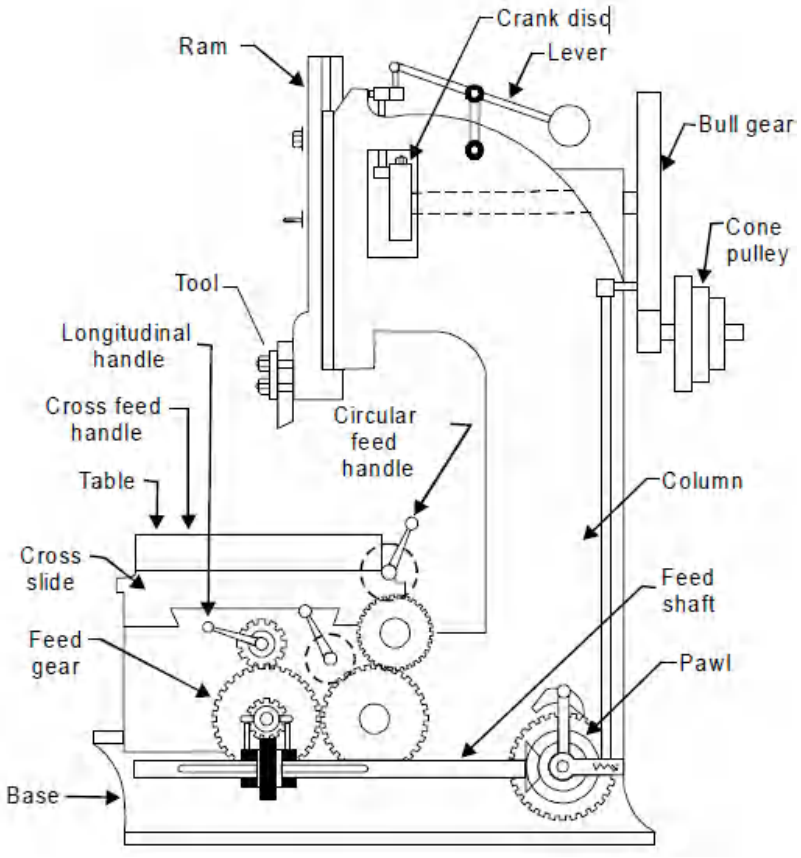


Fig. 2.3.6 Slotter and its various parts

Operations Performed on a Slotting Machine

A slotter is a very economical machine tool when used for certain classes of work given as under.

(i) It is used for machining vertical surfaces
(ii) It is used angular or inclined surfaces
(iii) It is used It is used to cut slots, splines keyways for both internal and external jobs such as machining internal and external gears,
(iv) It is used for works as machining concave, circular, semi-circular and convex surfaces
(v) It is used for shaping internal and external forms or profiles
(vi) It is used for machining of shapes which are difficult to produce on shaper
(vii) It is used for internal machining of blind holes
(viii) it is used for machining dies and punches, and

Since a slotter works slowly. It has less use in mass production work. It can be substituted by the broaching machine.

2.4 Milling Machine

A milling machine is a machine tool that removes metal as the work is fed against a rotating multipoint cutter. The milling cutter rotates at high speed and it removes metal at a very fast rate with the help of multiple cutting edges. One or more number of cutters can be mounted simultaneously on the arbor of milling machine. This is the reason that a milling machine finds wide application in production work. Milling machine is used for machining flat surfaces, contoured surfaces, surfaces of revolution, external and internal threads, and helical surfaces of various cross-sections. Typical components produced by a milling are given in Fig. 2.4.1. In

many applications, due to its higher production rate and accuracy, milling machine has even replaced shapers and slotters.

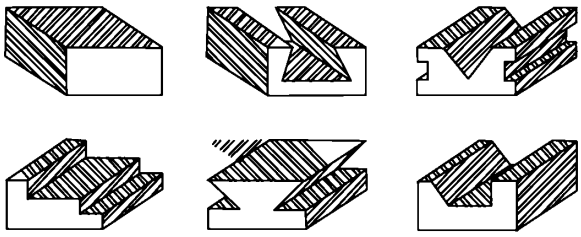


Fig. 2.4.1 Job surfaces generated by milling machine

Work Principle of Milling

In milling machine, the metal is cut by means of a rotating cutter having multiple cutting edges. For cutting operation, the workpiece is fed against the rotary cutter. As the workpiece moves against the cutting edges of milling cutter, metal is removed in form chips of trochoid shape. Machined surface is formed in one or more passes of the work. The work to be machined is held in a vice, a rotary table, a three jaw chuck, an index head, between centers, in a special fixture or bolted to machine table. The rotatory speed of the cutting tool and the feed rate of the workpiece depend upon the type of material being machined.

Milling Methods

There are two distinct methods of milling classified as follows:

1. Up-milling or conventional milling, and
2. Down milling or climb milling.

UP-Milling or Conventional Milling Procedure

In the up-milling or conventional milling, as shown in Fig. 2.4.2, the metal is removed in form of small chips by a cutter rotating against the direction of travel of the workpiece. In this type of milling, the chip thickness is minimum at the start of the cut and maximum at the end of cut. As a result the cutting force also varies from zero to the maximum value per tooth movement of the milling cutter. The major disadvantages of up-milling process are the tendency of cutting force to lift the work from the fixtures and poor surface finish obtained. But being a safer process, it is commonly used method of milling.

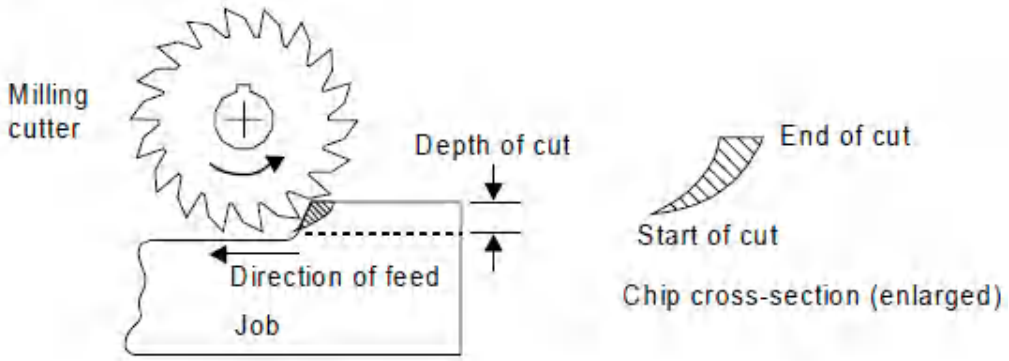


Fig. 2.4.2 Principal of up-milling

Down-Milling or Climb Milling

Down milling is shown in Fig. 2.4.3. It is also known as climb milling. In this method, the metal is removed by a cutter rotating in the same direction of feed of the workpiece. The effect of this is that the teeth cut downward instead of upwards. Chip thickness is maximum at the start of the cut and minimum in the end. In this method, it is claimed that there is less friction involved and consequently less heat is generated on the contact surface of the cutter and workpiece. Climb milling can be used advantageously on many kinds of work to increase the number of pieces per

sharpening and to produce a better finish. With climb milling, saws cut long thin slots more satisfactorily than with standard milling. Another advantage is that slightly lower power consumption is obtainable by climb milling, since there is no need to drive the table against the cutter.

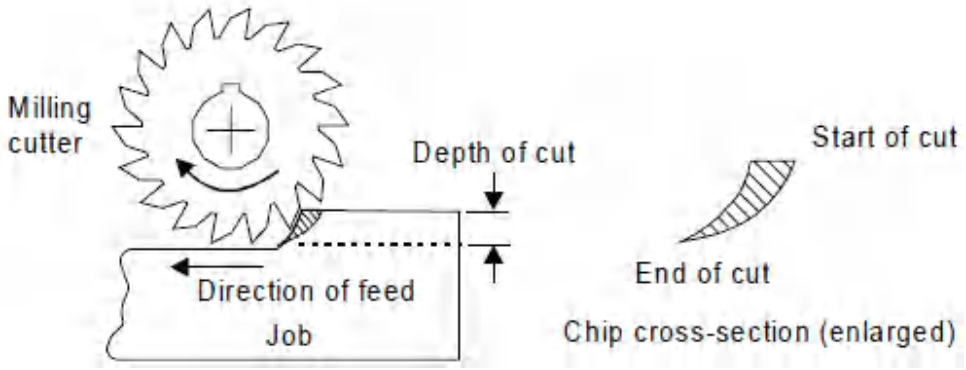


Fig. 2.4.3 Principal of down-milling

Types of Milling Cutters

Milling cutters are made in various forms to perform certain classes of work, and they may be classified as:

(1) Plain milling cutters,
(2) Side milling cutters,
(3) Face milling cutter,
(4) Angle milling cutters,
(5) End milling cutter,
(6) Fly cutter,
(7) T-slot milling cutter,
(8) Formed cutters
(9) Metal slitting saw,

Milling cutters may have teeth on the periphery or ends only, or on both the periphery and ends. Peripheral teeth may be straight or parallel to the cutter axis, or they may be helical, sometimes referred as spiral teeth.

Types of Milling Machines

Milling machine rotates the cutter mounted on the arbor of the machine and at the same time automatically feed the work in the required direction. The milling machine may be classified in several forms, but the choice of any particular machine is determined primarily by the size of the workpiece to be undertaken and operations to be performed. With the above function or requirement in mind, milling machines are made in a variety of types and sizes. According to general design, the distinctive types of milling machines are:

(1) Column and knee type milling machines
    a) Hand milling machine
    b) Horizontal milling machine (Fig. 2.4.5)
    c) Universal milling machine
    d) Vertical milling machine

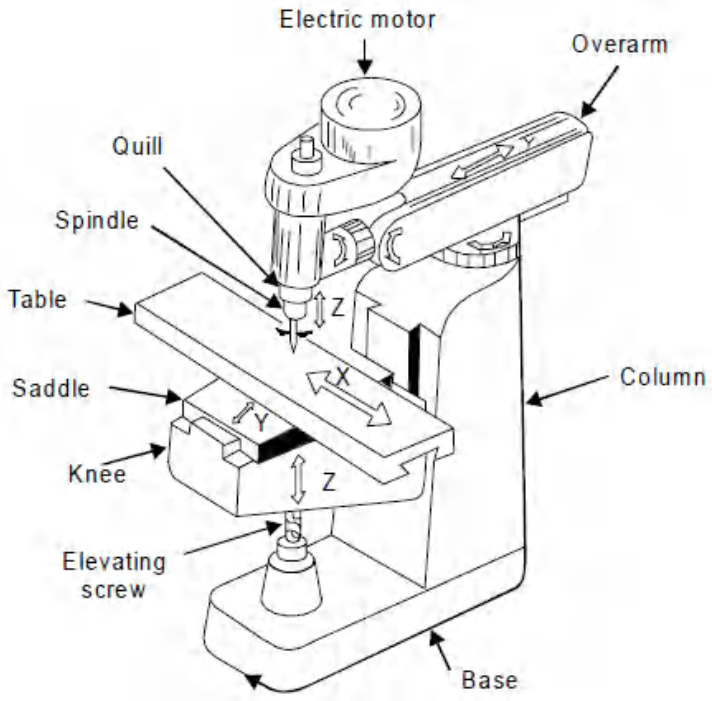


Fig. 2.4.4 Horizontal column and knee type milling machine

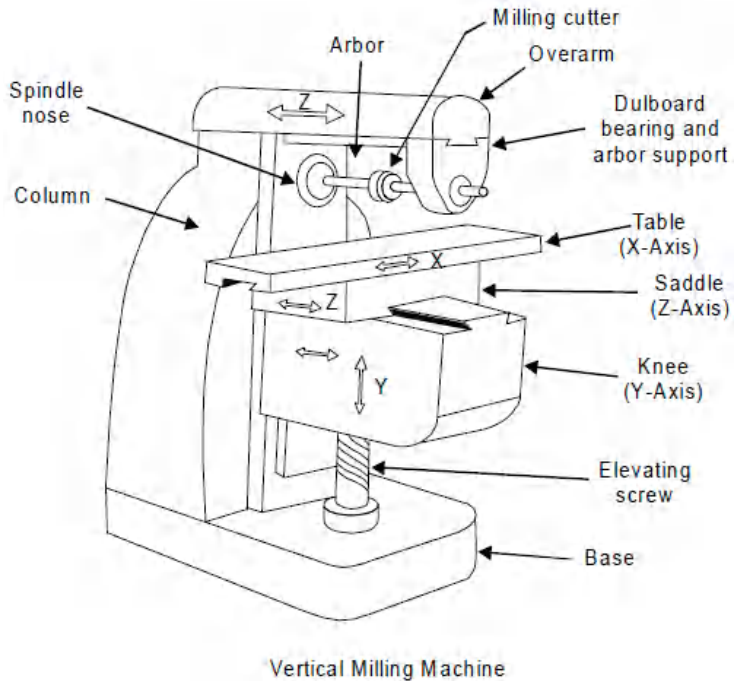


Fig. 2.4.5 Vertical column and knee type milling machine

Operations Performed on Milling Machine

Unlike a lathe, a milling cutter does not give a continuous cut, but begins with a sliding motion between the cutter and the work. Then follows a crushing movement, and then a cutting operation by which the chip is removed. Many different kinds of operations can be performed on a milling machine but a few of the more common operations will now be explained. These are:

Plain milling or slab milling

Fig. 2.4.6(a) illustrates the plain and slab milling operation. It is a method of producing a plain, flat, horizontal surface parallel to the axis of rotation of the cutter.

Side milling

Fig. 2.4.6(c) illustrates the side milling operation. It is the operation of production of a flat vertical surface on the side of a work-piece by using a side milling cutter.

Angular milling

Fig. 2.4.6(d) illustrates angular milling operation. It is a method of producing a flat surface making an angle to the axis of the cutter.

Gang-milling

Fig. 2.4.6(e) illustrates the gang milling operation. It is a method of milling by means of two or more cutters simultaneously having same or different diameters mounted on the arbor of the milling machine.

Form milling

Fig. 24.6(f) illustrates the form milling operation. It is, a method of producing a surface having an irregular outline.

End milling

Fig. 2.4.6(g) illustrates end milling operation. It is a method of milling slots, flat surfaces, and profiles by end mills.

Profile milling

Fig. 2.4.6(h) illustrates profile milling operation. It is the operation of reproduction of an outline of a template or complex shape of a master die on a workpiece.

Saw milling

Fig. 2.4.6(i) illustrates saw milling operation. It is a method of producing deep slots and cutting materials into the required length by slitting saws.

T-slot milling

Fig. 2.4.6(j) illustrates T-slot milling operation.

Keyway milling

Fig. 2.4.6(k) illustrates keyway milling operation.

Gear cutting milling

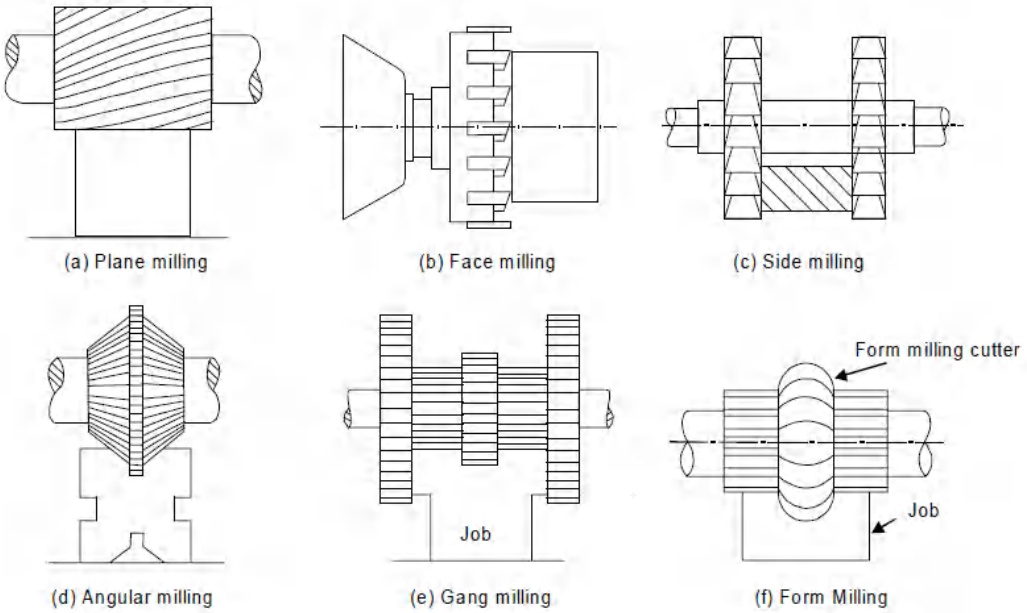
Fig. 2.4.6(l) illustrates gear cutting milling operation.

Helical milling

Fig. 24.9(m) illustrates helical milling operation.

Flute milling

It is a method of grooving or cutting of flutes on drills, reamers, taps, etc,



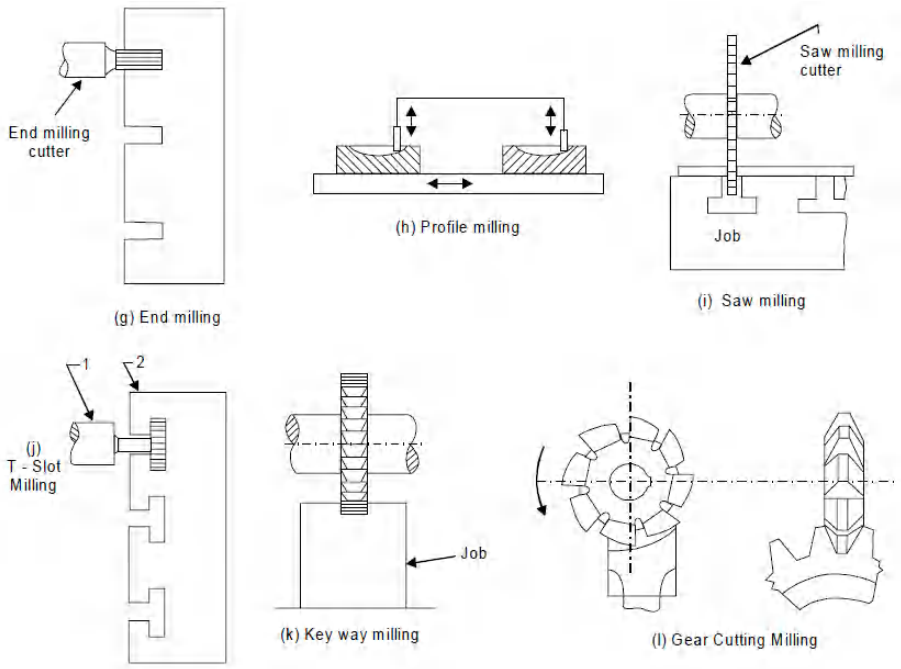


Fig. 2.4.6 Type of plain milling

Straddle milling

It is a method of milling two sides of a piece of work by employing two side-milling cutters at the same time.

Thread milling

It is a method of milling threads on dies, screws, worms, etc. both internally and externally. As an alternative to the screw cutting in a lathe, this method is being more extensively introduced now a day in modern machine shops.

Questions

1. Describe the working principle of the lathe.
2. Explain the parts of a centre lathe using neat sketch.
3. Explain following parts of a lathe by neat sketches:
   (*i*) Lathe Bed *(ii)* Carriage *(iii)* Headstock (iv) Tailstock
4. How can you specify a lathe?
5. Name the operations, which can be performed on a lathe.
6. Lists the accessories of a lathe? Explain them with neat sketches.
7. What is the use of follower rest and steady rest?
8. Explain the difference between three jaw chuck and four jaw chuck.
9. Discuss the merits and demerits of a geared-head drive over cone-pulley drive.
10. Describe the procedure of cutting right hand V- heads of the lathe.
11. How can you specify a shaper?
12. Explain the principle of quick return motion mechanism of a shaper. What is need of this mechanism?
13. State the working principle of milling machine.
14. How will you classify milling machines?
15. Using neat sketch, describe the principal parts of the milling machine by neat sketches.
16. Differentiate between up milling and down milling.

Chapter three

3. Mechanism of Chip Information

(I) describe with illustration the mechanism of chip formation in machining
- ductile materials and
- brittle materials

(II) illustrate and assess geometrical characteristics of ductile chips :
- chip reduction coefficient & cutting ratio
- shear angle and cutting strain

(III) Identify and state the causes, characteristics and effects of built-up-edge (BUE) formation.

(IV) Classify chips and identify the condition for different chip forms.

Basic introduction to Mechanism of chip formation in machining

Machining is a semi-finishing or finishing process essentially done to impart required or stipulated dimensional and form accuracy and surface finish to enable the product to

- Fulfill its basic functional requirements
- Provide better or improved performance
- Render long service life.

Machining is a process of gradual removal of excess material from the preformed blanks in the form of chips.
The form of the chips is an important index of machining because it directly or indirectly indicates:

- Nature and behaviour of the work material under machining condition Specific energy requirement (amount of energy required to remove unit volume of work material) in machining work
- Nature and degree of interaction at the chip-tool interfaces.

The form of machined chips depends mainly upon:

- Work material
- Material and geometry of the cutting tool
- Levels of cutting velocity and feed and also to some extent on depth of cut
- Machining environment or cutting fluid that affects temperature and friction at the chip-tool and work-tool interfaces.

Knowledge of basic mechanism(s) of chip formation helps to understand the characteristics of chips and to attain favourable chip forms.

Mechanism of chip formation in machining ductile materials
During continuous machining the uncut layer of the work material just ahead of the cutting tool (edge) is subjected to almost all sided compression as indicated in Fig. 3.1

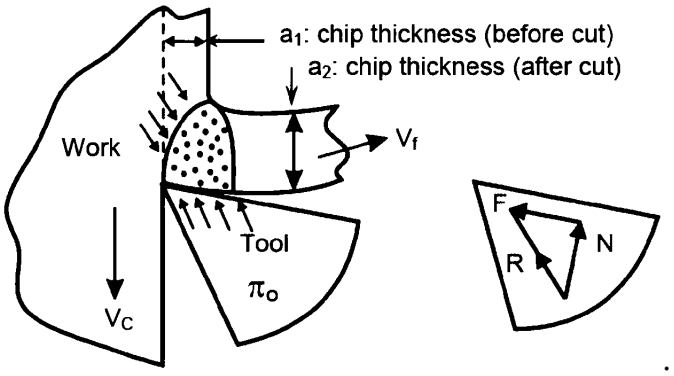


Fig. 3.1.1 Compression of work material (layer) ahead of the tool tip

The force exerted by the tool on the chip arises out of the normal force, N and frictional force, F as indicated in Fig. 3.1. Due to such compression, shear stress develops, within that compressed region, in different magnitude, in different directions and rapidly increases in magnitude. Whenever and wherever the value of the shear stress reaches or exceeds the shear strength of that work material in the deformation region, yielding or slip takes place resulting shear deformation in that region and the plane of maximum shear stress. But the forces causing the shear stresses in the region of the chip quickly diminishes and finally disappears while that region moves along the tool rake surface towards and then goes beyond the point of chip-tool engagement. As a result the slip or shear stops propagating long before total separation takes place. In the mean time the succeeding portion of the chip starts undergoing compression followed by yielding and shear. This phenomenon repeats rapidly resulting in formation and removal of chips in thin layer

by layer. This phenomenon has been explained in a simple way by Piispannen [1] using a card analogy as shown in Fig. 3.1.2.

In actual machining chips also, such serrations are visible at their upper surface as indicated in Fig. 3.1.2. The lower surface becomes smooth due to further plastic deformation due to intensive rubbing with the tool at high pressure and temperature. The pattern of shear deformation by lamellar sliding, indicated in the model, can also be seen in actual chips by proper mounting, etching and polishing the side surface of the machining chip and observing under microscope.

The pattern and extent of total deformation of the chips due to the primary and the secondary shear deformations of the chips ahead and along the tool face,
as indicated in Fig. 3.1.3, depend upon
.

- Work material
- Tool; material and geometry
- The machining speed (V_c) and feed (f_o)
- Cutting fluid application

[1] Piispannen V., "Theory of formation of metal chips", J. Applied Physics, Vol. 19, No. 10, 1948, pp. 876

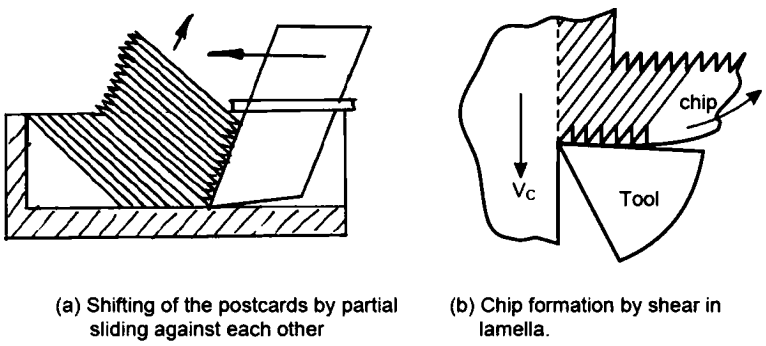


Fig. 3.1.2 Piispanen model of card analogy to explain chip formation in machining ductile materials

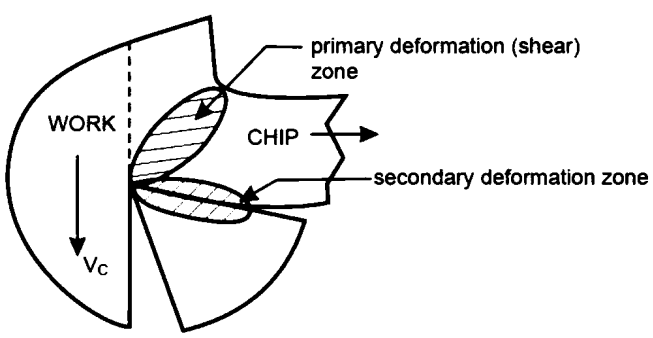


Fig. 3.1.3 Primary and secondary deformation zones in the chip

The overall deformation process causing chip formation is quite complex and hence needs thorough experimental studies for clear understanding the phenomena and its dependence on the affecting parameters. The feasible and popular experimental methods [2] for this purpose are:

- Study of deformation of rectangular or circular grids marked on the side surface as shown in Fig. 3.1.4
- Microscopic study of chips frozen by drop tool or quick stop apparatus

- Study of running chips by high speed camera fitted with low magnification microscope.

[2] Bhattacharya, A.., "Metal cutting – Theory and Practice", Book, New Central Book Agency, Kolkata.

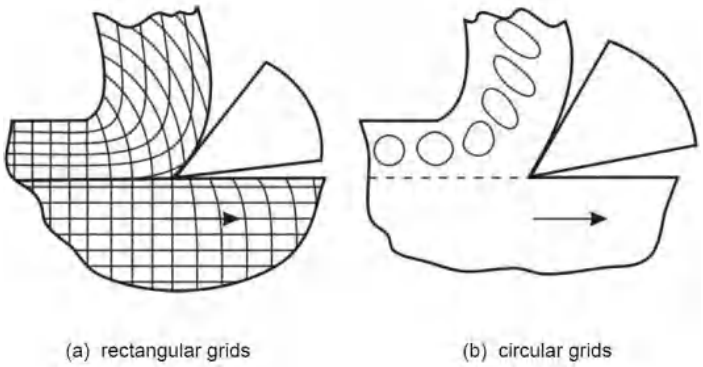


Fig. 3.1.4 Pattern of grid deformation during chip formation

It has been established by several analytical and experimental methods including circular grid deformation that though the chips are initially compressed ahead of the tool tip, the final deformation is accomplished mostly by shear in machining ductile materials. However, machining of ductile materials generally produces flat, curved or coiled continuous chips.

Mechanism of chip formation in machining brittle materials

The basic two mechanisms involved in chip formation are

- Yielding-generally for ductile materials
- Brittle fracture-generally for brittle materials

During machining, first a small crack develops at the tool tip as shown in Fig. 3.5 due to wedging action of the cutting edge. At the sharp crack-tip stress concentration takes place. In case of ductile materials immediately yielding takes place at the crack-tip and reduces the effect of stress concentration and prevents its propagation as crack. But in case of brittle materials the initiated crack quickly propagates, under stressing action, and total separation takes place from the parent workpiece through the minimum resistance path as indicated in Fig. 3.1.5.

Machining of brittle material produces discontinuous chips and mostly of irregular size and shape. The process of forming such chips is schematically shown in Fig. 3.1.6.

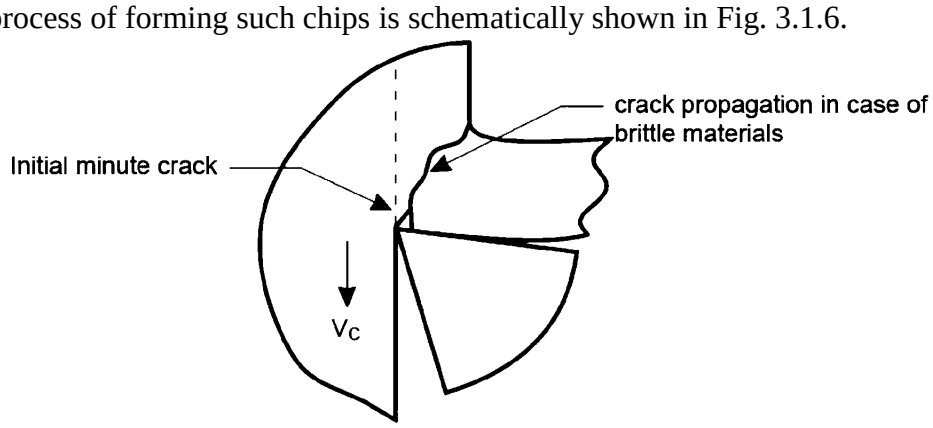


Fig. 3.5 Development and propagation of crack causing chip separation

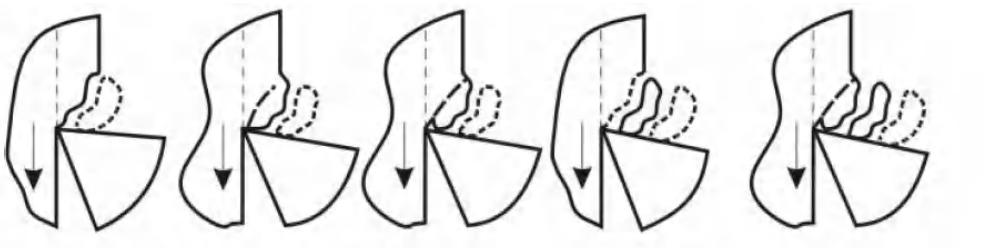


Fig. 3.1.6 Schematic view of chip formation in machining brittle materials

3.2 Geometry and characteristics of chip forms

The geometry of the chips being formed at the cutting zone follow a particular pattern especially in machining ductile materials. The major section of the engineering materials being machined are ductile in nature, even some semi-ductile or semi-brittle materials behave ductile under the compressive forces at the cutting zone during machining. The pattern and degree of deformation during chip formation are quantitatively assessed and expressed by some factors, the values of which indicate about the forces and energy required for a particular machining work.

Chip reduction coefficient or cutting ratio

The usual geometrical features of formation of continuous chips are schematically shown in Fig. 3.2.1. The chip thickness (a_1) usually becomes larger than the uncut chip thickness (a_1). The reason can be attributed to

- compression of the chip ahead of the tool
- frictional resistance to chip flow
- lamellar sliding according to Piispannen

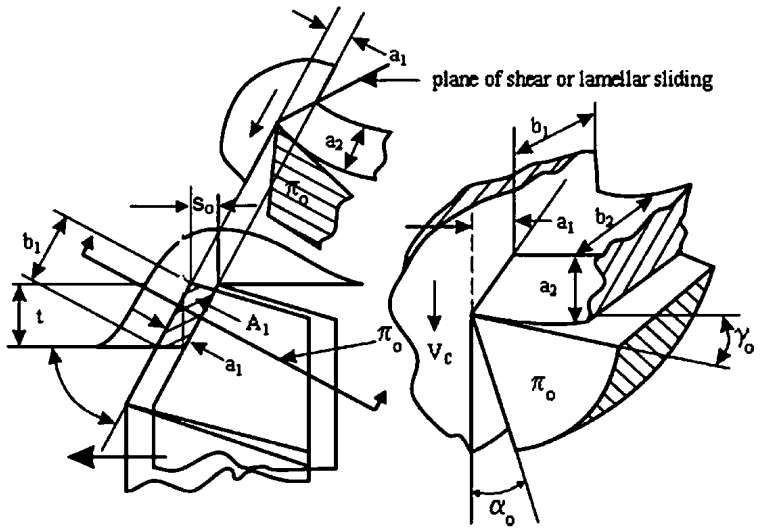


Fig. 3.2.1 *Geometrical features of continuous chips' formation.*

The significant geometrical parameters involved in chip formation are shown in Fig. 3.2.1 and those parameters are defined (in respect of straight turning) as:

t = depth of cut (mm)-perpendicular penetration of the cutting tool tipin work surface

f_o = feed (mm/rev) -axial travel of the tool per revolution of the job

b_1 = width (mm) of chip bfore cut

b_2 = width (mm) of chip after cut

a_1 = thickness (mm) of uncut layer (or chip before cut)

a_2 = chip thickness (mm)-thickness of chip after cut

A_1= cross section (area, mm^2) of chip before cut

The degree of thickening of the chip is expressed by

$$\zeta = \frac{a_2}{a_1} = \quad \zeta > 1.00 \text{ (since } a_2 > a_1) \tag{3.1}$$

Where, ζ = chip reduction coefficient.

$$a_1 = f_o \sin\varphi \tag{3.2}$$

Where φ = principal cutting edge angle

Larger value of ζ means more thickening i.e., more effort in terms of forces or energy required to accomplish the machining work. Therefore it is always desirable to reduce a_2 or ζ without sacrificing productivity, i.e. metal removal rate (MRR).

Chip thickening is also often expressed by the reciprocal of ζ as,

$$\frac{1}{\zeta} = r = \frac{a_1}{a_2} \tag{3.3}$$

Where, r = cutting ratio

The value of chip reduction coefficient, ζ (and hence cutting ratio) depends mainly upon

- tool rake angle, Γ
- Chip-tool interaction, mainly friction, μ

Roughly in the following way [3]

$$\zeta = e^{\mu\left(\frac{\pi}{2} - \Gamma_0\right)} \quad \text{[For orthogonal cutting]} \tag{3.4}$$

$\frac{\pi}{2}$ *and* Γ_0 are in radians

The simple but very significant expression (3.1.4) clearly depicts that the value of ζ can be desirably reduced by

- Using tool having larger positive rake
- Reducing friction by using lubricant

The role of rake angle and friction at the chip-tool interface on chip reduction coefficient are also schematically shown in Fig. 3.2.2

[3] Kronenberg, M., "A new approach to some relationships in the Theory of Metal Cutting", J. Applied Physics, Vol.6, No. 6, 1945.

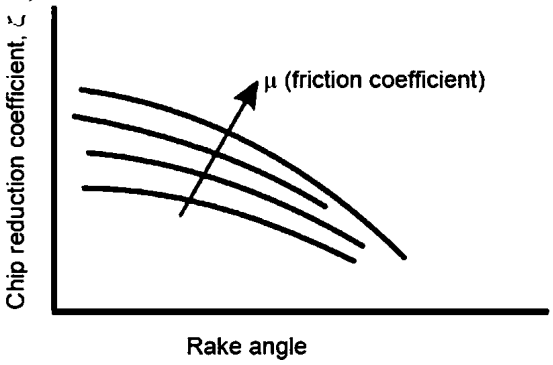


Fig. 3.2.2 Role of rake angle and friction on chip reduction coefficient

Chip reduction coefficient, ζ is generally assessed and expressed by the ratio of the chip thickness, after (a_2) and before cut (a_1) as in equation 3.1.1. But ζ can also be expressed or assessed by the ratio of

- Total length of the chip before (L_1) and after cut (L_2)
- Cutting velocity, V_c and chip velocity, V_f

Considering total volume of chip produced in a given time,

$$a_1 b_1 L_1 = a_2 b_2 L_2 \tag{3.5}$$

The width of chip, b generally does not change significantly during machining unless there is side flow for some adverse situation.

Therefore assuming, b_1=b_2 in equation (3.1.5), ζ comes up to be,

$$\zeta\left(=\frac{a_2}{a_1}\right)=\frac{L1}{L2} \quad (3.6)$$

Again considering unchanged material flow (volume) ratio, Q

$$Q = (a_1b_1)\,V_c = (a_2b_2)V_f \quad (3.7)$$

Taking $b_1 = b_2$,

$$\zeta\left(=\frac{a_2}{a_1}\right)=\frac{Vc}{Vf} \quad (3.8)$$

Equation (3.1.8) reveals that the chip velocity, V_f will be lesser than the cutting velocity, V_c and the ratio is equal to the cutting ratio, $\frac{1}{\zeta} = r$

Shear angle

It has been observed that during machining, particularly ductile materials, the chip sharply changes its direction of flow (relative to the tool) from the direction of the cutting velocity, V_C to that along the tool rake surface after thickening by shear deformation or slip or lamellar sliding along a plane. This plane is called shear plane and is schematically shown in Fig. 3.1.3

Shear plane: Shear plane is the plane of separation of work material layer in the form of chip from the parent body due to shear along that plane.

Shear angle: Angle of inclination of the shear plane from the direction of cutting velocity [as shown in Fig. 3.2.3].

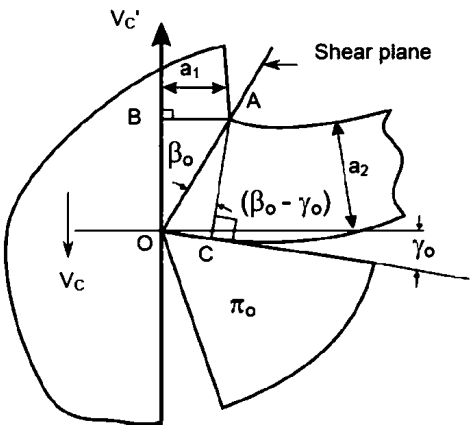


Fig. 5.2.3 Shear plane and shear angle in chip formation

The value of shear angle, denoted by β_o (taken in orthogonal plane) depends upon

Chip thickness before and after cut i.e. ζ

• Rake angle, Γ_0 (in orthogonal plane)

From Fig. 5.2.3

$AC = a_2 = OA\cos(\beta o - \Gamma_0)$ and $AB = a1 = OA\sin \beta o$

Dividing a2 by a1

$$\frac{a_2}{a_1} = \zeta = \frac{\cos(\beta o - \Gamma_0)}{\sin \beta o} \quad (3.9)$$

$$\text{Or } tan\beta o = \frac{\cos \Gamma_0}{\zeta - \sin \Gamma_0} \quad (3.10)$$

Replacing chip reduction coefficient, ζ by cutting ratio, r, the equation (5.1.10) changes to

$$tan\beta o = \frac{r\cos \Gamma_0}{1 - r\sin \Gamma_0} \quad (3.11)$$

Vice-versa. It is also evident from equation (3.1.10) as well as equation (3.1.4) that shear angle increases both directly and indirectly with the increase in tool rake angle. Increase in shear angle means more favourable machining condition requiring lesser specific energy.

Cutting strain

The magnitude of strain, that develops along the shear plane due to machining action, is called cutting strain (shear). The relationship of this cutting strain, ε with the governing parameters can be derived from Fig. 3.1.10.

Due to presence of the tool as an obstruction the layer 1 has been shifted to position 2 by sliding along the shear plane. From Fig. 3.1.10,

Cutting strain (average), $\varepsilon = \frac{\Delta S}{Y} = \frac{PM}{ON}$

Or, $\varepsilon = \frac{PN+NM}{ON} = \frac{PN}{ON} + \frac{NM}{ON}$

Or, $\varepsilon = cot\beta_0 + tan(\beta_0 + \Gamma_0)$ (3.12)

3.3 Built-up-Edge (BUE) formation

In machining ductile metals like steels with long chip-tool contact length, lot of stress and temperature develops in the secondary deformation zone at the chip-tool interface. Under such high stress and temperature in between two clean surfaces of metals, strong bonding may locally take place due to adhesion similar to welding. Such bonding will be encouraged and accelerated if the chip tool materials have mutual affinity or solubility. The weldment starts forming as an embryo at the most favourable location and thus gradually grows as schematically shown in Fig. 3.3.1.

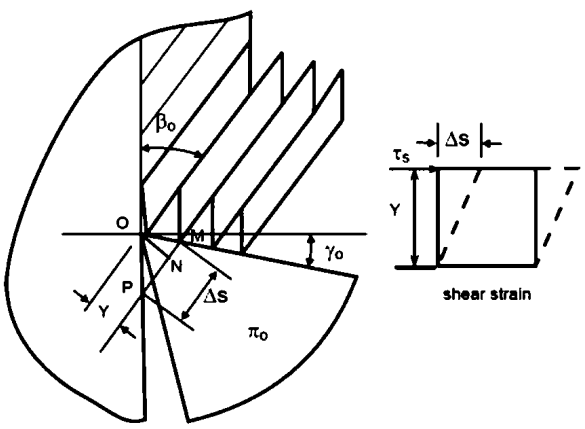


Fig. 3.2.1 Cutting strain in machining

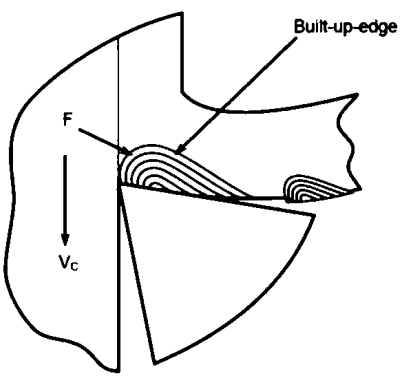


Fig. 3.3.2 Scheme of built-up-edge formation

With the growth of the BUE, the force, F (shown in Fig. 3.3.2) also gradually increases due to wedging action of the tool tip along with the BUE formed on it. Whenever the force, F exceeds the bonding force of the BUE, the BUE is broken or sheared off and taken away by the flowing chip. Then again BUE starts forming and growing. This goes on repeatedly.

Characteristics of BUE

Built-up-edges are characterized by its shape, size and bond strength, which depend upon:

- work tool materials
- stress and temperature, i.e., cutting velocity and feed
- cutting fluid application governing cooling and lubrication.

BUE may develop basically in three different shapes as schematically shown in Fig. 3.3.3.

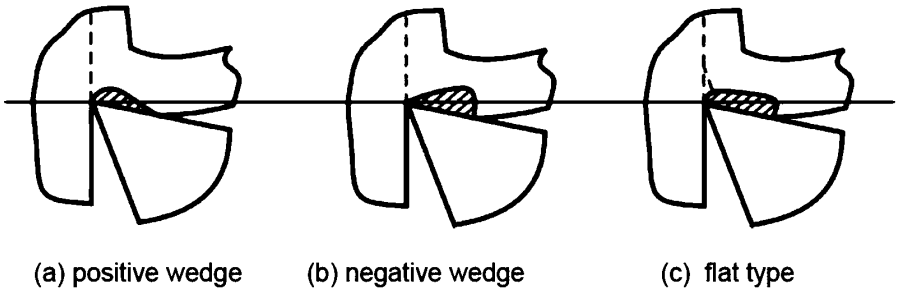


Fig. 3.3.3 Different forms of built-up-edge.

In machining too soft and ductile metals by tools like high speed steel or uncoated carbide the BUE may grow larger and overflow towards the finished surface through the flank as shown in Fig. 3.2.4

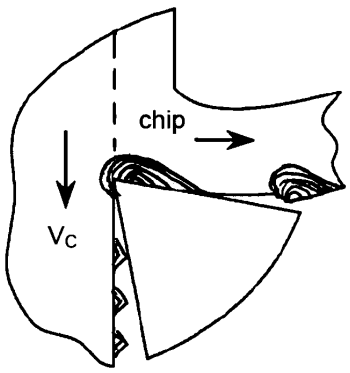


Fig. 3.2.4 Overgrowing and overflowing of BUE causing surface roughness

While the major part of the detached BUE goes away along the flowing chip, a small part of the BUE may remain stuck on the machined surface and spoils the surface finish. BUE formation needs certain level of temperature at the interface depending upon the mutual affinity of the work-tool materials. With the increase in V_c and S_o the cutting temperature rises and favours BUE formation. But if V_c is raised too high beyond certain limit, BUE will be squashed out by the flowing chip before the BUE grows. Fig.3.3.5 shows schematically the role of increasing V_c and S_o on BUE formation (size). But sometime the BUE may adhere so strongly that it remains strongly bonded at the tool tip and does not break or shear off even after reasonably long time of machining. Such detrimental situation occurs in case of certain tool-work materials and at speed-feed conditions which strongly favour adhesion and welding. Size of BUE Cutting

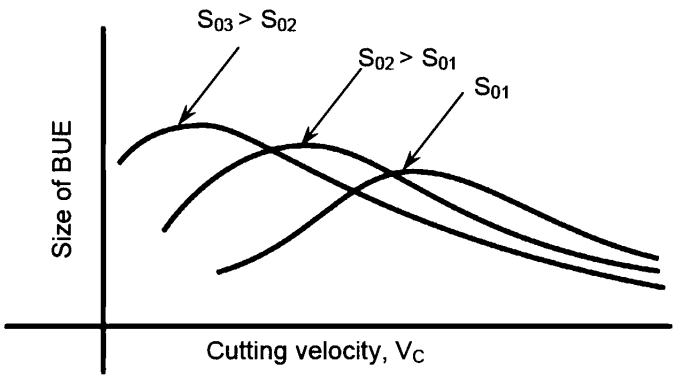


Fig. 3.3.5 Role of cutting velocity and feed on BUE formation.

- Effects of BUE formation

Formation of BUE causes several harmful effects, such as:

- It unfavourably changes the rake angle at the tool tip causing increase in cutting forces and power consumption
- Repeated formation and dislodgement of the BUE causes fluctuation in cutting forces and thus induces vibration which is harmful for the tool, job and the machine tool.
- Surface finish gets deteriorated
- May reduce tool life by accelerating tool-wear at its rake surface by adhesion and flaking

Occasionally, formation of thin flat type stable BUE may reduce tool wear at the rake face.

3.4 Types of chips and conditions for formation of those chips

Different types of chips of various shape, size, colour etc. are produced by machining depending upon

- type of cut, i.e., continuous (turning, boring etc.) or intermittent cut (milling)
- work material (brittle or ductile etc.)
- cutting tool geometry (rake, cutting angles etc.)
- levels of the cutting velocity and feed (low, medium or high)
- cutting fluid (type of fluid and method of application)

The basic major types of chips and the conditions generally under which such types of chips form are given below:

- Discontinuous type
  - of irregular size and shape : - work material – brittle like grey cast iron
  - of regular size and shape : - work material ductile but hard and work hardenable
    - Feed – large
    - Tool rake – negative
    - Cutting fluid – absent or inadequate
- Continuous type
  - Without BUE : -work material – ductile
    - Cutting velocity – high
    - Feed – low
    - Rake angle – positive and large
    - Cutting fluid – both cooling and lubricating
  - With BUE : - Work material – ductile
    - Cutting velocity – medium
    - Feed – medium or large
    - Cutting fluid – inadequate or absent.
- Jointed or segmented type
  - Work material – semi-ductile
  - Cutting velocity – low to medium
  - Feed – medium to large
  - Tool rake – negative
  - Cutting fluid – absent

Often in machining ductile metals at high speed, the chips are deliberately broken into small segments of regular size and shape by using chip breakers mainly for convenience and reduction of chip-tool contact length.

Example

During plain turning mild steel by a tool of geometry, 0_0, 0_0, 8_0, 7_0, 15_0, 90_0, 0 (mm) at f_0= 0.2 mm/rev, the chip thickness was found to be 0.5 mm. Determine the values of ζ and β_0 in the above case.

$$\zeta = \frac{a_2}{a_1} = \frac{a_2}{f_o \sin \emptyset} = \frac{0.5}{0.2 X \sin 90^0} = 2.5$$

$$tan\beta_0 = \frac{cos\gamma_0}{\zeta - \sin\gamma_0} \quad [\ then\ \gamma_0 = 0^0]$$

$$= \frac{1}{\zeta} = \frac{1}{2.5} = 0,\ \therefore \beta_0 = tan^{-1}(0.4) = 21.8^0$$

Self Test

Identify the correct one out of the four given answers

1. In turning mild steel the value of ζ will be
   (a) > 1.0
   (b) < 1.0
   (c) = 1.0
   (d) none of the above
2. .The value of shear angle, β depends upon
   (a) tool rake angle
   (b) friction at chip-tool interface
   (c) built – up – edge formation
   (d) all of the above
3. Shaping grey cast iron block will produce
   (a) continuous chip with BUE
   (b) continuous chip without BUE
   (c) discontinuous chip of irregular size & shape
   (d) discontinuous chip of regular size & shape
4. The value of chip reduction coefficient, ζ does not depend upon
   (a) cutting velocity
   (b) depth of cut
   (c) cutting tool material
   (d) tool rake angle

Answer 1 – (a), 2 – (d), 3 – (c) and 4 – (b)

Chapter Four

4. Basic Introduction to Welding Technology

4.1 Introduction

Welding is a process for joining two similar or dissimilar metals by fusion. It joins different metals/alloys, with or without the application of pressure and with or without the use of filler metal. The fusion of metal takes place by means of heat. The heat may be generated either from combustion of gases, electric arc, electric resistance or by chemical reaction. During some type

of welding processes, pressure may also be employed, but this is not an essential requirement for all welding processes. Welding provides a permanent joint but it normally affects the metallurgy of the components. It is therefore usually accompanied by post weld heat treatment for most of the critical components. The welding is widely used as a fabrication and repairing process in industries. Some of the typical applications of welding include the fabrication of ships, pressure vessels, automobile bodies, off-shore platform, bridges, welded pipes, sealing of nuclear fuel and explosives, etc. Most of the metals and alloys can be welded by one type of welding process or the other. However, some are easier to weld than others. To compare this ease in welding term 'weldability' is often used. The weldability may be defined as property of a metal which indicates the ease with which it can be welded with other similar or dissimilar metals. Weldability of a material depends upon various factors like the metallurgical changes that occur due to welding, changes in hardness in and around the weld, gas evolution and absorption, extent of oxidation, and the effect on cracking tendency of the joint. Plain low carbon steel (C-0.12%) has the best weldability amongst metals. Generally it is seen that the materials with high castability usually have low weldability.

4.2 Terminological Elements of Welding Process

The terminological elements of welding process used with common welding joints such as base metal, fusion zone, weld face, root face, root opening toe and root are depicted in Fig.4.1

4.2.1 Edge preparations

For welding the edges of joining surfaces of metals are prepared first. Different edge preparations may be used for welding butt joints, which are given in Fig 4.2.

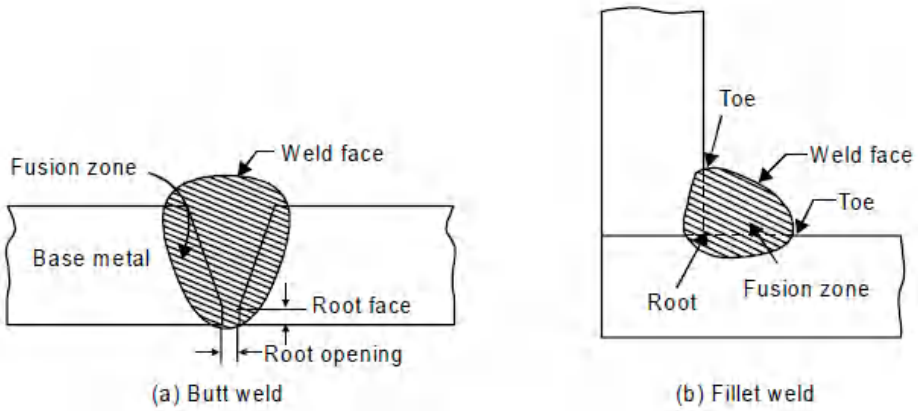


Fig. 4.1 Terminological elements of welding process

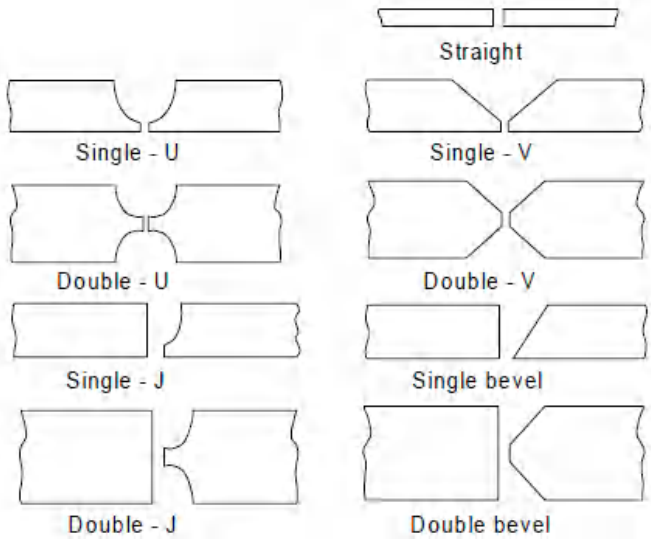


Fig. 4.2 Butt welding joints edge preparations

4.2.2 Welding joints

Some common welding joints are shown in Fig. 4.3. Welding joints are of generally of two major kinds namely lap joint and butt joint. The main types are described as under.

4.2.2.1 Lap weld joint

Single-Lap Joint

This joint, made by overlapping the edges of the plate, is not recommended for most work. The single lap has very little resistance to bending. It can be used satisfactorily for joining two cylinders that fit inside one another.

Double-Lap Joint

This is stronger than the single-lap joint but has the disadvantage that it requires twice as much welding.

Tee Fillet Weld

This type of joint, although widely used, should not be employed if an alternative design is possible.

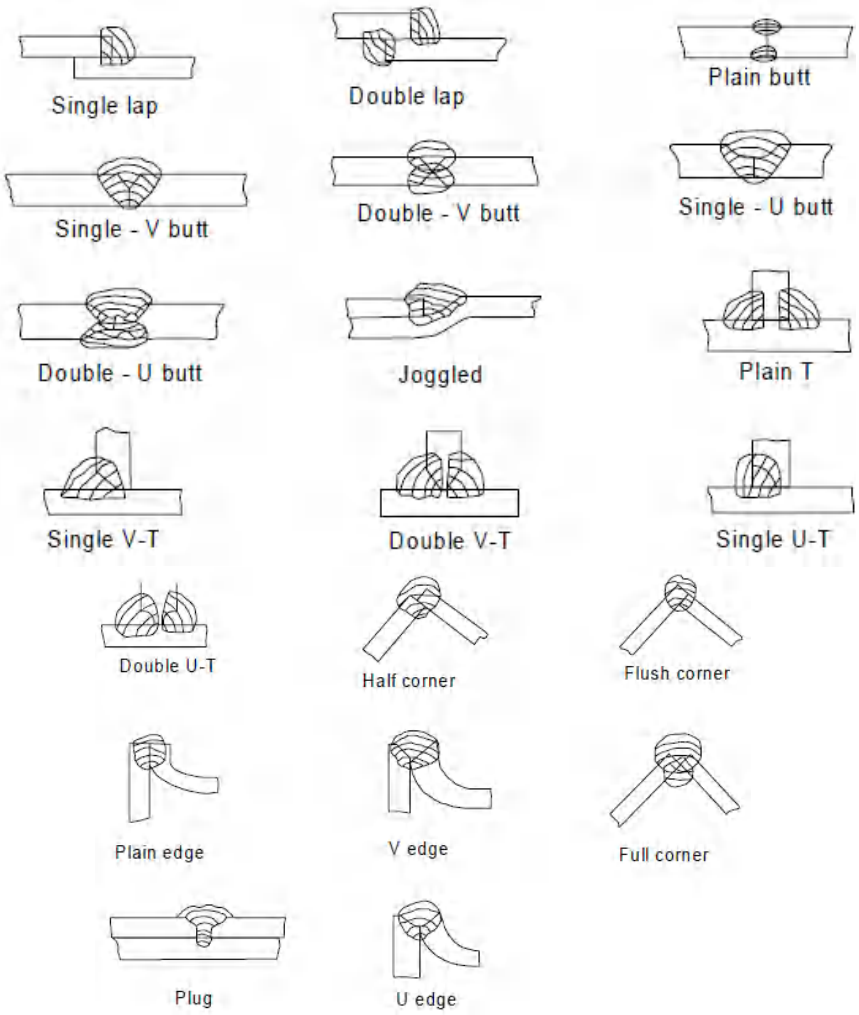


Fig. 4.3 Types of welding joints

4.2.2.2 Butt weld joint

Single-Vee Butt Weld

It is used for plates up to 15.8 mm thick. The angle of the vee depends upon the technique being used, the plates being spaced approximately 3.2 mm.

Double-Vee Butt Weld

It is used for plates over 13 mm thick when the welding can be performed on both sides of the plate. The top vee angle is either 60° or 80°, while the bottom angle is 80°, depending on the technique being used.

4.2.3 Welding Positions

As shown in Fig. 4.4, there are four types of welding positions, which are given as:

1. Flat or down hand position
2. Horizontal position
3. Vertical position
4. Overhead position

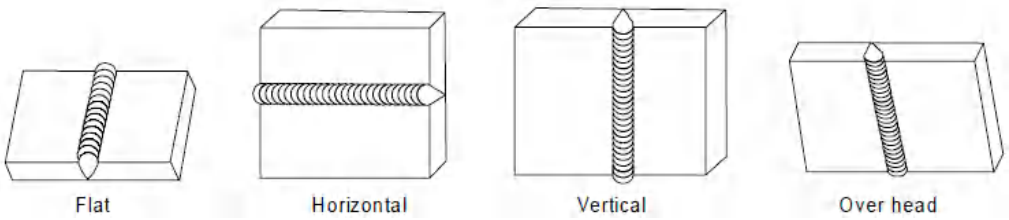


Fig. 4.4 Kinds of welding positions

4.2.3.1 Flat or Downhand Welding Position

The flat position or down hand position is one in which the welding is performed from the upper side of the joint and the face of the weld is approximately horizontal. This is the simplest and the most convenient position for welding. Using this technique, excellent welded joints at a fast speed with minimum risk of fatigue to the welders can be obtained.

4.2.3.2 Horizontal Welding Position

In horizontal position, the plane of the workpiece is vertical and the deposited weld head is horizontal. The metal deposition rate in horizontal welding is next to that achieved in flat or down hand welding position. This position of welding is most commonly used in welding vessels and reservoirs.

4.2.3.3 Veritical Welding Position

In vertical position, the plane of the workpiece is vertical and the weld is deposited upon a vertical surface. It is difficult to produce satisfactory welds in this position due to the effect of the force of gravity on the molten metal. The welder must constantly control the metal so that it does not run or drop from the weld. Vertical welding may be of two types viz., vertical-up and vertical-down. Vertical-up welding is preferred when strength is the major consideration. The vertical-down welding is used for a sealing operation and for welding sheet metal.

4.2.3.4 Overhead Welding Position

The overhead position is probably even more difficult to weld than the vertical position. Here the pull of gravity against the molten metal is much greater. The force of the flame against the weld serves to counteract the pull of gravity. In overhead position, the plane of the workpiece is horizontal. But the welding is carried out from the underside. The electrode is held with its welding end upward. It is a good practice to use very short arc and basic coated electrodes for overhead welding.

4.3 Advantages and Disadvantages of Welding

Advantages

1. Welding is more economical and is much faster process as compared to other processes (riveting, bolting, casting etc.)
2. Welding, if properly controlled results permanent joints having strength equal or sometimes more than base metal.
3. Large number of metals and alloys both similar and dissimilar can be joined by welding.

4. General welding equipment is not very costly.
5. Portable welding equipments can be easily made available.
6. Welding permits considerable freedom in design.
7. Welding can join welding jobs through spots, as continuous pressure tight seams, end-to-end and in a number of other configurations.
8. Welding can also be mechanized.

Disadvantages

1. It results in residual stresses and distortion of the workpieces.
2. Welded joint needs stress relieving and heat treatment.
3. Welding gives out harmful radiations (light), fumes and spatter.
4. Jigs, and fixtures may also be needed to hold and position the parts to be welded
5. Edges preparation of the welding jobs are required before welding
6. Skilled welder is required for production of good welding
7. Heat during welding produces metallurgical changes as the structure of the welded
8. joint is not same as that of the parent metal

4.4 Classification of Welding and Allied Processes

There are different welding, brazing and soldering methods are being used in industries today. There are various ways of classifying the welding and allied processes. For example, they may be classified on the basis of source of heat, i.e., blacksmith fire, flame, arc, etc. and the type of interaction i.e., liquid / liquid (fusion welding), solid/solid (solid state welding) or liquid/solid state. Welding processes may also be classified in two categories namely plastic (forge) and fusion. However, the general classification of welding and allied processes is given as under.

(A) Welding Processes

1. Oxy-Fuel Gas Welding Processes

I. Air-acetylene welding
II. Oxy-acetylene welding
III. Oxy-hydrogen welding
IV. Pressure gas welding

2. **Arc Welding Processes**

I. Carbon Arc Welding
II. Shielded Metal Arc Welding
III. Submerged Arc Welding
IV. Gas Tungsten Arc Welding
V. Gas Metal Arc Welding
VI. Plasma Arc Welding
VII. Atomic Hydrogen Welding
VIII. Electro-slag Welding
IX. Stud Arc Welding
X. Electro-gas Welding

3. Resistance Welding

I. Spot Welding
II. Seam Welding
III. Projection Welding
IV. Resistance Butt Welding
V. Flash Butt Welding
VI. Percussion Welding.
VII. High Frequency Resistance Welding
VIII. High Frequency Induction Welding

4. **Solid-State Welding Processes**

I. Forge Welding
II. Cold Pressure Welding
III. Friction Welding
IV. Explosive Welding
V. Diffusion Welding
VI. Cold Pressure Welding
VII. Thermo-compression Welding

5. Thermit Welding Processes

I. Thermit Welding
II. Pressure Thermit Welding

6. Radiant Energy Welding Processes

I. Laser Welding
II. Electron Beam Welding

(B) Allied Processes

1. Metal Joining or Metal Depositing Processes

I. Soldering
II. Brazing
III. Braze Welding
IV. Adhesive Bonding
V. Metal Spraying
VI. Surfacing

2. Thermal Cuting Processes

I. . Gas Cutting
II. Arc Cutting

Some of the important and widely used welding processes are discussed in the rest chapter.

4.5 Effects of Welding Heat

During the process of welding, the metal is heated over a range of temperature up to fusion and then allowed to cool. Heating and cooling causes metallurgical and mechanical effects on the metal pieces being welded. The region of the base metal which is affected by metallurgical change due to the welding heat is called the heat affected zone. In this zone, the metal has been heated and cooled through a range of temperature great enough to cause changes in the structure of the metal. The amount of change may be controlled by using the suitable welding processes. Sometimes, the original properties may be restored by heat treatment after welding. Although the mechanical strength of weld metals is at least equal to that of the base metal but the metallurgical changes can reduce greatly the associated properties of the joint particularly for shock and fatigue. Mechanical effects of welding heat are the distortion and the residual stress resulting from welding. The magnitude of these effects depends on the factors of design and welding procedure. But the effects will always be present to a certain extent in any structure fabricated or repaired by non-pressure welding. Because of expansion and contraction of the heated portion the distortion and residual stresses set up. The base metal heated locally will expand and upset owing to the restraint imposed by tile surrounding cold metal. This upset portion of the base metal will contract on cooling beyond its original dimensions and thereby setup internal stresses causing distortion. If the pieces being welded are not tree to move, high residual stresses will be formed which may cause cracking during welding.

The residual stresses also reduce load carrying capacity of the structure. The residual stresses may be relieved by heat treatment. Preheating the whole structure is helpful to reduce residual stresses. Certain procedures and proper welding sequences are also used in removing the distortion and internal stress. It is to be noted that the flow of heat in the weld zone is highly directional towards the adjacent cold metal, which produces columnar grains at right angle to the

fusion line. The columnar structure is a characteristic of the metal of single pass welds. Thus the original structure consisting of ferrite and pearlite in slabs is changed to another microstructure. The composition of the first crystal which form a molten alloy may quite different from the composition of the liquid, but as the freezing proceeds, the crystals readjust their composition to that of the initial liquid alloy in order to satisfy the condition of equilibrium. The weld metal when it is in the molten state can dissolve in ore gases, which come into contact with it, like oxygen, nitrogen and hydrogen. But as the metal cools it looses its dissolving capacity and the dissolved gases become free from the metal creating gas pockets and porosity in the final weld.
Welding processes widely used in the industry include oxy-acetylene, manual metal arcor shielded metal arc, submerged arc, gas metal arc, gas tungsten arc welding, resistance welding, thermit welding and cold pressure welding. Most of these processes have special fields of influence like resistance welding is popular with the automobile industry, thermit welding for joining rails. Gas metal arc welding is particularly suited for welding of low carbon steel structures as also welding of stainless steels and aluminum. It is more popular in aeronautical and nuclear industries. Submerged arc welding is used for ship building. Cold pressure welding is preferred by food processing industry. However, Arc welding and oxyacetylene welding, processes are the general purpose processes with a wide range of applications. Some of the typical applications of welding include the fabrication of ships, pressure vessels, automobile bodies, off-shore platform, bridges, welded pipes, sealing of nuclear fuel and explosives, etc. The knowledge of welding is much essential to make welded fabrications a success.

4.6 Welding Defects

Defects in welding joints are given in 4.5 (*i-viii*)

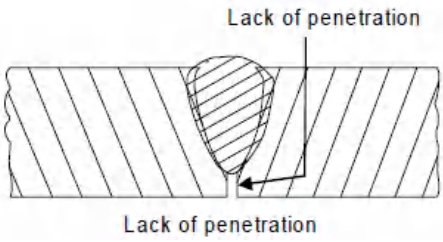


Fig.4.5 (i)

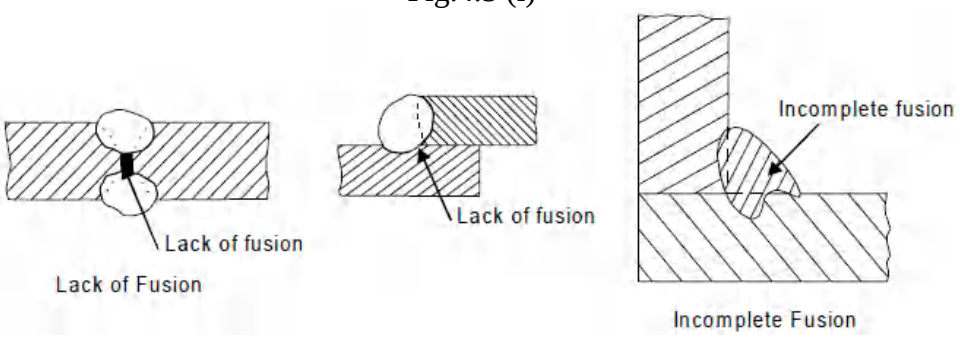


Fig.4.5 (ii)

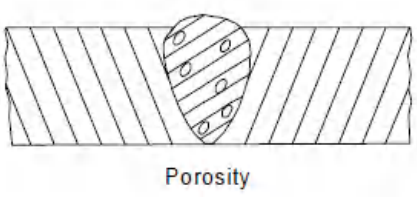


Fig. 4.5 (iii)

Fig. 4.5 (iv)

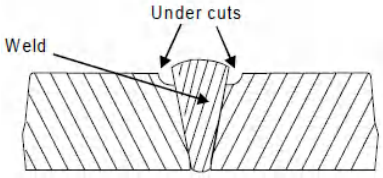


Fig.4.5 (v)

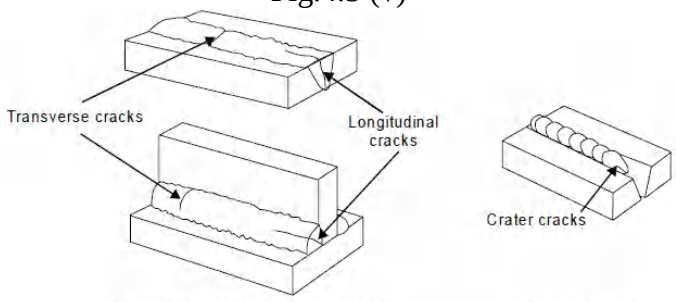


Fig.4.5 (vi)

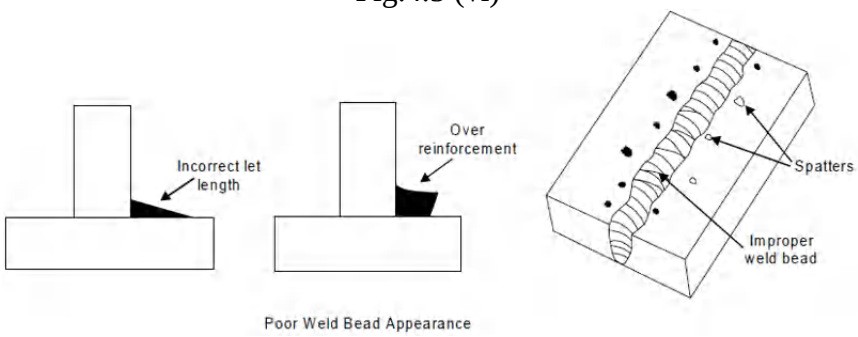


Fig.4.5 (vii)

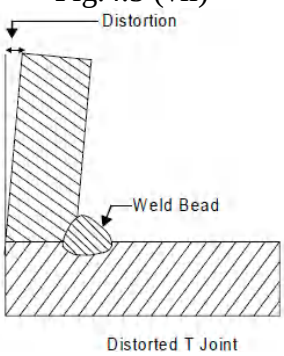


Fig.4.5 (viii)

1. Lack of Penetration (Fig. 4.5 (i))

It is the failure of the filler metal to penetrate into the joint. It is due to

a) Inadequate de-slagging
b) Incorrect edge penetration
c) Incorrect welding technique.

2. Lack of Fusion (Fig. 4.5 (ii))

Lack of fusion is the failure of the filler metal to fuse with the parent metal. It is duo to

a) Too fast a travel
b) Incorrect welding technique
c) Insufficient heat

3. Porosity (Fig. 4.5 (iii))

It is a group of small holes throughout the weld metal. It is caused by the trapping of gas during the welding process, due to

a) Chemicals in the metal
b) Dampness
c) Too rapid cooling of the weld.

4. Slag Inclusion (Fig. 4.5 (iv))
It is the entrapment of slag or other impurities in the weld. It is caused by
a) Slag from previous runs not being cleaned away,
b) Insufficient cleaning and preparation of the base metal before welding commences.

5. Undercuts (Fig. 4.5 (v))
These are grooves or slots along the edges of the weld caused by
a) Too fast a travel
b) Bad welding technique
c) Too great a heat build-up.

6. Cracking (Fig. 4.5 (vi))
It is the formation of cracks either in the weld metal or in the parent metal. It is due to
a) Unsuitable parent metals used in the weld
b) Bad welding technique.

7. Poor Weld Bead Appearance (Fig. 4.5 (vii))
If the width of weld bead deposited is not uniform or straight, then the weld bead is termed as poor. It is due to improper arc length, improper welding technique, damaged electrode coating and poor electrode and earthing connections. It can be reduced by taking into considerations the above factors.

8. Distortion (Fig. 4.5 (viii))
Distortion is due to high cooling rate, small diameter electrode, poor clamping and slow arc travel speed

9. Overlays
These consist of metal that has flowed on to the parent metal without fusing with it. The defect is due to
a) Contamination of the surface of the parent metal
b) Insufficient heat

10. Blowholes
These are large holes in the weld caused by
a) Gas being trapped, due to moisture.
b) Contamination of either the filler or parent metals.

11. Burn Through
It is the collapse of the weld pool due to
a) Too great a heat concentration
b) Poor edge preparation.

12. Excessive Penetration
It is where the weld metal protrudes through the root of the weld. It is caused by
a) Incorrect edge preparation
b) Too big a heat concentration
c) Too slow a travel.

Self Test

1. What is welding? How is it classified?
2. What are the advantages, disadvantages and applications of welding joints over other joints?
3. Explain the various types of joints commonly used in welding.
4. Explain the different kinds of welding positions with neat sketch.
5. Using neat sketch show the various standard location of elements of a welding symbol.
6. Classify the various welding processes in detail. Describe each in brief.

Chapter Five

5. Oxy-Fuel Gas Welding Process

5.1 Basic Introduction to Oxy-Fuel Gas Welding Process

Oxyfuel welding is a welding process where the heat for fusion is supplied by an torch using oxygen and a fuel gas. When several different fuel gasses can be used: A fusion welding process which joins metals, using the heat of combustion of an oxygen /air and fuel gas (i.e. acetylene, hydrogen propane or butane) mixture is usually referred as ‘gas welding’. The intense heat (flame) thus produced melts and fuses together the edges of the parts to be welded, generally with the addition of a filler metal. Operation of gas welding is shown in Fig. 5.1. The fuel gas generally employed is acetylene; however gases other than acetylene can also be used though

with lower flame temperature. Oxy-acetylene flame is the most versatile and hottest of all the flames produced by the combination of oxygen and other fuel gases. Other gases such as Hydrogen, Propane, Butane, Natural gas etc., may be used for some welding and brazing applications.

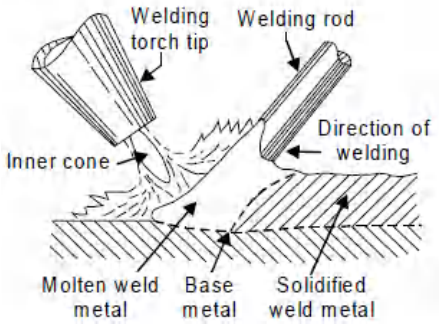


Fig. 5.1 Gas welding operation

Common Fuel Gases

Acetylene (C_2H_2) - Widely used, good availability and user familiarity high, flame and heat-temperature transfer characteristics. Acetylene is unstable at pressures above 15psi gage pressure and has a wide explosive limits range (2.5 to 80%).

Methylacetylene-Propadiene Stabilized (MPS, C_3H_4) - A mixture of several fuel gases with operating characteristics similar to Acetylene. However it requires about double the oxygen volume to achieve a neutral flame (oxygen costs will be higher). Higher regulator pressures may be used.

Natural Gas (mostly methane, CH4) - Produces a lower temperature, less intense flame than acetylene. Thus more gas must be used to achieve similar results. A two-piece tip must be used. Natural gas is delivered via low-pressure pipelines.

Propane (C_8H_8) - Highest total heat value, but also highest oxygen usage. Available in liquid form and easily transported to remote work-sites. Narrow explosive limits range (2.3 to 9.5%) and can be used at high (150 psi) line pressure.

Propylene (C_3H_6) - Sold under a variety of brand names (MAPP gas, etc.). Similar to MPS

5.1.1 Oxy-Acetylent Welding

In this process, acetylene is mixed with oxygen in correct proportions in the welding torch and ignited. The flame resulting at the tip of the torch is sufficiently hot to melt and join the parent metal. The oxy-acetylene flame reaches a temperature of about 3300°C and thus can melt most of the ferrous and non-ferrous metals in common use. A filler metal rod or welding rod is generally added to the molten metal pool to build up the seam slightly for greater strength.

***Typical* startup procedures**

Always use a flint and steel spark lighter to light the oxygen acetylene flame.

- Never use a butane lighter to light the flame
- Never stand directly in the path of a regulator when opening the cylinder
- Check for leaks using by listening for “Hissing” or by using a soapy “Bubble” solution
- Adjust the regulators to the correct operating pressure
- Slightly open and close the Oxygen and Acetylene valves at the torch head to purge any atmosphere from the system.
- Verify that equipment visually appears safe IE: Hose condition, visibility of gauges
- Clean torch orifices with a “tip cleaners” (a small wire gauge file set used to clean slag and dirt form the torch tip)
- Crack (or open) cylinder valves slightly allowing pressure to enter the regulators slowly
- Opening the cylinder valve quickly will “Slam” the regulator and will cause failure

- The special form of the mixing chamber guarantees highest possible safety against flashback

5.1.1.1 Types of Welding Flames

In oxy-acetylene welding, flame is the most important means to control the welding joint and the welding process. The correct type of flame is essential for the production of satisfactory welds. The flame must be of the proper size, shape and condition in order to operate with maximum efficiency. There are three basic types of oxy-acetylene flames.

1. Neutral welding flame (Acetylene and oxygen in equal proportions).
2. Carburizing welding flame or reducing (excess of acetylene).
3. Oxidizing welding flame (excess of oxygen).

Heat of Combustion - The total of the heat generated by the primary and secondary reactions.

The primary reaction occurs at the inner cone and results from combustion utilizing the supplied pure oxygen. The concentrated heat of the prim ary reaction (inner cone) is essential for welding applications.The secondary reaction occurs in the outer flame envelope and results from combustion of end-products ($2CO + H_2$) of the primary reaction and air.

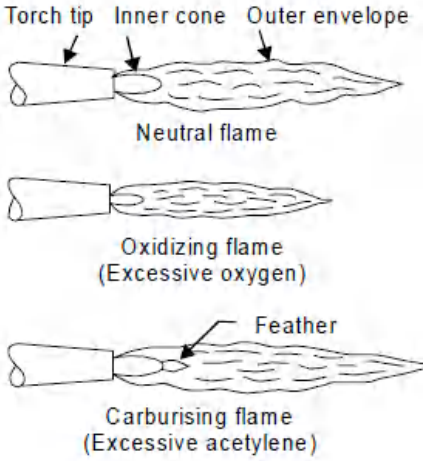
Combustion Intensity - A method of evaluating the fuel gases for heating purposes. Combustion Intensity (C_i) is the product of Combustion Velocity (C_v) and Heat of Combustion (C_h)… $Ci=C_v$ x C_h

Dark core: escaping gas mixture

- Brightly shining centre cone: acetylene decomposition ($C_2H_2 \rightarrow 2C+H_2$)
- Welding zone**:** 1st stage of combustion ($2C + H_2 + O_2$ (cylinder) $\rightarrow 2CO + H_2$)
- Outer flame: 2nd stage of combustion ($4CO + 2H_2 + 3O_2$ (air) $\rightarrow 4CO_2 + 2H_2O$
- Complete reaction: $2C2H_2 + 5O2 \rightarrow 4CO_2 + 2H_2O$
- The type of flame produced depends upon the ratio of oxygen to acetylene in the gas mixture which leaves the torch tip.

A neutral flame adjustment allows the differentiation of three zones of a chemical reaction.

The gas welding flames are shown in Fig 5.2.



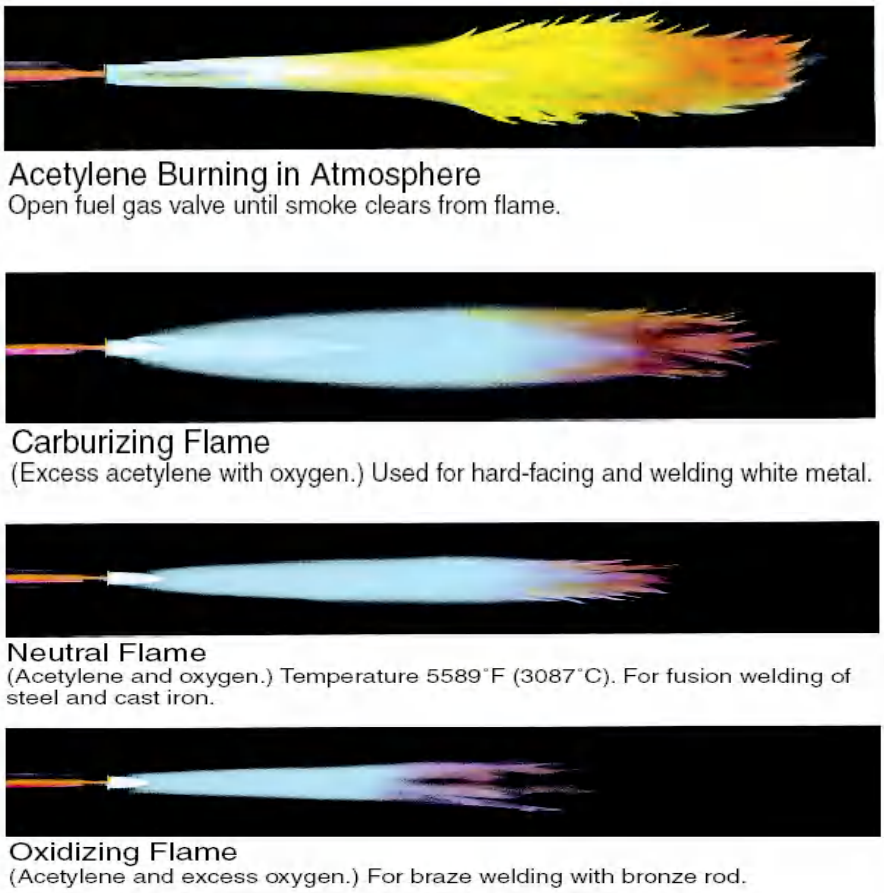


Fig. 5.2 Gas welding flames

Neutral Welding Flame

A neutral flame results when approximately equal volumes of oxygen and acetylene are mixed in the welding torch and burnt at the torch tip. The temperature of the neutral flame is of the order of about 5900°F (3260°C). It has a clear, well defined inner cone, indicating that the combustion is complete. The inner cone is light blue in color. It is surrounded by an outer flame envelope, produced by the combination of oxygen in the air and superheated carbon monoxide and hydrogen gases from the inner cone. This envelope is usually a much darker blue than the inner cone. A neutral flame is named so because it affects no chemical change on the molten metal and, therefore will not oxidize or carburize the metal. The neutral flame is commonly used for the welding of mild steel, stainless steel, cast Iron, copper, and aluminium.

Carburising or Reducing Welding Flame

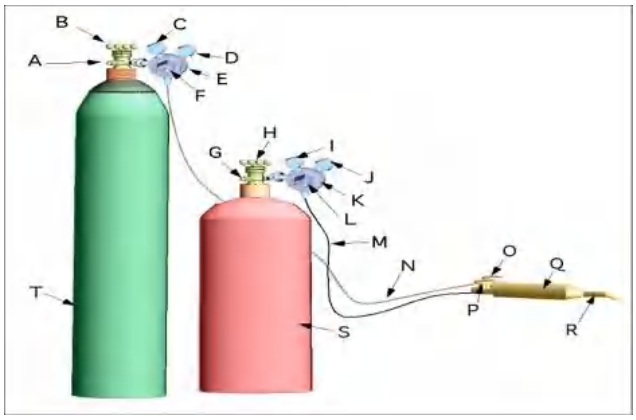
The carburizing or reducing flame has excess of acetylene and can be recognized by acetylene feather, which exists between the inner cone and the outer envelope. The outer flame envelope is longer than that of the neutral flame and is usually much brighter in color. With iron and steel, carburizing flame produces very hard, brittle substance known as iron carbide. A reducing flame may be distinguished from carburizing flame by the fact that a carburizing flame contains more acetylene than a reducing flame. A reducing flame has an approximate temperature of 3038°C. A carburizing-flame is used in the welding of lead and for carburizing (surface hardening) purpose. A reducing flame, on the other hand, does not carburize the metal; rather it ensures the absence of the oxidizing condition. It is used for welding with low alloy steel rods and for welding those metals, (e.g., non-ferrous) that do not tend to absorb carbon. This flame is very well used for welding high carbon steel.

Oxidising Welding flame

The oxidizing flame has an excess of oxygen over the acetylene. An oxidizing flame can be recognized by the small cone, which is shorter, much bluer in color and more pointed than that of the neutral flame. The outer flame envelope is much shorter and tends to fan out at the end. Such a flame makes a loud roaring sound. It is the hottest flame (temperature as high as 6300°F) produced by any oxy-fuel gas source. But the excess oxygen especially at high temperatures tends to combine with many metals to form hard, brittle, low strength oxides. Moreover, an excess of oxygen causes the weld bead and the surrounding area to have a scummy or dirty appearance. For these reasons, an oxidizing flame is of limited use in welding. It is not used in the welding of steel. A slightly oxidizing flame is helpful when welding (*i*) Copper-base metals (*ii*) Zinc-base metals and (*iii*) A few types of ferrous metals such as manganese steel and cast iron. The oxidizing atmosphere in these cases, create a base metal oxide that protects the base metal.

5.1.1.2 Gas Welding Equipments

An arrangement of oxy acetylene welding set up is shown in Fig.5.2. The basic tools and equipments used for oxy-acetylene welding are following:



A. Oxygen safety disc
B. Oxygen cylinder valve
C. Oxygen cylinder pressure gauge
D. Oxygen working pressure gauge
E. Oxygen regulator
F. Oxygen regulator adjusting screw
G. Acetylene cylinder safety disc
H. Acetylene cylinder valve
I. I.Acetylene cylinder pressure gauge
J. Acetylene working pressure gauge
K. K. Acetylene regulator
L. Acetylene regulator adjusting screw
M. Acetylene hose
N. Oxygen hose
O. Oxygen torch valve
P. Acetylene torch valve
Q. Torch
R. Welding tip
S. Acetylene cylinder
T. Oxygen cylinder

Fig. 5.2 Oxy acetylene welding set up

Acetylene and oxygen gas is stored in compressed gas cylinders. These gas cylinders differ widely in capacity, design and colour code. However, in most of the countries, the standard size of these cylinders is 6 to 7m^3 and is painted black for oxygen and maroon for acetylene. An acetylene cylinder is filled with some absorptive material, which is saturated with a chemical solvent acetone. Acetone has the ability to absorb a large volume of acetylene and release it as the pressure falls. If large quantities of acetylene gas are being consumed, it is much cheaper to generate the gas at the place of use with the help of acetylene gas generators. Acetylene gas is generated by carbide-to-water method. Oxygen gas cylinders are usually equipped with about 40 litres of oxygen at a pressure of about 154 Kgf/cm^2 at 21°C. To provide against dangerously excessive pressure, such as could occur if the cylinders were exposed to fire, every valve has a

safety device to release the oxygen before there is any danger of rupturing the cylinders. Fragile discs and fusible plugs are usually provided in the cylinders valves in case it is subjected to danger.

Gas pressure regulators

Gas pressure regulators are employed for regulating the supply of acetylene and oxygen gas from cylinders. A pressure regulator is connected between the cylinder and hose leading to welding torch. The cylinder and hose connections have left-handed threads on the acetylene regulator while these are right handed on the oxygen regulator. A pressure regulator is fitted with two pressure gauges, one for indication of the gas pressure in the cylinder and the other for indication of the reduced pressure at which the gas is going out.

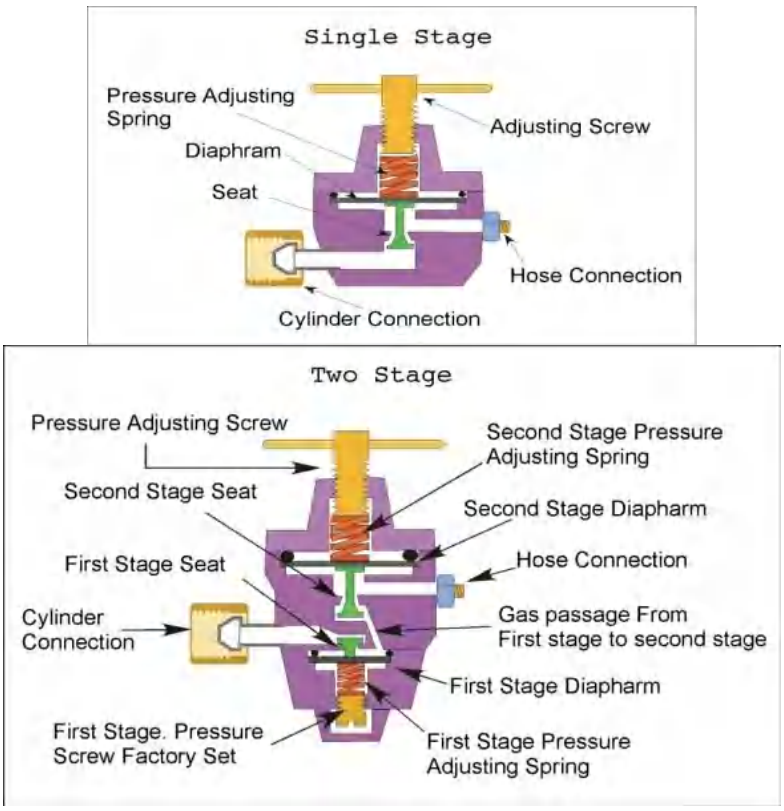


Fig. 5.3 pressure regulater

Oxygen and Acetylene Regulator Pressure Settings

- Regulator pressure may vary with different torch styles and tip sizes.
- PSI (pounds per square inch) is sometimes shown as PSIG (pounds per square inch - gauge)
- Common gauge settings for cutting
  - 1/4" material Oxy 30-35psi Acet 3-9 psi
  - 1/2" material Oxy 55-85psi Acet 6-12 psi
  - 1" material Oxy 110-160psi Acet 7-15 psi
- Check the torch manufactures data for optimum pressure settings

Regulator Problems (Regulator Creep)

- Regulator creep is a potentially dangerous condition that occurs when the regular does not maintain working pressure.

- When the system is on, and no gas is flowing, the working pressure slowly increases.

- Potential outcomes:
  - Rupture of regulator safety relief valve.
  - Explosion of low pressure gauge.
  - Rupture of gas hose.
- Causes
  - Foreign material inside the regulator.
  - Failure to release the regulator adjusting screw before opening the cylinder.
  - Normal wear
- The bourdon tube inside the regulator can be damaged, distorted. When this occurs, the gauge needle does not return to zero.

Welding torch

Fig 5.4 shows the construction of the welding torch. It is a tool for mixing oxygen and acetylene in correct proportion and burning the mixture at the end of a tip. Gas flow to the torch is controlled with the help of two needle valves in the handle of the torch. There are two basic types of gas welding torches:

1. Positive pressure (also known as medium or equal pressure), and
2. Low pressure or injector type

The positive pressure type welding torch is the more common of the two types of oxyacetylene torches.

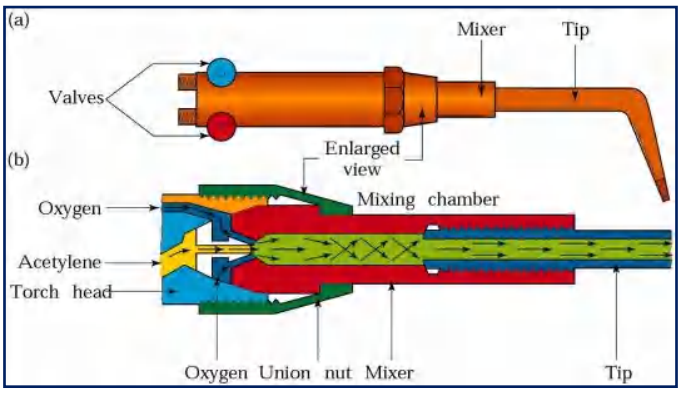


Fig. 5.4 oxy-fuel Welding torch: a) oxy-fuel torch and cross-sectional torch

Torch tips

It is the portion of the welding apparatus through which the gases pass just prior to their ignition and burning. A great variety of interchangeable welding tips differing in size, shape and construction are available commercially. The tip sizes are identified by the diameter of the opening. The diameter of the tip opening used for welding depends upon the type of metal to be welded.

Hose pipes

The hose pipes are used for the supply of gases from the pressure regulators. The most common method of hose pipe fitting both oxygen and acetylene gas is the reinforced rubber hose pipe. Green is the standard color for oxygen hose, red for acetylene, and black hose for other industrially available welding gases.

Goggles

These are fitted with colored lenses and are used to protect the eyes from harmful heat and ultraviolet and infrared rays.

Gloves

These are required to protect the hands from any injury due to the heat of welding process.

Spark-lighter

It is used for frequent igniting the welding torch.

Filler rods

Gas welding can be done with or without using filler rod. When welding with the filler rod, it should be held at approximately 900 to the welding tip. Filler rods have the same or nearly the same chemical composition as the base metal. Metallurgical properties of the weld deposit can be controlled by the optimum choice of filler rod. Most of the filler rods for gas welding also contain deoxidizers to control the oxygen content of weld pool.

Fluxes

Fluxes are used in gas welding to remove the oxide film and to maintain a clean surface. These are usually employed for gas welding of aluminium, stainless steel, cast iron, brass and silicon bronze. They are available in the market in the form of dry powder, paste, or thick solutions.

5.1.1.3 Safety Recommendations for Gas Welding

Welding and cutting of metals involve the application of intense heat to the objects being welded or cut. This intense heat in welding is obtained from the use of inflammable gases, (e.g. acetylene, hydrogen, etc.) or electricity. The intense welding heat and the sources employed to produce it can be potentially hazardous. Therefore, to protect persons from injury and to protect building and equipment against fire, etc., a set of recommendations concerning safety and health measures for the welders and those concerned with the safety of the equipments etc., have been published by BIS and many other similar but International organizations. By keeping in mind these recommendations or precautions, the risks associated with welding can be largely reduced. Therefore, it is suggested that the beginner in the field of gas welding must go through and become familiar with these general safety recommendations, which are given below.

1. Never hang a torch with its hose on regulators or cylinder valves.
2. . During working, if the welding tip becomes overheated it may be cooled by plunging the torch into water; close the acetylene valve but leave a little oxygen flowing.
3. Always use the correct pressure regulators for a gas. Acetylene pressure regulator should never be used with any other gas.
4. Do not move the cylinder by holding the pressure regulator and also handle pressure regulators carefully.
5. Use pressure regulator only at pressures for which it is intended.
6. Open cylinder valves slowly to avoid straining the mechanism of pressure regulator
7. For repairs, calibrations and adjustments purposes, the pressure regulators should be sent to the supplier.
8. Do cracking before connecting pressure regulator to the gas cylinder.
9. Inspect union nuts and connections on regulators before use to detect faulty seats
10. Which may cause leakage of gas when the regulators are attached to the cylinder valves?
11. Hose connections shall be well fittings and clamped properly otherwise securely fastened to these connections in such a manner as to withstand without leakage a pressure twice as great as the maximum delivery pressure of the pressure regulators provided on the system.
12. Protect the hose from flying sparks, hot slag, hot workpiece and open flame. If dirt goes into hose, blow through (with oxygen, not acetylene) before coupling to torch or regulator.
13. Store hose on a reel (an automobile wheel) when not in use.
14. Never allow the hose to come into contact with oil or grease; these deteriorate the rubber and constitute a hazard with oxygen.
15. Use the correct color hose for oxygen (green/black) and acetylene (red) and never
16. Use oxygen hose for acetylene or vice versa.
17. Always protect hose from being trampled on or run over. Avoid tangle and kinks.
18. Never leave the hose so that it can be tripped over.

Hazards of fumes, gases and dusts can be minimized by (i) improving general ventilation of the place where welding is carried out (ii) using local exhaust units, and (iii) wearing individual respiratory protective equipment.

Self Test

1. The regulator diaphragm is often made from _____?
   A. reinforced rubber
   B. malleable iron
   C. tempered aluminum
   D. stainless steel, ***answer (D)***
2. The hose nuts for oxygen and acetylene differ greatly, because the acetylene hose nut has.
   A. A left hand thread.
   B. Has a grove cut around it.
   C. May have ACET stamped on it.
   D. All of the above, ***answer (D)***
3. An oxygen cylinder must be able to withstand a _____ pressure of 3300 psi (22753 kPa) to be qualified for service.
   A. Atmospheric
   B. Hydrostatic, ***answer (B)***
   C. hydroscopic
   D. Vapor
4. Why the area above 15 psig is often marked with a red band on a acetylene low pressure regulator?

Answer

-Acetylene pressure above 15 psi is unstable and should not be used

5. A flint and steel spark lighter is the generally used to light the oxyacetylene flame. True
6. What is the maximum safe working gauge pressure for acetylene gas?
   A. 8 psig (55 kPa)
   B. 15 psig (103 kPa), ***answer (B)***
   C. 22 psig (152 kPa)
   D. 30 psig (207 kPa)
7. The color of and oxygen hose on a oxyacetylene welding outfit is _____? ***answer* is green**
8. The color of and acetylene oxygen hose on a oxyacetylene welding outfit is _____? ***answer* is Red**
9. The type of safety device is used on a oxygen cylinder.
   A. A fusible plug
   B. A check valve
   C. A pressure safety disk, ***answer (C)***
   D. spring loaded plug
10. No part of an oxygen cylinder walls may be thinner than _____?
    A. 1/4”in (6.4 mm), ***answer (A)***
    B. 3/8”in (9.5 mm)
    C. 3/16”in (4.8 mm)
    D. 7/32”in (5.6 mm)
11. To prevent the occurrence of flashbacks, a _____ should be installed between either the torch and hoses or regulators and hoses.
    A. A two way check valve

B. Flame screen
C. Flashback arrestor, ***answer (C)***
D. Three way check valve

Chapter Six

6. **Consumable Electrode Welding Process**:

Arc welding a group of fusion welding processes that use an electric arc to produce the heat required for melting the metal and filler material. An arc welding joins two metals together by generating an electric arc between a coated metal electrode and a base metal. When the electrode and work piece are in contact, current flows and when they are separated an arc is generated and the current continues to flow. The arc is generated by the electrons liberated form cathode and moving towards anode. The arc changes electrical energy into heat and light. About 70% of the heat liberated due to striking of electrons at anode raises the anode temperature to very values (5,000 to 30,000C). This heat melts the base metal as well as tip of the electrode in the area surrounding the arc. A weld is formed when the mixture of molten base and electrode metal solidifies in the weld area. Since 70% heat is generated at anode a workpiece connected to anode will melt 50% faster as compared to if connected with cathode. This is why work piece is usually made positive and electrode as negative and is termed as straight polarity. The coating of the electrode produces a gas which shields the weld from the atmosphere and helps to maintain the weld shape. This coating is later removed in the form of slag. The slag coating over the weld insulates the hot weld from contaminants in the air during cooling. This process, in which an electric arc between an electrode and a workpiece or between two electrodes is utilized to weld base metals, is called an arc welding process. For further clarification basic principle of arc welding is shown in Fig 6.1. However the basic elements involved in arc welding process are shown in Fig. 6.1. Most of these processes use some shielding gas while others employ coatings or fluxes to prevent the weld pool from the surrounding atmosphere. The various arc welding processes are:

1. Carbon Arc Welding
2. Shielded Metal Arc Welding
3. Flux Cored Arc Welding
4. Gas Tungsten Arc Welding
5. Gas Metal Arc Welding
6. Plasma Arc Welding
7. Atomic Hydrogen Welding
8. Electroslag Welding
9. Stud Arc Welding
10. Electrogas Welding

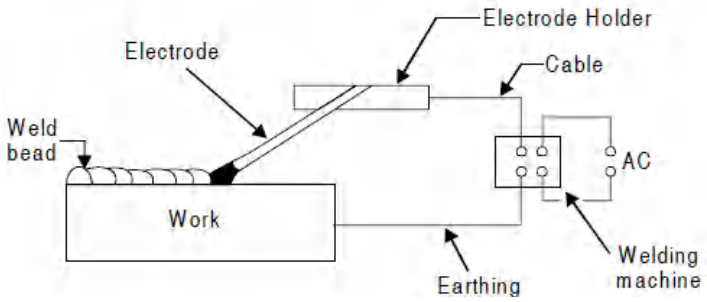


Fig. 6.1 Principle of arc welding

6.2 Arc Welding Equipment

Arc welding power source

Both direct current (DC) and alternating current (AC) are used for electric arc welding, each having its particular applications. DC welding supply is usually obtained from generators driven by electric motor or if no electricity is available by internal combustion engines. For AC welding

supply, transformers are predominantly used for almost all arc welding where mains electricity supply is available. They have to step down the usual supply voltage (200-400 volts) to the normal open circuit welding voltage (50-90 volts). The power supply of the arc welding apparatus must maintain a relatively constant current with only a slight change in voltage.

a. Varying voltage and current will result in an uneven arc that creates splatters and uneven welds.
b. There are three main types of power supplies.

Generators

a. Generator powered arc welding machines run on direct current.
b. These welding machines are commonly used in industry and are noisy, expensive to purchase, and costly to operate.

Transformers

These machines are generally the cheapest to purchase and run on an alternating current.

Rectifiers (Changes AC to DC)

The rectifier is a more versatile arc welding power supply that can be run on either direct or alternating current.

The following factors influence the selection of a power source:

1. Type of electrodes to be used and metals to be welded
2. Available power source (AC or DC)
3. Required output
4. Duty cycle
5. Efficiency
6. Initial costs and running costs
7. Available floor space
8. Versatility of equipment

6.3 Other auxiliary equipments

1. **Ground Clamp**
   a. The ground clamp completes the full electrical circuit so thatenough heat will be available for the welding job.
   b. The ground clamp must be securely fastened to the metal being welded or to an adjoining workbench or piece of metal.
2. **Electrode Holder (or Stinger)**
   a. The stinger receives the amperage and directs it through the electrode to form the arc.
   b. The electrode holder should be well insulated, have a strong spring to firmly grasp the electrode, and a release lever to exchange the electrodes easily.

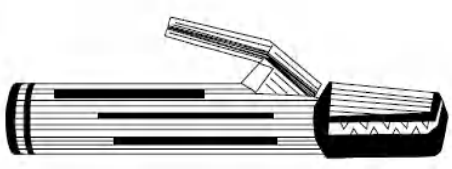


Fig.6.2.1 Electrode holder

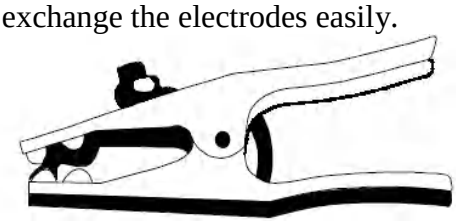


Fig. 6.2.1 Earth clamp

3. **Cables**
   a. The cables allow both the ground clamp and the stinger to be mobile.
   b. The cables should also be well insulated and protected from the heat during welding.
4. Protective clothing must be worn at all times when welding. The heat created during arc welding creates flying molten sparks and ultraviolet and infrared rays that can burn the skin.
5. **Leather Gloves**

a. Gloves protect the hands from burns during welding.
b. The gloves should be made of thick leather and have long cuffs to protect the wrist and prevent sparks from falling into them.

6. **Leather or Cotton Sleeves**
   a. A NONFLAMMABLE material should be worn on the arms to protect from burns due to sparks and intense heat.
7. **Body Protection**
   a. Either a leather apron or coveralls or workshirt made of a flame-retardant material will protect the body during arc welding.
   b. All protective clothing should fit properly and be free of openings or rips into which a spark might enter or the intense heat might penetrate.
8. **Footwear.**
   a. Leather boots should be worn while arc welding.
   b. Never wear open-toed shoes while working with hot metal or a welding apparatus.
9. Arc Welding Helmets and Shields - The brilliant light given off by the electric arc produces invisible ultraviolet and infrared rays, which can severely burn the eyes and skin. NEVER LOOK AT THE ARC WITH THE NAKED EYE. Helmets and shields are equipped with special filtered lenses that reduce the intensity of the light and prevent the ultraviolet and infrared rays from reaching the eyes.
   a. The welding helmet is designed specifically for the purpose of arc welding.
   b. The welding helmet fits on the head using a plastic adjustable headband.
   c. The helmet leaves both hands free for working and positioning materials.
   d. Many helmets have clear lenses under the filtered lenses that can be used when chipping slag.
10. **The hand shield is used for observing**.
   a. It is NOT advisable to use the hand shield when welding since one hand must be used to hold the shield in place.
   b. The protective lenses come in different shades depending on the type of welding to be done. Different types of welding use different amounts of voltage and current which determine the intensity of the light and the amount of ultraviolet and infrared rays produced. Spot welding requires the fewest amperes and thus requires the least amount of shading in the lens. Arc welding machines require from less than 30 to over 400 amperes. Lens shades range from number 5 (which provides the least amount of protection) to shade 14 (which provides the most protection).
   c. Shade 5 is used for light spot welding.
   d. Shades 6 and 7 are suitable for welding with up to 30 amperes.
   e. Shade 8 is for welding with 30-75 amperes.
   f. Shade 10 can be used when welding with 75-200 amperes.
   g. Shade 12 is used when welding with 200-400 amperes.Shade 14 is required when welding with over 400 amperes.
11. Cover glasses are clear lenses that are used to stop flying slag or metal, thus protecting the filter lenses. There are 3 different types of cover glass currently available.
   a. Clear, unbreakable plastic is the cheapest and lasts the longest.
   b. Chemically treated glass is used to reduce pitting but it can be expensive.
   c. Plain glass is very susceptible to breaking, pitting, and splatter sticks and is NOT recommended.
12. Filter lenses must be changed if a crack or chip occurs in order to prevent ultraviolet and infrared rays from reaching the eyes. The shades of the lenses must also be changed. If the shade is too dark, the worker will be unable to see the work that is being performed. If the shade is too light, proper eye protection is not achieved. Many

welding helmets have interchangeable lenses. The lens changing procedure is as follows:

a. Remove the lift-up mechanism on the helmet or the lens frame lock.
b. Slide the old filter lens out and insert the new one.
c. Reinsert the lift-up mechanism or the lens frame lock.
d. Put the helmet on and search for light leaks. If leaks are present,
e. The lens must be readjusted.

13. Goggles Goggles must be worn when chipping slag if a shell lens is not provided in the helmet.
14. Tongs - The heat of the arc will heat all of the metal being welded. Always use tongs to carry or maneuver the metal stock.
15. Slag Hammer or Chipping Hammer - The slag hammer is used to remove slag from the weld for proper cooling.
16. Electrode
    a. The electrode consists of an internal metal core and an outer coating called flux which shields the weld. The core melts into the molten base metal to produce the metal bond. An arc is set up between electrode and workpiece. Welding electrodes are classified into following types-
        I. Consumable Electrodes
            - ✓ Bare Electrodes
            - ✓ Coated Electrodes
        II. Non-consumable Electrodes
            - ✓ Carbon or Graphite Electrodes
            - ✓ Tungsten Electrodes

Consumable Electrodes

Consumable electrode is made of different metals and their alloys. The end of this electrode starts melting when arc is struck between the electrode and workpiece. Thus consumable electrode itself acts as a filler metal. Bare electrodes consist of a metal or alloy wire without any flux coating on them. Coated electrodes have flux coating which starts melting as soon as an electric arc is struck. This coating on melting performs many functions like prevention of joint from atmospheric contamination, arc stabilizers etc.

Non-consumable

Non-consumable electrodes are made up of high melting point materials like carbon, pure tungsten or alloy tungsten etc. These electrodes do not melt away during welding. But practically, the electrode length goes on decreasing with the passage of time, because of oxidation and vaporization of the electrode material during welding. The materials of nonconsumable electrodes are usually copper coated carbon or graphite, pure tungsten, thoriated or zirconiated tungsten.

6.4 **Concepts and General Requirements for Obtaining Sound Welds**

The ideal weld is one in which there is complete continuity between the parts joined and every part of the joint is indistinguishable from the material in which the joint is made. Although this ideal is never achieved in practice, welds which give satisfactory service can be made in many ways. Not every welding process is equally suitable for each material, type of joint or application, and much of the skill of the welding engineer consists in the recognition of the essential requirements, which a particular weld must satisfy and the choice of the appropriate welding process.

Each welding process must fulfil a number of conditions. Most important, energy in some form, usually heat, must be supplied to the joint so that the parts can be united by being fused together. The heat may be generated by a flame, an arc, the resistance to an electric current, radiant energy or by mechanical means. In a limited number of processes such as pressure welding the union of the parts is accomplished without melting, but energy is expended in forcing together the parts to be joined and heat may be used to bring the weld region to a plastic condition. Fusion is generally considered as synonymous with melting, but in the context of welding it is desirable to distinguish at once between these words. By common usage the word fusion implies melting with subsequent union, and it is possible for the parts of a joint to be melted but not fused together.

Two surfaces can only be unified satisfactorily if they are free from oxide or other contaminants. Cleaning the surfaces before welding, though helpful, is not usually adequate and it is a feature of every welding process that the contaminated surface film is dissolved or dispersed. This may be done by the chemical action of a flux or the sputtering of an electric arc or even by mechanical means such as rupturing and rubbing. The contaminants which must be removed from the surface are of three types organic films, adsorbed gases and chemical compounds of the base metal, generally oxides. Heat effectively removes thin organic films and adsorbed gases so that with the majority of welding processes where heat is employed it is the remaining oxide film which is of greatest importance.

Once removed, surface films and particularly nitrides, must be prevented from forming during the process of welding. In almost every welding process, therefore, there must be some way of excluding the atmosphere while the process is carried out. If a flux is used for cleaning the fusion faces of the joint, this also performs the function of shielding. If a flux is not used shielding can be provided by a blanket of an inert gas, or a gas which does not form refractory compounds with the base metal. The atmosphere may also be excluded mechanically by welding with the faces to be joined in close contact. The ultimate in protection from the atmosphere is obtained by removing it entirely by welding in a vacuum. Where the welding operation is carried out at high speed and with such limited heating that there is no time for appreciable oxidation, shielding may be unnecessary. It is possible with a few processes, however, for any contaminated molten metal to be expelled before the joint is completed or for the properties of the weld metal to be corrected by making alloying additions to the weld pool.

One further important requirement is that the joint produced by the welding process should have satisfactory metallurgical properties. In methods which involve melting of some part of the joint it is often necessary to add deoxidants or alloying additions, just as is done in the foundry. Frequently the material to be welded must have a controlled composition. Some alloys-happily few-are unweldable by almost any process, but a great many are only suitable for welding if their composition is controlled within close limits. These considerations are the basis of welding metallurgy.

To Summarize: every welding process must fulfil four requirements:

1. A supply of energy to create union by fusion or pressure.
2. A mechanism for removing superficial contamination from the joint faces.

3. Avoidance of atmospheric contamination or its effects.
4. Control of weld metallurgy.

6.3 Carbon Arc Welding

In this process, a pure graphite or baked carbon rod is used as a non-consumable electrode to create an electric arc between it and the workpiece. The electric arc produces heat and weld can be made with or without the addition of filler material. Carbon arc welding may be classified as-

(1) Single electrode arc welding, and
(2) Twin carbon electrode arc welding

In single electrode arc welding, an electric arc is struck between a carbon electrode and the workpiece. Welding may be carried out in air or in an inert atmosphere. Direct current straight polarity (DCSP) is preferred to restrict electrode disintegration and the amount of carbon going into the weld metal. This process is mainly used for providing heat source for brazing, braze welding, soldering and heat treating as well as for repairing iron and steel castings. It is also used for welding of galvanized steel and copper. In twin carbon arc welding the arc struck between two carbon electrodes produces heat and welds the joint. The arc produced between these two electrodes heats the metal to the melting temperature and welds the joint after solidification. The power source used is AC (Alternating Current) to keep the electrodes at the same temperature. Twin-electrode carbon arc welding can be used for welding in any position. This process is mainly used for joining copper alloys to each other or to ferrous metal. It can also be used for welding aluminium, nickel, zinc and lead alloys.

6.4 Shielded Metal Arc Welding (SMAW) or Manual Metal Arc Welding (MMAW)

Shielded metal arc welding (SMAW) is a commonly used arc welding process manually carried by welder. It is an arc welding process in which heat for welding is produced through an electric arc set up between a flux coated electrode and the workpiece. The core of the covered electrode consists of either a solid metal rod of drawn or cast material or one fabricated by encasing metal powders in a metallic sheath. The core rod conducts the electric current to the arc and provides filler metal for the joint. The primary functions of the electrode covering are to provide arc stability and to shield the molten metal from the atmosphere with gases created as the coating decomposes from the heat of the arc. The shielding employed, along with other ingredients in the covering and the core wire, largely controls the mechanical properties, chemical composition, and metallurgical structure of the weld metal, as well as the arc characteristics of the electrode. The composition of the electrode covering varies according to the type of electrode.

Shielded metal arc welding is by far the most widely used of the various arc welding processes. It employs the heat of the arc to melt the base metal and the tip of a consumable covered electrode. The electrode and the work are part of an electric circuit illustrated in Fig.1. This circuit begins with the electric power source and includes the welding cables, an electrode holder, a workpiece connection, the workpiece (weldment), and an arc welding electrode. One of the two cables from the power source is attached to the work. The other is attached to the electrode holder.

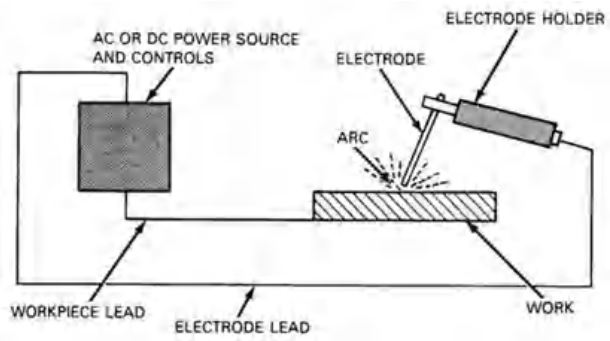


Fig. 6.4.1 Elements of Shielded Metal Arc Welding Circuit

Welding commences when an arc is struck between the tip of the electrode and the work. The intense heat of the arc melts the tip of the electrode and the surface of the work close to the arc. Tiny globules of molten metal rapidly form on the tip of the electrode, then transfer through the arc stream into the molten weld pool. In this manner, filler metal is deposited as the electrode is progressively consumed. The arc is moved over the work at an appropriate arc length and travel speed, melting and fusing a portion of the base metal and continuously adding filler metal. Since the arc is one of the hottest of the commercial sources of heat [temperatures above 5000ºC have been measured at it's centre], melting of the base metal takes place almost instantaneously upon arc initiation. If welds are made in either the flat or the horizontal position, metal transfer is induced by the force of gravity, gas expansion, electric and electromagnetic forces, and surface tension. For welds in other positions, gravity works against the other forces.

The process requires sufficient electric current to melt both the electrode and a proper amount of base metal. It also requires an appropriate gap between the tip of the electrode and the base metal or the molten weld pool. These requirements are necessary to set the stage for coalescence. The sizes and types of electrodes for shielded metal arc welding define the arc voltage requirements (within the overall range of 16 to 40 V) and the amperage requirements (within the overall range of 20 to 550 A). The current may be either alternating or direct, depending upon the electrode being used, but the power source must be able to control the level of current within a reasonable range in order to respond to the complex variables of the welding process itself.

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Covered Electrodes

In addition to establishing the arc and supplying filler metal for the weld deposit, the electrode introduces other materials into or around the arc, or both. Depending upon the type of electrode being used, the covering performs one or more of the following functions:

1. Provides scavengers, deoxidizers, and fluxing agents to cleanse the weld and prevent excessive grain growth in the weld metal.
2. Establishes the electrical characteristics of the electrode.
3. Provides a slag blanket to protect the hot weld metal from the air and enhance the mechanical properties, bead shape, and surface cleanliness of the weld metal.
4. Provides a means of adding alloying elements to change the mechanical properties of the weld metal.
5. Provides a gas to shield the arc and prevent excessive atmospheric contamination of the molten filler metal.

Functions 1 and 4 prevent the pickup of oxygen and nitrogen from the air by the molten filler metal in the arc stream and by the weld metal as it solidifies and cools. Either alternating current (ac) or direct current (dc) may be employed for shielded metal arc welding, depending upon the current supplied by the power source and the electrode selected. The specific type of current employed influences the performance of the electrode. Each current type has its advantages and limitations, and these must be considered when selecting the type of current for a specific application. Factors, which need to be considered, are as follows:

Voltage drop in the welding cables is lower with ac. This makes ac more suitable if the welding is to be done at long distances from the power supply. However, long cables, which carry ac should not be coiled because the inductive losses encountered in such cases can be substantial.

Low Current: With small diameter electrodes and low welding currents, dc provides better operating characteristics and a more stable arc.

Arc Starting: Striking the arc is generally easier with dc, particularly if small diameter electrodes are used. With ac, the welding current passes through zero each half cycle, and this presents problems for arc starting and arc stability.

Arc Length: Welding with a short arc length (low arc voltage) is easier with dc than with ac. This is an important consideration, except for the heavy iron powder electrodes. With those electrodes, the deep crucible formed by the heavy covering automatically maintains the proper arc length when the electrode tip is dragged on the surface of the joint.

Arc Blow: Alternating current rarely presents a problem with arc blow because the magnetic field is constantly reversing (120 times per second). Arc blow can be a significant problem with dc welding of ferritic steel because of unbalanced magnetic fields around the arc.

Welding Position: Direct current is somewhat better than ac for vertical and overhead welds because lower amperage can be used. With suitable electrodes, however, satisfactory welds can be made in all positions with ac.

Metal Thickness: Both sheet metal and heavy sections can be welded using dc. The welding of sheet metal with ac is less desirable than with dc. Arc conditions at low current levels required for thin materials are less stable on ac power than on dc power.

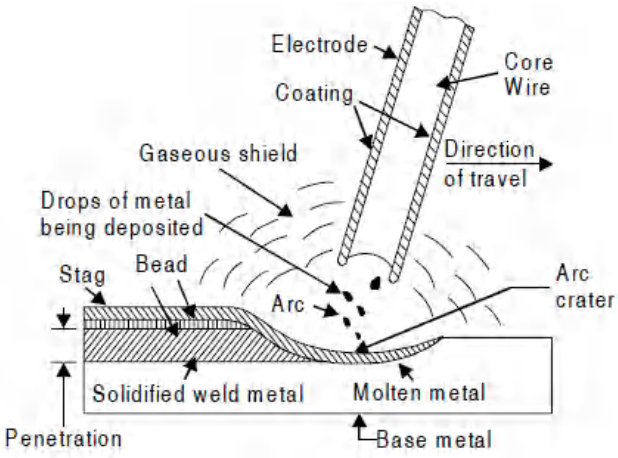


Fig. 6.4.1 Arc welding operation

Advantages SMAW

1. Shielded Metal Arc Welding (SMAW) can be carried out in any position with highest weld quality.
2. MMAW is the simplest of all the arc welding processes.
3. This welding process finds innumerable applications, because of the availability of a wide variety of electrodes.
4. Big range of metals and their alloys can be welded easily.
5. The process can be very well employed for hard facing and metal resistance etc.
6. Joints (e.g., between nozzles and shell in a pressure vessel) which because of their position are difficult to be welded by automatic welding machines can be easily accomplished by flux shielded metal arc welding.
7. The MMAW welding equipment is portable and the cost is fairly low.

Limitations

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

Applications

1. Today, almost all the commonly employed metals and their alloys can be welded by this process.
2. Shielded metal arc welding is used both as a fabrication process and for maintenanceand repair jobs.
3. The process finds applications in
   a. Building and Bridge construction
   b. Automotive and aircraft industry, etc.
   c. Air receiver, tank, boiler and pressure vessel fabrication
   d. Ship building

e. Pipes and
f. Penstock joining

Functions of Electrode Coating Ingredients

The covering coating on the core wire consists of many materials which perform a number of functions as listed below:

1. . Welding electrodes are used to join various similar and dissimilar metals as plain carbon steels, cast iron, copper, aluminium, magnesium and their alloys, stainless steels and other alloy steels.
2. Slag forming ingredients, like silicates of magnesium, aluminium, sodium, potassium, iron oxide, china clay, mica etc., produce a slag which because of its light weight forms a layer on the molten metal and protects the same from atmospheric contamination.
3. Arc stabilizing constituents like calcium carbonate, potassium silicate, titanates, magnesium silicates, etc.; add to arc stability and ease of striking the same.
4. Gas shielding ingredients, like cellulose, wood, wood flour, starch, calcium carbonate etc. form a protective gas shield around the electrode end, arc and weld pool
5. Deoxidizing elements like ferro-manganese, and ferro-silicon, refine the molten
6. It limits spatter, produces a quiet arc and easily removable slag.
7. Alloying elements like ferro alloys of manganese, molybdenum etc., may be added to impart suitable properties and strength to the weld metal and to make good the loss of some of the elements, which vaporize while welding.
8. Iron powder in the coating improves arc behavior, bead appearance helps increase metal deposition rate and arc travel speed.
9. The covering improves penetration and surface finish.
10. Core wire melts faster than the covering, thus forming a sleeve of the coating which constricts and produces an arc with high concentrated heat.
11. Coating saves the welder from the radiations otherwise emitted from a bare electrode while the current flows through it during welding.
12. . Proper coating ingredients produce weld metals resistant to hot and cold cracking.Suitable coating will improve metal deposition rates.

6.5 Submerged arc Welding

Schematic submerged arc welding process is shown in Fig. 6.5.1. In this welding process, a consumable bare electrode is used in combination with a flux feeder tube.

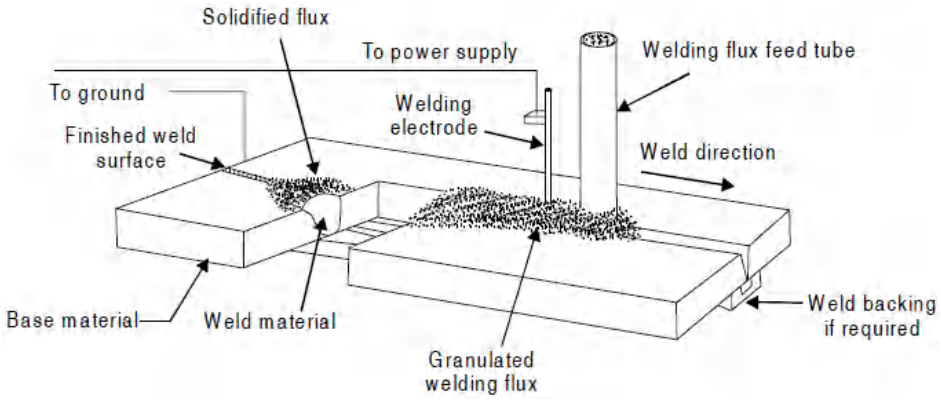


Fig. 6.5.1 Schematic submerged arc welding process

The submerged arc welding process is similar to the gas metal arc welding process except the arc is struck under a blanket of granular flux, hence the name submerged arc welding. The filler metal is a continuously-fed wire electrode like GMAW and FCAW. However, higher deposition

rates can be achieved in SAW by using larger diameter electrodes (up to 1/4") and higher currents (650-1500 Amperes). Since the process is almost fully mechanized, several variants of the process can be utilized such as multiple torches and narrow gap welding. The arc, end of the bare electrode and molten pool remain completely submerged under blanket of granular flux. The feed of electrode and tube is automatic and the welding is homogenous in structure. No pressure is applied for welding purposes. This process is used for welding low carbon steel, bronze, nickel and other non-ferrous materials. SAW has the highest deposition rate of all the deep penetrating arc welding processes making it ideal for thick section and multi-pass welding. Variations of the process can utilize dual arc welding, twin arc welding, multiple torch, and narrow groove welding to increase productivity. Since the arc is completely submerged in the flux, there is no arc radiation. Screens or light filtering lenses are not needed. Additionally, the smoke and fumes are trapped within the flux and thus minimizing smoke and fumes.

Advantages schematic submerged arc welding process

- High deposition rates
- No arc flash or glare
- Minimal smoke and fumes
- Flux and wire added separately - extra dimension of control
- Easily automated
- Joints can be prepared with narrow grooves
- Can be used to weld carbon steels, low alloy steels, stainless steels, chromium-molybdenum steels, nickel base alloys

There are some limitations with the process, however. The flux which shields the arc and weld pool in SAW also obstructs the operator's view of the joint and molten weld pool. This makes observation of the pool and joint impossible during welding; thus, correction of problems during welding can be very difficult. Because of the high current levels common to this process, it is normally not suited for thinner materials. Due to the presence of a granulated flux, submerged arc welding is limited to the flat and horizontal positions. As with SMAW and FCAW, SAW produces a slag which must be completely removed after each pass.

Disadvantages schematic submerged arc welding process

- Flux obstructs view of joint during welding
- Flux is subject to contamination of porosity
- Normally not suitable for thin material
- Restricted to the flat position for grooves - flat and horizontal for fillets
- Slag removal required
- Flux handling equipment.

6.6 Gas Metal ARC Welding (GMAW) or Metal Inert Gas Welding (MIG)

Metal inert gas arc welding (MIG) or more appropriately called as gas metal arc welding (GMAW) utilizes a consumable electrode and hence, the term metal appears in the title. There are other gas shielded arc welding processes utilizing the consumable electrodes, such as flux cored arc welding (FCAW) all of which can be termed under MIG. Though gas tungsten arc welding (GTAW) can be used to weld all types of metals, it is more suitable for thin sheets. MIG

welding is operated in semiautomatic, machine, and automatic modes. All commercially important metals may be able to welded with this process in all positions by choosing the appropriate shielding gas, electrode, and welding conditions. When thicker sheets are to be welded, the filler metal requirement makes GTAW difficult to use. In this situation, the GMAW comes handy. The typical setup for GMAW or MIG welding process is shown in Fig. 6.6.1. The consumable electrode is in the form of a wire reel which is fed at a constant rate, through the feed rollers. The welding torch is connected to the gas supply cylinder which provides the necessary inert gas. The electrode and the work-piece are connected to the welding power supply. The power supplies are always of the constant voltage type only. The current from the welding machine is changed by the rate of feeding of the electrode wire. Normally DC arc welding machines are used for GMAW with electrode positive (DCRP). The DCRP increases the metal deposition rate and also provides for a stable arc and smooth electrode metal transfer. With DCSP, the arc becomes highly unstable and also results in a large spatter. But special electrodes having calcium and titanium oxide mixtures as coatings are found to be good for welding steel with DCSP. In the GMAW process, the filler metal is transferred from the electrode to the joint. Depending on the current and voltage used for a given electrode, the metal transfer is done in different ways.

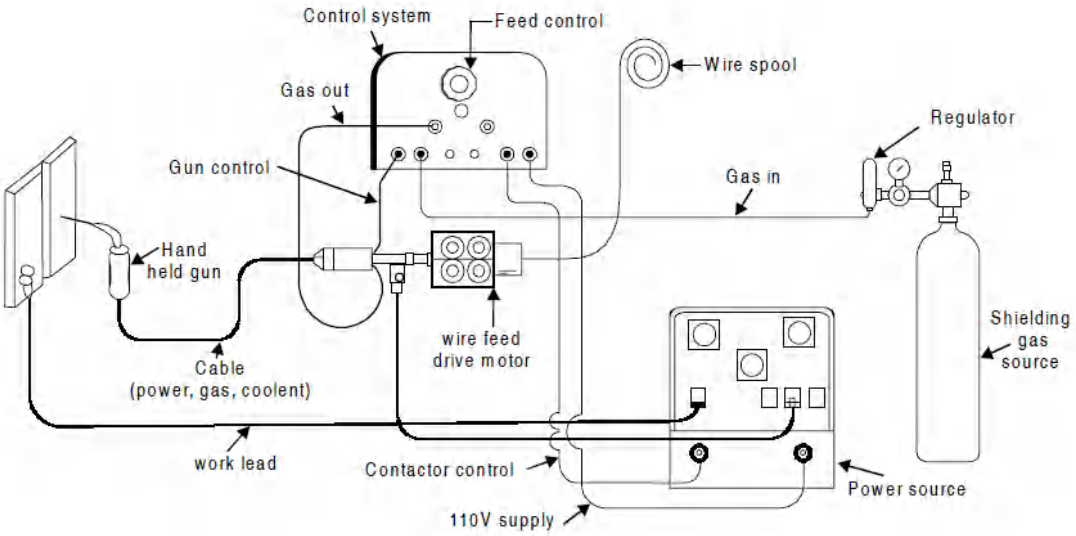


Fig. 6.6.1 Gas metal arc welding (GMAW) set up

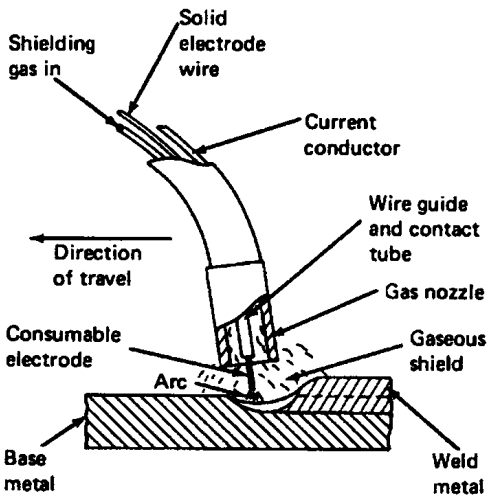


Fig.6.6.2 Details of GMAW process

Power

Most applications of gas metal arc welding use a constant voltage power supply. As a result, any change in arc length (which is directly related to voltage) results in a large change in heat input and current. A shorter arc length causes a much greater heat input, which makes the wire electrode melt more quickly and thereby restore the original arc length. This helps operators keep the arc length consistent even when manually welding with hand-held welding guns. To achieve a similar effect, sometimes a constant current power source is used in combination with an arc voltage-controlled wire feed unit. In this case, a change in arc length makes the wire feed rate adjust to maintain a relatively constant arc length. In rare circumstances, a constant current power source and a constant wire feed rate unit might be coupled, especially for the welding of metals with high thermal conductivities, such as aluminum. This grants the operator additional control over the heat input into the weld, but requires significant skill to perform successfully.

Alternating current is rarely used with GMAW; instead, direct current is employed and the electrode is generally positively charged. Since the anode tends to have a greater heat concentration, these results in faster melting of the feed wire, which increases weld penetration and welding speed? The polarity can be reversed only when special emissive-coated electrode wires are used, but since these are not popular, a negatively charged electrode is rarely employed.

Electrode

Electrode selection is based primarily on the composition of the metal being welded, the process variation being used, joint design and the material surface conditions. Electrode selection greatly influences the mechanical properties of the weld and is a key factor of weld quality. In general the finished weld metal should have mechanical properties similar to those of the base material with no defects such as discontinuities, entrained contaminants or porosity within the weld. To achieve these goals a wide variety of electrodes exist. All commercially available electrodes contain deoxidizing metals such as silicon, manganese, titanium and aluminum in small percentages to help prevent oxygen porosity. Some contain denitriding metals such as titanium and zirconium to avoid nitrogen porosity. Depending on the process variation and base material being welded the diameters of the electrodes used in GMAW typically range from 0.7 to 2.4 mm but can be as large as 4 mm. The smallest electrodes, generally up to 1.14 mm are associated with the short-circuiting metal transfer process, while the most common spray-transfer process mode electrodes are usually at least 0.9 mm.

Shielding gas

Shielding gases are necessary for gas metal arc welding to protect the welding area from atmospheric gases such as nitrogen and oxygen, which can cause fusion defects, porosity, and weld metal embrittlement if they come in contact with the electrode, the arc, or the welding metal. This problem is common to all arc welding processes; for example, in the older Shielded-Metal Arc Welding process (SMAW), the electrode is coated with a solid flux which evolves a protective cloud of carbon dioxide when melted by the arc. In GMAW, however, the electrode wire does not have a flux coating, and a separate shielding gas is employed to protect the weld. This eliminates slag, the hard residue from the flux that builds up after welding and must be chipped off to reveal the completed weld.

The choice of a shielding gas depends on several factors, most importantly the type of material being welded and the process variation being used. Pure inert gases such as argon and helium are only used for nonferrous welding; with steel they do not provide adequate weld penetration (argon) or cause an erratic arc and encourage spatter (with helium). Pure carbon dioxide, on the other hand, allows for deep penetration welds but encourages oxide formation, which adversely affect the mechanical properties of the weld. lts low cost makes it an attractive choice, but because of the reactivity of the arc plasma, spatter is unavoidable and welding thin materials is difficult. As a result, argon and carbon dioxide are frequently mixed in a 75%/25% to 90%/10% mixture. Generally, in short circuit GMAW, higher carbon dioxide content increases the weld heat and energy when all other weld parameters (volts, current, electrode type and diameter) are held the same. As the carbon dioxide content increases over 20%, spray transfer GMAW becomes increasingly problematic, especially with smaller electrode diameters.

Argon is also commonly mixed with other gases, oxygen, helium, hydrogen, and nitrogen. The addition of up to 5% oxygen (like the higher concentrations of carbon dioxide mentioned above) can be helpful in welding stainless steel, however, in most applications carbon dioxide is preferred. Increased oxygen makes the shielding gas oxidize the electrode, which can lead to porosity in the deposit if the electrode does not contain sufficient deoxidizers. Excessive oxygen, especially when used in application for which it is not prescribed, can lead to brittleness in the heat affected zone. Argon-helium mixtures are extremely inert, and can be used on nonferrous materials. A helium concentration of 50%–75% raises the required voltage and increases the heat in the arc, due to helium's higher ionization temperature. Hydrogen is sometimes added to argon in small concentrations (up to about 5%) for welding nickel and thick stainless steel workpieces. In higher concentrations (up to 25% hydrogen), it may be used for welding conductive materials such as copper. However, it should not be used on steel, aluminum or magnesium because it can cause porosity and hydrogen embrittlement.

Shielding gas mixtures of three or more gases are also available. Mixtures of argon, carbon dioxide and oxygen are marketed for welding steels. Other mixtures add a small amount of helium to argon-oxygen combinations, these mixtures are claimed to allow higher arc voltages and welding speed. Helium also sometimes serves as the base gas, with small amounts of argon and carbon dioxide added. However, because it is less dense than air, helium is less effective at shielding the weld than argon-which is denser than air. It also can lead to arc stability and penetration issues, and increased spatter, due to its much more energetic arc plasma. Helium is also substantially more expensive than other shielding gases. Other specialized and often proprietary gas mixtures claim even greater benefits for specific applications. The desirable rate of shielding-gas flow depends primarily on weld geometry, speed, current, the type of gas, and the metal transfer mode. Welding flat surfaces requires higher flow than welding grooved materials, since gas disperses more quickly. Faster welding speeds, in general, mean that more gas must be supplied to provide adequate coverage. Additionally, higher current requires greater flow, and generally, more helium is required to provide adequate coverage than if argon is used. Perhaps most importantly, the four primary variations of GMAW have differing shielding gas flow requirements—for the small weld pools of the short circuiting and pulsed spray modes,

about 10 L/min is generally suitable, whereas for globular transfer, around 15 L/min is preferred. The spray transfer variation normally requires more shielding-gas flow because of its higher heat input and thus larger weld pool. Typical gas-flow amounts are approximately 20–25 L/min.

Metal Transfer

Filler metal can be transferred from the electrode to the work in two ways: when the electrode contacts the molten weld pool, thereby establishing a short circuit, which is known as short circuiting transfer (short circuiting arc welding); and when discrete drops are moved across the arc gap under the influence of gravity or electromagnetic forces. Drop transfer can be either globular or spray type.

Shape, size, direction of drops (axial or nonaxial), and type of transfer are determined by a number of factors. The factors having the most influence are:

1. Magnitude and type of welding current
2. Current density
3. Electrode composition
4. Electrode extension
5. Shielding gas
6. Power supply characteristics.

Axially directed transfer refers to the movement of drops along a line that is a continuation of the longitudinal axis of the electrode. Nonaxially directed transfer refers to movement in any other direction.

Short Circuiting Transfer

Short circuiting arc welding uses the lowest range of welding currents and electrode diameters associated with MIG welding. This type of transfer produces a small, fast-freezing weld pool that is generally suited for the joining of thin sections, out-of-position welding, and filling of large root openings. When weld heat input is extremely low, plate distortion is small. Metal is transferred from the electrode to the work only during a period when the electrode is in contact with the weld pool. There is no metal transfer across the arc gap. The electrode contacts the molten weld pool at a steady rate in a range of 20 to over 200 times each second. As the wire touches the weld metal, the current increases. It would continue to increase if an arc did not form. The rate of current increase must be high enough to maintain a molten electrode tip until filler metal is transferred. It should not occur so fast that it causes spatter by disintegration of the transferring drop of filler metal. The rate of current increase is controlled by adjustment of the inductance in the power source. The value of inductance required depends on both the electrical resistance of the welding circuit and the temperature range of electrode melting. The open circuit voltage of the power source must be low enough so that an arc cannot continue under the existing welding conditions. A portion of the energy for arc maintenance is provided by the inductive storage of energy during the period of short circuiting.

As metal transfer only occurs during short circuiting, shielding gas has very little effect on this type of transfer. Spatter can occur. It is usually caused either by gas evolution or electromagnetic forces on the molten tip of the electrode.

Globular Transfer

With a positive electrode (dcrp), globular transfer takes place when the current density is relatively low, regardless of the type of shielding gas. However, carbon dioxide (CO2) shielding yields this type of transfer at all usable welding currents. Globular transfer is characterized by a drop size of greater diameter than that of the electrode. Globular, axially directed transfer can be achieved in a substantially inert gas shield without spatter. The arc length must be long enough to assure detachment of the drop before it contacts the molten metal. However, the resulting weld is likely to be unacceptable because of lack of fusion, insufficient penetration, and excessive reinforcement. Carbon dioxide shielding always yields nonaxially directed globular transfer. This is due to electromagnetic repulsive force acting upon the bottom of the molten drops. Flow of electric current through the electrode generates several forces that act on the molten tip. The most important of these are pinch force and anode reaction force. The magnitude of the pinch force is a direct function of welding current and wire diameter, and is usually responsible for drop detachment. With CO2 shielding, the wire electrode is melted by the arc heat conducted through the molten drop. The electrode tip is not enveloped by the arc plasma. The molten drop grows until it detaches by short circuiting or gravity.

Spray Transfer

In a gas shield of at least 80 percent argon or helium, filler metal transfer changes from globular to spray type as welding current increases for a given size electrode. For all metals, the change takes place at a current value called the globular-to-spray transition current. Spray type transfer has a typical fine arc column and pointed wire tip associated with it. Molten filler metal transfers across the arc as fine droplets. The droplet diameter is equal to or less than the electrode diameter. The metal spray is axially directed. The reduction in droplet size is also accompanied by an increase in the rate of droplet detachment, as illustrated in figure 10-47. Metal transfer rate may range from less than 100 to several hundred droplets per second as the electrode feed rate increases from approximately 100 to 800 in./min (42 to 339 mm/s).

The GMAW process enjoys widespread use because of its ability to provide high quality welds, for a wide range of ferrous and non-ferrous alloys, at a low price.

GMAW also has the following advantages:-

- The ability to join a wide range of material types and thicknesses. Receive
- Simple equipment components are readily available and affordable.
- GMAW has higher electrode efficiencies, usually between 93% and 98%, when compared to other welding processes.
- Higher welder efficiencies and operator factor, when compared to other open arc welding processes.
- GMAW is easily adapted for high-speed robotic, hard automation and semiautomatic welding applications.
- All-position welding capability.
- Excellent weld bead appearance.
- Lower hydrogen weld deposit — generally less than 5 mL/100 g of weld metal.
- Lower heat input when compared to other welding processes.
- A minimum of weld spatter and slag makes weld clean up fast and easy.

- Less welding fumes when compared to SMAW (Shielded Metal Arc Welding) and FCAW (Flux-Cored Arc Welding) processes.
- Generally, lower cost per length of weld metal deposited when compared to other open arc welding processes.
- Lower cost electrode.
- Less distortion with GMAW-P (Pulsed Spray Transfer Mode), GMAW-S (Short-Circuit Transfer Mode) and STT (Surface Tension Transfer).
- Handles poor fit-up with GMAW-S and STT modes.
- Reduced welding fume generation.
- Minimal post-weld cleanup.

Limitations of GMAW

- The lower heat input characteristic of the short-circuiting mode of metal transfer restricts its use to thin materials.
- The higher heat input axial spray transfer generally restricts its use to thicker base materials.
- The higher heat input mode of axial spray is restricted to flat or horizontal welding positions.
- The use of argon based shielding gas for axial spray and pulsed spray transfer modes is more expensive than 100% carbon dioxide (CO2).

Self Test

1. What is welding? How is it classified?
2. What are the advantages, disadvantages and applications of welding joints over other joints?
3. Explain the various types of joints commonly used in welding.
4. Explain the different kinds of welding positions with neat sketch.
5. Using neat sketch show the various standard location of elements of a welding symbol.
6. Classify the various welding processes in detail. Describe each in brief.
7. What effect does welding have on the grain-size of a metal? What effect will pre-heating have on the microstructure of the weld-area in high carbon steel? Show it with the help of neat diagram.
8. How is gas welding performed? How is the flame adjusted?
9. Sketch the three types of gas welding flames and give differences between them.
10. Give the advantages, limitations and applications of gas welding?
11. Describe gas welding techniques in detail?
12. What procedure and care will you follow in operating?
    I. A low pressure plant
    II. A high pressure plant.
13. How will you obtain neutral, oxidizing and reducing flames using welding torch in gas welding?
14. What are the main requirements of a good flux used in gas welding?
15. What is a gas welding rod?
16. Give the complete procedure of gas welding. Compare high pressure and low pressure gas welding.
17. Sketch an oxygen cylinder. How does it differ from acetylene cylinder?

18. How will you generate and store acetylene gas?
19. Sketch a single stage pressure reduction regulator and explain its working.
20. Define electric arc welding. Discuss with the help of neat sketch, the principle of arc welding.
21. What is straight polarity and reverse polarity? Give a list of equipments required in general for electric arc welding.
22. Explain the principle of arc-welding.
23. What do you understand by the term polarity?
24. What is the advantage of having different polarities?
25. Compare the merits and demerits of using A.C and D.C for arc welding.
26. Describe briefly the methods of carbon arc and metallic arc welding.
27. Compare A.C. power source welding with D.C. power source welding. Explain the principle of atomic hydrogen welding.

Chapter Seven

7. Non-Consumable Electrode Welding (TIG Welding, and Plasma arc Welding)

Non-Consumable Electrode Welding process that uses a non-consumable electrode made of tungsten, an inert or semi-inert gas mixture, and a separate filler material. Especially useful for welding thin materials, this method is characterized by a stable arc and high quality welds, but it requires significant operator skill and can only be accomplished at relatively low speeds. It can be used on nearly all weldable metals, though it is most often applied to stainless steel and light metals. It is often used when quality welds are extremely important, such as aircraft and naval applications.

Gas tungsten welding (**GTAW**), also known as **tungsten inert gas** (**TIG**) **welding**, is an arc welding process that uses a non-consumable tungsten electrode to produce the weld. TIG is an arc welding process that uses an arc between a tungsten electrode and the weld pool. The process is used with shielding gas and without the application of pressure. The process may be used with or without the addition of filler metal. Fig.7.1 shows the gas tungsten arc welding process.

TIG has become indispensable as a tool for many industries because of the high-quality welds produced and low equipment costs. The purpose of this chapter is to discuss the fundamentals of the GTAW process, the equipment and consumables used the process procedures and variables, applications, and safety considerations.

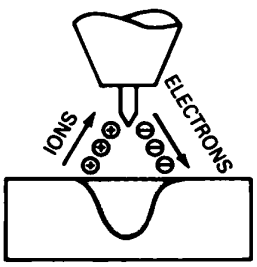
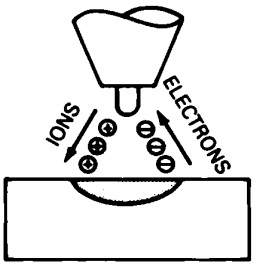
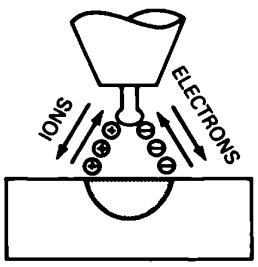
The possibility of using helium to shield a welding arc and molten weld pool was first investigated in the 1920's. However, nothing was done with this method until the beginning of World War II when a great need developed in the aircraft industry to replace riveting for joining reactive materials such as aluminium and magnesium. Using a tungsten electrode and direct current arc power with the electrode negative, a stable, efficient heat source was produced with which excellent welds could be made.

Helium was elected to provide the necessary shield because, at the time, it was the only readily available inert gas. The process has been called non-consumable electrode welding and TIG (tungsten inert gas) welding. However, the AWS terminology for this process is TIG, because shielding gas mixtures which are not inert can be used for certain applications.

Since the early days of the invention, numerous improvements have been made to the process and equipment. Welding power sources have been developed specifically for the process. Some provide pulsed dc and variable polarity ac welding power. Water-cooled and gas-cooled torches were developed. The tungsten electrode has been alloyed with small amounts of active elements to increase its emissivity; this has improved arc starting, arc stability, and electrode life. Shielding gas mixtures have been identified for improved welding performance. Researchers are presently pursuing further improvements, in such areas as automatic controls, vision and penetration sensors, and arc length controls.

The heat-affected zone, the molten metal, and the tungsten electrode are all shielded from the atmosphere by a blanket of inert gas fed through the TIG torch. Inert gas is that which is inactive, or deficient in active chemical properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air. It does not burn, and adds nothing to or takes anything from the metal. Inert gases such as argon and helium do not chemically react or combine with other gases. They possess no odor and are transparent, permitting the welder maximum visibility of the arc. In some instances a small amount of reactive gas such as hydrogen can be added to enhance travel speeds. The TIG process can produce temperatures of up to 19,426° C. The torch contributes only heat to the workpiece. If filler metal is required to make the weld, it may be added manually in the same manner as it is added in the oxyacetylene welding process. There are also a number of filler metal feeding systems available to accomplish the task automatically. Figure shows the essentials of the manual TIG process.

Characteristics of current types for GTAW

CURRENT TYPE	DCEN	DCEP	AC (BALANCED)
ELECTRODE POLARITY	NEGATIVE	POSITIVE	
ELECTRON AND ION FLOW PENETRATION CHARACTERISTICS			
OXIDE CLEANING ACTION	NO	YES	YES-ONCE EVERY HALF CYCLE
HEAT BALANCE IN THE ARC (APPROX.)	70% AT WORK END 30% AT ELECTRODE END	30% AT WORK END 70% AT ELECTRODE END	50% AT WORK END 50% AT ELECTRODE END
PENETRATION	DEEP; NARROW	SHALLOW: WIDE	MEDIUM
ELECTRODE CAPACITY	EXCELLENT e.g., 1/8 in. (3.2 mm) 400 A	POOR e.g., 1/4 in. (6.4 mm) 120 A	GOOD e.g., 1/8 in. (3.2 mm) 225 A

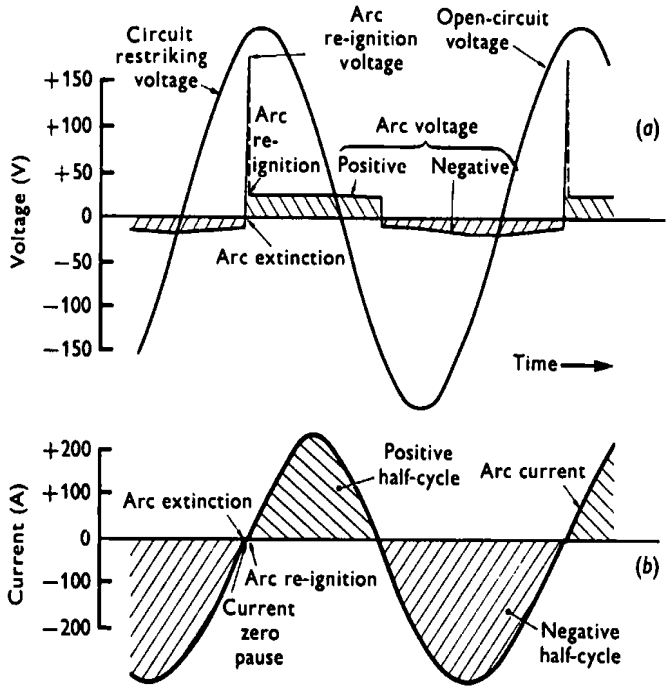


Fig..7.1.1 Basic waveforms of voltage and current for self re-ignition in tungsten arc welding (for clarity the duration of the arc reignition stage and current zero pause has been exaggerated). (a) Voltage record (b) Current record.

GTAW with DCEN produces deep penetration because it concentrates the heat in the joint area. No cleaning action occurs with this polarity. The heat generated by the arc using this polarity occurs in the workpiece, thus a smaller electrode can be used as well as a smaller gas cup and reduced gas flow. The more concentrated arc allows for faster travel speeds.

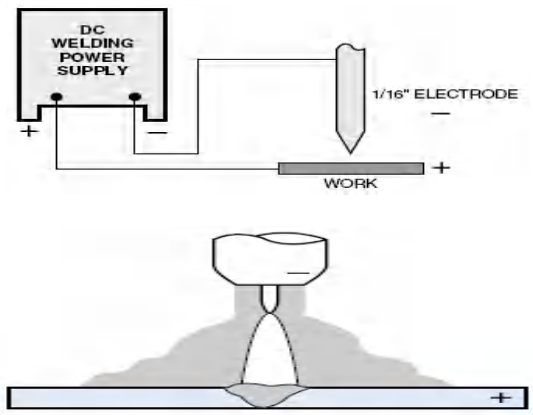


Fig.7.2 Direct current electrode negative

GTAW with DCEP produces good cleaning action as the argon gas ions flowing toward the work strike with sufficient force to break up oxides on the surface. Since the electrons flowing toward the electrode cause a heating effect at the electrode, weld penetration is shallow. Because of the lack of penetration and the required use of very large tungsten, continuous use of this polarity is rarely used for GTAW.

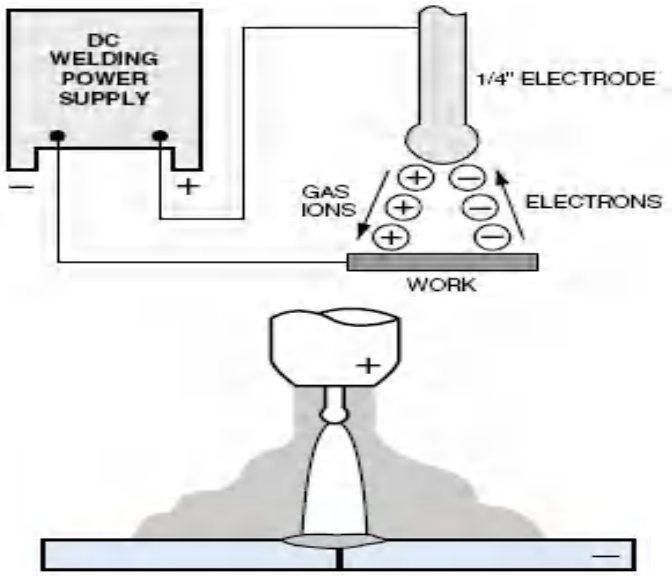


Fig.7.3 Direct Current Electrode Positive

GTAW with AC combines the good weld penetration of DCEN with the desired cleaning action of DCEP. With certain types of AC waveforms high frequency helps re-establish the arc, which breaks each half cycle. Medium size tungstens are generally used with this process.

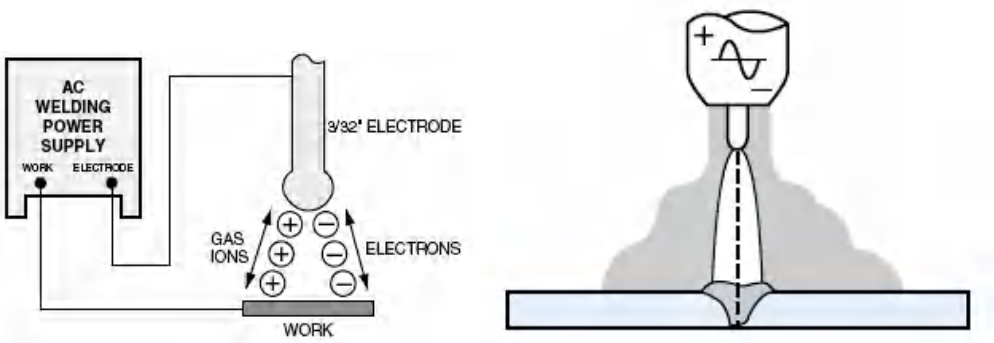


Fig.7.3 Nature of current on weld bead

Table 7.1 Arc rectification

Indicators for the Welder	Results	Cures*
Arc noise	Tungsten inclusions	Don't dwell in the weld pool
Weld pool oscillation	Erratic arc	Add filler metal
Tungsten electrode breakdown	Lack of cleaning action	Keep arc moving along weld joint

Shielding Gases

Argon

Argon has low thermal conductivity which means it is not a good conductor of heat. This results in a more compact, higher density arc. Arc density refers to the concentration of energy in the

arc. With argon this energy is confined to a narrow or more “pinpointed” area. Argon provides excellent arc stability and cleaning action even at low amperages

HELIUM

Unlike argon, helium has high thermal conductivity. Due to this higher thermal conductivity, the arc column expands, reducing current density in the arc. The arc column will become wider and more flared out than the arc column with argon shielding gas. Because of its higher ionization potential, it is more difficult to start an arc with helium shielding gas, especially at lower amperages. Argon is used almost exclusively when welding at 150 amps and lower. Because helium is a light gas, flow rates are usually two or three times higher than argon for equivalent shielding. The cost of helium is considerably more than argon, and with the increased flow rate, total cost of shielding goes up sharply. The cost must be weighed against increased penetration on thick material and the increased travel speed attainable.

Hydrogen

Just as helium is mixed with argon to take advantage of the best features of both gases, hydrogen is mixed with argon to further constrict the arc and produce a cleaner weld with a greater depth to width ratio (penetration). This mix is used primarily for welding austenitic stainless steel and some nickel alloys. The addition of hydrogen to argon also increases travel speed. It should be noted that an argon hydrogen mix will introduce the risk of hydrogen cracking and metal porosity particularly in multipass welds.

Nitrogen

Nitrogen when mixed with argon provides the capability of producing more energy to the work than with argon alone. This can be particularly beneficial when welding materials of high conductivity such as copper. However, a nitrogen mix cannot be used on ferrous metals such as steel and stainless steel because nitrogen pick up in the weld pool causes a significant reduction in strength and a weaker, more porous bead.

Materials

Gas tungsten arc welding is most commonly used to weld stainless steel and nonferrous materials, such as aluminum and magnesium, but it can be applied to nearly all metals, with a notable exception being zinc and its alloys. Its applications involving carbon steels are limited not because of process restrictions, but because of the existence of more economical steel welding techniques, such as gas metal arc welding and shielded metal arc welding. Furthermore, GTAW can be performed in a variety of other-than-flat positions, depending on the skill of the welder and the materials being welded.

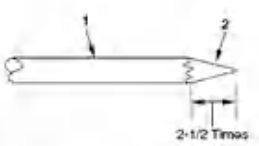
Preparing Mild Steel for Welding

Mild steel should always be mechanically cleaned prior to welding. Rust, paint, oil and grease, or any surface contaminants should be removed. Hot-rolled products such as angle iron, plate, and pipe may contain a heavy mill scale. For best results, remove scale prior to welding. Black pipe usually contains a varnish type coating, which should be removed before welding. Low carbon

steels, commonly referred to as mild steels, are readily welded by the GTAW process. These groups of steels are available in many different alloys and types. The familiar structural shapes, plates, and hot rolled sheet metal are usually comprised of what is termed “semi-killed steel”. This term means the steel has been partially deoxidized during manufacture. The steel, however, still contains some oxygen, and this oxygen can cause problems when welding. These problems will appear in the form of bubbles in the weld pool, and possibly in the finished weld bead. “Killed steel” has had more oxygen removed in its manufacture, and presents less of a problem when welding. A filler wire containing sufficient silicon and manganese, added as deoxidizers, is necessary. Lower grade filler rods used for oxyacetylene welding of many hot rolled products are not suitable for making high-quality GTAW welds.

Electrode

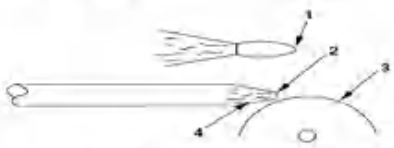
The electrode used inTIG is made of tungsten or a tungsten alloy, because tungsten has the highest melting temperature among pure metals, at 3,422 °C (6,192 °F). As a result, the electrode is not consumed during welding, though some erosion (called burn-off) can occur. Electrodes can have either a clean finish or a ground finish—clean finish electrodes have been chemically cleaned, while ground finish electrodes have been ground to a uniform size and have a polished surface, making them optimal for heat conduction. The diameter of the electrode can vary between 0.5 and 6.4 millimetres (0.02 and 0.25 in), and their length can range from 75 to 610 millimetres (3.0 to 24.0 in). for further information we have look the following figures and tables.



Elctrode Diameter

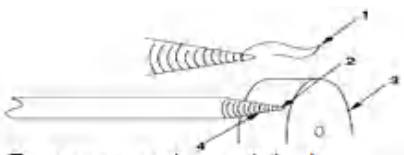
1. Tungsten
2.Tapered End

Grind end of tungsten on fine grit, hard abrasive wheel before welding. Do not use wheel of other jobs or tungsten can become contaminated causing lower weld qaulity



Ideal Tungsten Preparation-Stable

1. Stable Arc
2. Flat
3. Grinding wheel
4. Straight Ground



Wrong Tugesten preparaation- wandering Arc

1. Arc wander
2. point
3. Grinding wheel
4. Radical Ground

The ball diameter should never exceed 1.5 times the electrode diameter

	This pure tungsten was used with alternating current with a sine Wave power source on aluminum. Notice the end is uniform in shape and possesses a "shiny bright" appearance
	is a 2% Thoriated tungsten ground to a taper and was used with direct current ectrode negative, or a similar shape for Advanced Square wave applications
	is a 2% Thoriated tungsten used with an alternating current sine wave power source on aluminum. Note that this electrode has several small ball shaped projections rather than a round complete "ball end" like the pure tungsten
	is a pure tungsten used with alternating current sine wave power source or balance control set to excessive cleaning action on an AC wave controlled power source on aluminum. This electrode was subjected to a current above the rated capacity. Notice the "ball" started to droop to one side. It became very molten during operation and continuing to operate would have caused the molten end to drop into the weld pool

	is a pure tungsten that was tapered to a point and used on direct current electrode negative. Notice the "ball" tip characteristic of the pure tungsten. Pointing of pure tungsten is not recommended as the extreme point will always melt when the arc is established, and often times the molten tip will drop into the molten weld pool
	was severely contaminated by touching the filler rod to the tungsten. In this case, the contaminated area must be broken off and the electrode reshaped as desired
	did not have sufficient gas post flow. Notice the black surface which is oxidized because the atmosphere contacted the electrode before it cooled sufficiently. If this electrode were used, the oxidized surface will flake off and drop into the weld pool. Post flow time should be increased so the appearance is like electrode "A" after welding

PROBLEM 1: Burning Through Tungsten Fast	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Inadequate gas flow.	Check to be sure hose, gas valve, and torch are not restricted or the tank is not out of gas. Gas flow should typically be set at 15 to 20 cfh.
2. Operation on electrode positive (DCEP).	Switch to electrode negative (DCEN).
3. Improper size tungsten for current used.	General purpose tungsten size is 3/32" diameter at a maximum of 220 amps.
4. Excessive heating in torch body.	Air-cooled torches do get very warm. If using a water-cooled torch, coolant flow may be restricted or coolant may be low.
5. Tungsten oxidation during cooling.	Keep shielding gas flowing 10–15 seconds after arc stoppage. 1 second for each 10 amps of weld current.
6. Use of gas containing oxygen or CO_2.	Use argon gas.
7. Tungsten melting back into cup (AC).	If using pure tungsten, change to ceriated or lanthanated. If machine has Balance Control, adjust setting towards maximum penetration (70-90). Tungsten diameter may be too small for the amount of current being used. Increase tungsten size.

PROBLEM 2: Tungsten Contamination	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Tungsten melting into weld puddle.	Use less current or larger tungsten. Use ceriated (AC), thoriated (DC), or lanthanated tungsten.
2. Touching tungsten to weld puddle.	Keep tungsten from contacting weld puddle. Raise the torch so that the tungsten is off of the work piece 1/8" to 1/4".

PROBLEM 3: High-Frequency Present — No Arc Power	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Incomplete weld circuit.	Check work connection. Check all cable connections.
2. No shielding gas.	Check for gas flow at end of torch. Check for empty cylinder or closed shut-off valve. Gas flow should typically be set at 15 to 20 cfh.

PROBLEM 4: Porosity and Poor Weld Bead Color	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Condensation on base metal.	Blow out all air and moisture condensation from lines. Remove all condensation from base metal before welding. Metals stored in cold temperatures will condensate when exposed to warm temperatures.
2. Loose fittings in torch or hoses.	Tighten fittings on torch and all hoses.
3. Inadequate gas flow.	Adjust flow rate as necessary. Gas flow should typically be set at 15 to 20 cfh.
4. Defective gas hose or loose connection.	Replace gas hose and check connections for leaks, cuts, or pin holes.
5. Contaminated or improper filler metal.	Check filler metal type. Remove all grease, oil, or moisture from filler metal.
6. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.

PROBLEM 5: Yellow Powder or Smoke on Cup—Tungsten Discolor	
PROBABLE CAUSES	SUGGESTED REMEDY
1. Shielding gas flow rate too low.	Increase flow rate. Gas flow should typically be set at 15 to 20 cfh.
2. Incorrect shielding gas or mixture.	Use argon gas.
3. Inadequate post flow.	Increase post flow time. Set at 10 to 15 seconds.
4. Improper tungsten size or cup size.	Match tungsten size and cup size to joint being welded. General purpose tungsten size is 3/32" diameter and #8 cup.

PROBLEM 6: Unstable Arc	
PROBABLE CAUSES	SUGGESTED REMEDY
While AC Welding	
1. Excessive rectification in base metal.	Increase travel speed. Increase balance control toward more penetration. Add filler metal.
2. Improper shielding gas.	In some cases, when welding on 3/8" to 1/2" thick aluminum, argon/helium is used.
3. Incorrect arc length.	Use correct arc length. Adjust the torch so that the tungsten is off of the work piece 1/8" to 1/4".
4. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
5. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.
6. Frequency set too low.	On welders with adjustable AC frequency, increase frequency to give proper arc stability and direction. 100 to 180 Hertz is acceptable.
7. Improperly prepared tungsten.	With Squarewave and inverter machines, use pointed tungsten. Point will eventually round off after welding.

PROBLEM 6: Unstable Arc	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. Weld circuit polarity is incorrect.	Check polarity switch on welder. Select DCEN (Direct Current Electrode Negative).
2. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
3. Arc too long.	Shorten arc length. Lower torch so that the tungsten is off of the work piece no more than 1/8" to 1/4".
4. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.

PROBLEM 7: Arc Wanders	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. Improper arc length/tungsten in poor condition.	Lower the torch so that the tungsten is off of the work piece 1/8" to 1/4". Clean and sharpen tungsten.
2. Improperly prepared tungsten.	Grind marks should run lengthwise with tungsten, not circular. Use proper grinding method and wheel.
3. Light gray frosted appearance on end of tungsten.	Remove 1/2" of tungsten and repoint tungsten.
4. Improper gas flow.	Gas flow should typically be set at 15 to 20 cfh.
While AC Welding	
1. Improper tungsten preparation.	With Squarewave and inverter machines, use pointed tungsten. Point will eventually round off after welding.
2. Tungsten is contaminated.	Remove 1/2" of contaminated tungsten and repoint tungsten.
3. Base metal is contaminated.	Remove paint, grease, oil, and dirt, including mill scale from base metal.
4. Incorrect balance control setting.	Increase balance toward more penetration. Normal Balance Control setting is 70 - 90.
5. Improper tungsten size and type.	Select proper size and type. General purpose tungsten size is 3/32" diameter and ceriated or thoriated.
6. Excessive rectification in base metal.	Increase travel speed. Increase balance setting toward more penetration. Add filler metal.
7. Improper shielding gas flow.	Gas flow should typically be set at 15 to 20 cfh.
8. Frequency set too low.	Increase AC frequency on machines so equipped to stabilize and direct the arc. The higher the frequency, the narrower and deeper the penetration.

PROBLEM 8: Arc Will Not Start or is Difficult to Start	
PROBABLE CAUSES	SUGGESTED REMEDY
While DC Welding	
1. No shielding gas.	Gas flow should typically be set at 15 to 20 cfh.
2. Incorrect power supply switch positions.	Place switches in proper positions, either HF impulse or start HF.
3. Improper tungsten electrode.	Use ceriated or thoriated tungsten.
4. Loose connections.	Tighten all cable and torch connections.
5. Incomplete weld circuit.	Make sure work clamp is connected.
6. Improper tungsten size.	Use smallest tungsten possible. Most common tungsten size is 3/32" diameter.
While AC Welding	
1. Incomplete weld circuit.	Check work clamp to assure it is securely fastened to work.
2. Incorrect cable installation.	Check circuit breakers and fuses. Check and tighten all cable connections.
3. No shielding gas.	Check for gas flow at end of torch. Check for empty cylinder or closed shut-off valve. Gas flow should typically be set at 15 to 20 cfh.
4. Loss of high frequency.	Check torch and cables for cracked insulation or bad connections. Check spark gaps and adjust if necessary.
5. Improper tungsten size.	Use smallest tungsten possible. Most common tungsten size is 3/32" diameter.
6. Incorrect tungsten type.	Use ceriated, thoriated, or lanthanated tungsten.

Process Description

The TIG process is illustrated in Fig.7.1. The process uses a non-consumable tungsten (or tungsten alloy) electrode held in a torch. Shielding gas is fed through the torch to protect the

electrode, molten weld pool, and solidifying weld metal from contamination by the atmosphere. The arc is produced by the passage of current through the conductive, ionised shielding gas. The arc is established between the tip of the electrode and the work. Heat generated by the arc melts the base metal. Once the arc and weld pool are established, the torch is moved along the joint and the arc progressively melts the faying surfaces. Filler wire, if used, is usually added to the leading edge of the weld pool to fill the joint.

1. Torch
2. Electrode
3. Welding power source
4. Shielding gas

Process Advantages

The following are some advantages of the gas tungsten arc process:

1. It produces superior quality welds, generally free of defects.
2. It is free of the spatter, which occurs with other arc welding processes.
3. It can be used with or without filler metal as required for the specific application.
4. It allows excellent control of root pass weld penetration.
5. It can produce inexpensive autogenous welds at high speeds.
6. It can use relatively inexpensive power supplies.
7. It allows precise control of the welding variables.
8. It can be used to weld almost all metals, including dissimilar metal joints.
9. It allows the heat source and filler metal additions to be controlled independently.

Process Limitations

The following are some limitations of the gas tungsten arc process:

1. Deposition rates are lower than the rates possible with consumable electrode arc welding processes.
2. There is a need for slightly more dexterity and welder coordination than with gas metal arc welding or shielded metal arc welding for manual welding.
3. It is less economical than the consumable electrode arc welding processes for thicker sections greater than 3/8 in. (10 mm).
4. There is difficulty in shielding the weld zone properly in drafty environments.

Potential problems with the process include:

1. Tungsten inclusions can occur if the electrode is allowed to contact the weld pool.
2. Contamination of the weld metal can occur if proper shielding of the filler metal by the gas stream is not maintained.
3. There is low tolerance for contaminants on filler or base metals.
4. Possible contamination or porosity is caused by coolant leakage from water-cooled torches.
5. Arc blow or arc deflection, as with other processes.

Process Variables

The primary variables in TIG are arc voltage (arc length), welding current, travel speed, and shielding gas. The amount of energy produced by the arc is proportional to the current and

voltage. The amount transferred per unit length of weld is inversely proportional to the travel speed. The arc in helium is more penetrating than that in argon. However, because all of these variables interact strongly, it is impossible to treat them as truly independent variables when establishing welding procedures for fabricating specific joints.

Arc Current

As a general statement, arc current controls the weld penetration, the effect being directly proportional, if not somewhat exponential. Arc current also affects the voltage, with the voltage at a fixed arc length increasing in proportion to the current. For this reason, to keep a fixed arc length, it is necessary to change the voltage setting when the current is adjusted.

The process can be used with either direct or alternating current, the choice depending largely on the metal to be welded. Direct current with the electrode negative offers the advantages of deep penetration and fast welding speeds, especially when helium is used as the shield. Helium is the gas of choice for mechanised welding. Alternating current provides a cathodic cleaning (sputtering) which removes refractory oxides from the joint surfaces of aluminium and magnesium, allowing superior welds to be made. In this case, argon must be used for the shield because sputtering cannot be obtained with helium. Argon is the gas of choice for manual welding whether used with direct current or alternating current.

A third power option also is available, that of using direct current with the electrode positive. This polarity is used only rarely because it causes electrode overheating. These effects of polarity are explained in more detail in a following discussion of Direct Current.

Arc Voltage

The voltage measured between the tungsten electrode and the work is commonly referred to as the ‘arc voltage’. Arc voltage is a strongly dependent variable, affected by the following:

1. Arc current
2. Shape of the tungsten electrode tip
3. Distance between the tungsten electrode and the work
4. Type of shielding gas

The arc voltage is changed by the effects of the other variables, and is used in describing welding procedures only because it is easy to measure. Since the other variables such as the shield gas, electrode, and current have been predetermined, arc voltage becomes a way to control the arc length, a critical variable that is difficult to monitor. Arc length is important with this process because it affects the width of the weld pool; pool width is proportional to arc length. Therefore, in most applications other than those involving sheet, the desired arc length is as short as possible.

Of course, recognition needs to be given to the possibility of short circuiting the electrode to the pool or filler wire if the arc is too short. However, with mechanised welding, using a helium shield, DCEN power, and a relatively high current, it is possible to submerge the electrode tip below the plate surface to produce deeply penetrating but narrow welds at high speeds. This technique has been called buried arc. When arc voltage is being used to control arc length in critical applications, care must be taken to observe the other variables, which affect arc voltage. Among them are electrode and shielding gas contaminants, improperly fed filler wire,

temperature changes in the electrode, and electrode erosion. Should any of these change enough to affect the arc voltage during mechanised welding, the arc length must be adjusted to restore the desired voltage.

Travel Speed

Travel speed affects both the width and penetration of a gas tungsten arc weld. However, its effect on width is more pronounced than that on penetration. Travel speed is important because of its effect on cost. In some applications, travel speed is defined as an objective, with the other variables selected to achieve the desired weld configuration at that speed. In other cases, travel might be a dependent variable, selected to obtain the weld quality and uniformity needed under the best conditions possible with the other combination of variables. Regardless of the objectives, travel speed generally is fixed in mechanised welding while other variables such as current or voltage are varied to maintain control of the weld.

Wire feed

In manual welding, the way filler metal is added to the pool influences the number of passes required and the appearance of the finished weld. In machine and automatic welding, wire feed speed determines the amount of filler deposited per unit length of weld. Decreasing wire feed speed will increase penetration and flatten bead contour. Feeding the wire too slowly can lead to undercut, centreline cracking, and lack of joint fill. Increasing wire feed speed decreases weld penetration and produces a more convex weld.

Applications

The gas tungsten arc welding process is used with welding currents from 0.5 A up to 700~800 A and is one of the most versatile process of welding. The lowest currents are used with delicate air-cooled torches, to weld metal 0.05 mm thick. For these very low currents DCEN is usually used. A.c. is employed between 25 and 350 A, but above this current the risk of tungsten inclusions increases. Up to 800 A, DCEN is again used and these high currents are employed particularly for welding thick copper. Torches designed for up to about 100 A are entirely air cooled but for higher currents water-cooled torches must be used.

Although high welding currents permitting the welding of thick metal are possible, tungsten-arc welding is primarily a process for welding sheet metal or small parts. The process is at its best when welding single-pass or double-sided close butt joints, edge-joints or outside corner-joints. It is less suitable for fillet welds with which care must be taken to obtain good fusion into the root. Because it is so easily mechanised and gives high quality welds, the process is greatly favoured for precision welding in the aircraft, atomic energy and instrument industries. Circumferential and edge welds, for example, can-sealing joints, are very suitable for mechanised tungsten-arc welding. Arc-length control systems are sometimes used with mechanised welding in which the arc voltage provides a signal to raise or lower the welding head so that the arc can follow a curved or undulating surface.

Various automatic devices are available for welding tubes to tube-plates. Typical of these is the method in which a miniature torch revolves around a central spigot, which is fitted into the tube.

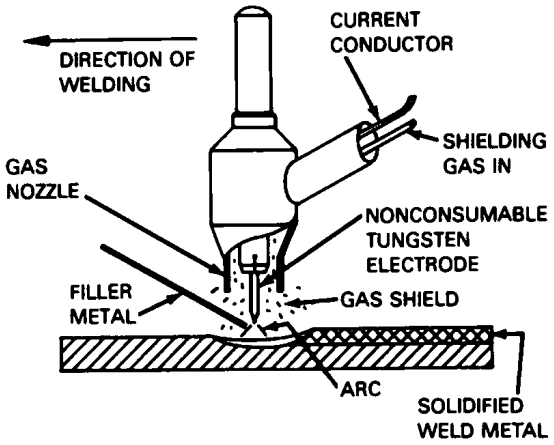


Fig.7.1-Gas Tungsten Arc Welding Operation

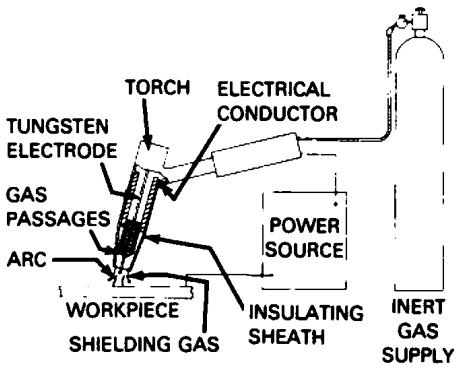


Fig.2-Gas Tungsten Arc Welding Equipment Arrangement

The heat-affected zone, the molten metal, and the tungsten electrode are all shielded from the atmosphere by a blanket of inert gas fed through the GTAW torch. Inert gas is that which is inactive, or deficient in active chemical properties. The shielding gas serves to blanket the weld and exclude the active properties in the surrounding air. It does not burn, and adds nothing to or takes anything from the metal. Inert gases such as argon and helium do not chemically react or combine with other gases. They possess no odor and are transparent, permitting the welder maximum visibility of the arc. In some instances a small amount of reactive gas such as hydrogen can be added to enhance travel speeds.

Self test.

In all the previous arc welding processes metal wire or electrodes material melts and droplets of metal deposit on the weldment. Some of that metal as it goes through the arc ionized into metal ions and electrons which conduct the electricity through the arc. In GTAW there are no metal ions (or very few metal ions) in the arc since the tungsten electrode is non-consumable. What carries the current in the GTAW arc?

7.2 Plasma Arc welds.

Plasma arc welding is an arc welding process wherein coalescence is produced by the heat obtained from a constricted arc setup between a tungsten/alloy tungsten electrode and the water-cooled (constricting) nozzle (non-transferred arc) or between a tungsten/alloy tungsten electrode and the job (transferred arc). The process employs two inert gases, one forms the arc plasma and the second shields the arc plasma. Filler metal may or may not be added as shown in fig.7.2.1.

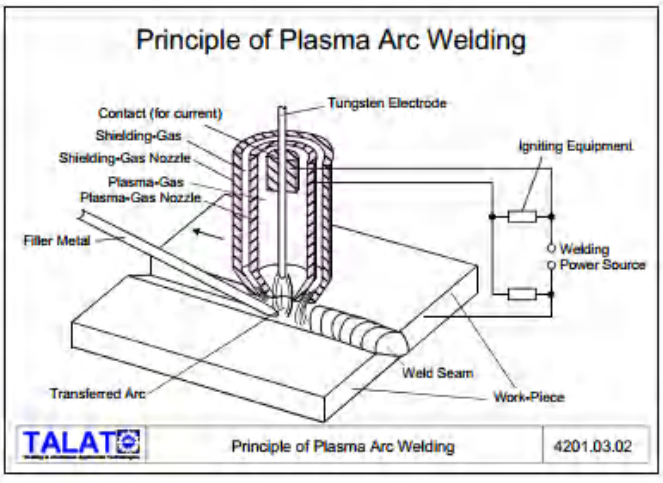


Fig. 72.1 Filler metal mechanism

History: The Plasma Arc welding and cutting process was invented by Robert M. Gage in 1953 and patented in 1957. The process was unique in that it could achieve precision cutting and welding on both thin and thick metals. It was also capable of spray coating hardening metals onto other metals. One example was the spray coating of the turbine blades of the moon bound Saturn rocket. Plasma arc welding is a constricted arc process. The arc is constricted with the help of a water-cooled small diameter nozzle which squeezes the arc, increases its pressure, temperature and heat intensely and thus improves arc stability, arc shape and heat transfer characteristics. Plasma arc welding process can be divided into two basic types:

A) Non-transferred arc process: The arc is formed between the electrode (-) and the water cooled constricting nozzle (+). Arc plasma comes out of the nozzle as a flame. The arc is independent of the work piece and the work piece does not form a part of the electrical circuit. Just as an arc flame (as in atomic hydrogen welding), it can be moved from one place to another and can be better controlled. The non transferred arc plasma possesses comparatively less energy density as compared to transferred arc plasma and it is employed for welding and in applications involving ceramics or metal plating (spraying). High density metal coatings can be produced by this process. A non-transferred arc is initiated by using a high frequency unit in the circuit.

B)Transferred arc process: The arc is formed between the electrode (-) and the work piece (+). In other words, arc is transferred from the electrode to the work piece. A transferred arc possesses high energy density and plasma jet velocity. For this reason it is employed to cut and melt metals. Besides carbon steels this process can cut stainless steel and nonferrous metals also where oxyacetylene torch does not succeed. Transferred arc can also be used for welding at high arc travel speeds. For initiating a transferred arc, a current limiting resistor is put in the circuit, which permits a flow of about 50 amps, between the nozzle and electrode and a pilot arc is

established between the electrode and the nozzle. As the pilot arc touches the job main current starts flowing between electrode and job, thus igniting the transferred arc. The pilot arc initiating unit gets disconnected and pilot arc extinguishes as soon as the arc between the electrode and the job is started. The temperature of a constricted plasma arc may be of the order of 8000 - 25000^0C. Three operating modes can be produced by varying bore diameter and plasma gas flow rate.

Microplasma: 0.1 to15A.
The microplasma arc can be operated at very low welding currents. The columnar arc is stable even when arc length is varied up to 20mm.

Medium current: 15 to 200A.
At higher currents, from 15 to 200A, the process characteristics of the plasma arc are similar to the TIG arc, but because the plasma is constricted, the arc is stiffer. Although the plasma gas flow rate can be increased to improve weld pool penetration, there is a risk of air and shielding gas entrainment through excessive turbulence in the gas shield.

Keyhole plasma: Over 100A.
By increasing welding current and plasma gas flow, a very powerful plasma beam is created which can achieve full penetration in a material, as in laser or electron beam welding. During welding, the hole progressively cuts through the metal with the molten weld pool flowing behind to form the weld bead under surface tension forces. This process can be used to weld thicker material (up to 10mm of stainless steel) in a single pass.

Power source
The plasma arc is normally operated with a DC, drooping characteristic power source. Because its unique operating features are derived from the special torch arrangement and separate plasma and shielding gas flows, a plasma control console can be added on to a conventional TIG power source. Purpose-built plasma systems are also available. The plasma arc is not readily stabilised with sine wave AC. Arc reignition is difficult when there is a long electrode to workpiece distance and the plasma is constricted, Moreover, excessive heating of the electrode during the positive half-cycle causes balling of the tip which can disturb arc stability.

Special-purpose switched DC power sources are available. By imbalancing the waveform to reduce the duration of electrode positive polarity, the electrode is kept sufficiently cool to maintain a pointed tip and achieve arc stability.

Arc starting
Although the arc is initiated using HF, it is first formed between the electrode and plasma nozzle. This 'pilot' arc is held within the body of the torch until required for welding then it is transferred to the workpiece. The pilot arc system ensures reliable arc starting and, as the pilot arc is maintained between welds, it obviates the need for HF which may cause electrical interference.

Electrode
The electrode used for the plasma process is tungsten-2%thoria and the plasma nozzle is copper. The electrode tip diameter is not as critical as for TIG and should be maintained at around 30-60 degrees. The plasma nozzle bore diameter is critical and too small a bore diameter for the current level and plasma gas flow rate will lead to excessive nozzle erosion or even melting. It is prudent to use the largest bore diameter for the operating current level.

Note: too large a bore diameter, may give problems with arc stability and maintaining a keyhole.

Plasma and shielding gases

The normal combination of gases is argon for the plasma gas, with argon plus 2 to 5% hydrogen for the shielding gas. Helium can be used for plasma gas but because it is hotter this reduces the current rating of the nozzle. Helium's lower mass can also make the keyhole mode more difficult.

Applications

Microplasma welding

Microplasma was traditionally used for welding thin sheets (down to 0.1 mm thickness), and wire and mesh sections. The needle-like stiff arc minimises arc wander and distortion. Although the equivalent TIG arc is more diffuse, the newer transistorised (TIG) power sources can produce a very stable arc at low current levels.

Medium current welding

When used in the melt mode this is an alternative to conventional TIG. The advantages are deeper penetration (from higher plasma gas flow), and greater tolerance to surface contamination including coatings (the electrode is within the body of the torch). The major disadvantage lies in the bulkiness of the torch, making manual welding more difficult. In mechanised welding, greater attention must be paid to maintenance of the torch to ensure consistent performance.

Keyhole welding

This has several advantages which can be exploited: deep penetration and high welding speeds. Compared with the TIG arc, it can penetrate plate thicknesses up to l0mm, but when welding using a single pass technique, it is more usual to limit the thickness to 6mm. The normal methods is to use the keyhole mode with filler to ensure smooth weld bead profile (with no undercut). For thicknesses up to 15mm, a vee joint preparation is used with a 6mm root face. A two-pass technique is employed and here, the first pass is autogenous with the second pass being made in melt mode with filler wire addition.

As the welding parameters, plasma gas flow rate and filler wire addition (into the keyhole) must be carefully balanced to maintain the keyhole and weld pool stability, this technique is only suitable for mechanised welding. Although it can be used for positional welding, usually with current pulsing, it is normally applied in high speed welding of thicker sheet material (over 3 mm) in the flat position. When pipe welding, the slope-out of current and plasma gas flow must be carefully controlled to close the keyhole without leaving a hole.

Advantages of Plasma Arc Welding over TIG Welding

- Reliable arc ignition due to pilot arc
- Stable arc
- Insensitive to changes in torch-to-work distance
- Higher welding speeds
- Less distortion due to narrow HAZ
- One-sided welding possible also for thicker sheets
- Controlled through welding using the keyhole technique
- Less effort required for edge preparation
- Filler metal not required
- Deeper penetration
- Tungsten inclusions avoided

Self Testing

1. Which two of the following are common gases used for shielding in arc welding: (a) argon, (b) carbon monoxide, (c) fluorine, (d) flux, (e) helium, (f) hydrogen, and (g) nitrogen?
2. Which one of the following arc welding processes has the lowest heat transfer factor: (a) FCAW, (b) GMAW, (c) GTAW, or (d) SMAW?
3. Which one of the following arc welding processes uses a non consumable electrode: (a) FCAW, (b) GMAW, (c) GTAW, or (d) SMAW?
4. MIG welding is a term sometimes applied when referring to which one of the following processes: (a) FCAW, (b) GMAW, (c) GTAW, or (d) SMAW?
5. Which one of the following arc welding processes uses an electrode consisting of continuous consumable tubing containing flux and other ingredients in its core: (a) FCAW, (b) GMAW, (c) GTAW, or (d) SMAW?
6. Which one of the following arc-welding processes produces the highest temperatures: (a) CAW, (b) PAW, (c) SAW, or (a) TIG welding?
7.
8. **T**he GTAW process was primarily developed to weld.
    a. Thin metal
    b. Magnesium
    c. Aluminum, Stainless steel and pipe
    d. Both A and C above.
9. Which is an advantage of TIG?
    a. Travel speeds
    b. Easy to operate
    c. Sound welds
    d. Operating costs.
10. Which industry was primarily responsible for developing the TIG process?
    a. Defense.
    b. Commercial / Transportation
    c. Ship Building.
    d. Nuclear power plants.
11. Primary advantage of helium gas is.
    a. Travel speed / penetration
    b. Penetration / better shielding
    c. Better gas shielding
    d. Better shielding / travel speed.
12. What is a plasma arc?

Sample Answer

- PLASMA - a fluid part of the blood
- PLASMA - an ionized gas (Air)
    - When a gas is heated above 17,000 ^{0}F, electrons are free to move. The gas conducts electricity.

13. Which current polarity cannot be used for GTAW?
    a. Direct current reverse polarity
    b. Alternating current

c. Direct current straight polarity
d. None of the above

14. If insufficient cooling water is supplied to the shoes on electro slag welding what is likely to happen? Incase Plasma arc welding.
    a. the shoe will warp and liquid steel will flow out
    b. The shoe will melt and water will be absorbed by the weld metal later causing delayed or cold cracking.
    c. An explosion will occur.

Chapter Eight

8. Resistance Welding
8.1 Resistance Welding

In resistance welding the metal parts to be joined are heated by their resistance to the flow of an electrical current. Usually this is the only source of heat, but a few of the welding operations combine resistance heating with arc heating, and possibly with combustion of metal in the arc. The process applies to practically all metals and most combinations of pure metals and those alloys, which have only a limited plastic range, are welded by heating the parts to fusion (melting). Some alloys, however, may welded without fusion; instead, the parts are heated to a plastic state at which the applied pressure causes their crystalline structures to grow together. The welding of dissimilar metals may be accomplished by melting both metals frequently only the metal with the lower melting point is melted, and an alloy bond is formed at the surface of the unmelted metal. In resistance welding processes no fluxes are employed, the filler metal is rarely used and the joints are usually of the lap type. The amounts of heat generated in the workpiece depend on the following factors:

1. Magnitude of the current,
2. Resistance of the current conducting path, and

Mathematically, $H = IVt$

$= I(IR)t$

$= I^2Rt$ (8.1)

Where H = heat generated in joules
I = current in Amp.
R = resistance in ohms
t = time of current flow in seconds.

The current used in resistance welding operations is very high (5000 to 20,000 A, typically), although voltage is relatively low (usually below 10V).The duration t of the current is short in most processes, perhaps lasting 0.1 to 0.4 s in a typical spot-welding operation. The reason why such a high current is used in RW is because (1) the squared termin Eq. (8.1) amplifies the effect of current, and (2) the resistance is very low (around 0.0001 V). Resistance in the welding circuit is the sum of (1) resistance of the electrodes, (2) resistances of the workparts, (3) contact resistances between electrodes and workparts, and (4) contact resistance of the faying surfaces. Thus, heat is generated in all of these regions of electrical resistance. The ideal situation is for the faying surfaces to be the largest resistance in the sum, since this is the desired location of the weld. The resistance of the electrodes is minimized by using metals with very low resistivities, such as copper. Also, the electrodes are often water cooled to dissipate the heat that is generated there. The workpart resistances are a function of the resistivities of the base metals and the part thicknesses. The contact resistances between the electrodes and the parts are determined by the contact areas (i.e., size and shape of the electrode) and the condition of the surfaces (e.g., cleanliness of the work surfaces and scale on the electrode). Finally, the resistance at the faying surfaces depends on surface finish, cleanliness, contact area, and pressure. No paint, oil, dirt, or other contaminants should be present to separate the contacting surfaces.

Example Resistance Welding

1. A resistance spot-welding operation is performed on two pieces of 1.5-mm-thick sheet steel using 12,000 A for a 0.20 s duration. The electrodes are 6 mm in diameter at the contacting

surfaces. Resistance is assumed to be 0.0001 V, and the resulting weld nugget is 6 mm in diameter and 2.5 mm thick. The unit melting energy for the metal Um ¼ 12.0 J/ mm3. What portion of the heat generated was used to form the weld nugget, and what portion was dissipated into the work metal, electrodes, and surrounding air?

Solution: The heat generated in the operation is given by Eq. (8.1) as.

$$H = (12000)^2(0.2) * (0.0001V) = 2880 \text{ J}$$

The volume of the weld nugget (assumed disc-shaped) $V = 2.5\frac{\pi}{4}6^2 = 70.7mm^3$, the heat required to melt this volume of metal is Hw ¼ 70.7(12.0) ¼ 848 J. The remaining heat, 2880 _ 848 ¼ 2032 J (70.6% of the total), is lost into the work metal, electrodes, and surrounding air. In effect, this loss represents the combined effect of the heat transfer factor f1 and the melting factor f2. Success in resistance welding depends on pressure as well as heat. The principal functions of pressure in RW are to (1) force contact between the electrodes and the workparts and between the two work surfaces prior to applying current, and (2) press the faying surfaces together to accomplish coalescence when the proper welding temperature has been reached.

Types of Resistance welding

The major types of resistance welding are given as under:

1. Spot Welding
2. Seam Welding
3. Projection Welding
4. Resistance Butt Welding
5. Flash Butt Welding
6. Percussion Welding
7. High Frequency Resistance Welding
8. High Frequency Induction Welding

Some of the above important welding processes are discussed as under,

8.5 Spot Welding

In this process overlapping sheets are joined by local fusion at one or more spots, by the concentration of current flowing between two electrodes. This is the most widely used resistance welding process. A typical resistance spot welding machine is shown in Fig.8.1.2. It essentially consists of two electrodes, out of which one is fixed. The other electrode is fixed to a rocker arm (to provide mechanical advantage) for transmitting the mechanical force from a pneumatic cylinder. This is the simplest type of arrangement. The other possibility is that of a pneumatic or hydraulic cylinder being directly connected to the electrode without any rocker arm. For welding large assemblies such as car bodies, portable spot welding machines are used. Here the electrode holders and the pneumatic pressurizing system are present in the form of a portable assembly which is taken to the place, where the spot is to be made. The electric current, compressed air and the cooling water needed for the electrodes is supplied through cables and hoses from the main welding machine to the portable unit. In spot welding, a satisfactory weld is obtained when a proper current density is maintained. The current density depends on the contact area between the electrode and the work-piece. With the continuous use, if the tip becomes upset and- the contact area increases, the current density will be lowered and consequently the weld is obtained over a large area. This would not be able to melt the metal and hence there would be no proper fusion. A resistance welding schedule is the sequence of events that normally take place in each of the welds. The events are:

1. The squeeze time is the time required for the electrodes to align and clamp the two work-pieces together under them and provide the necessary electrical contact.
2. The weld time is the time of the current flow through the work-pieces till they are heated to the melting temperature.

3. The hold time is the time when the pressure is to be maintained on the molten metal without the electric current. During this time, the pieces are expected to be forged welded.
4. The off time is time during which, the pressure on the electrode is taken off so that the plates can be positioned for the next spot.

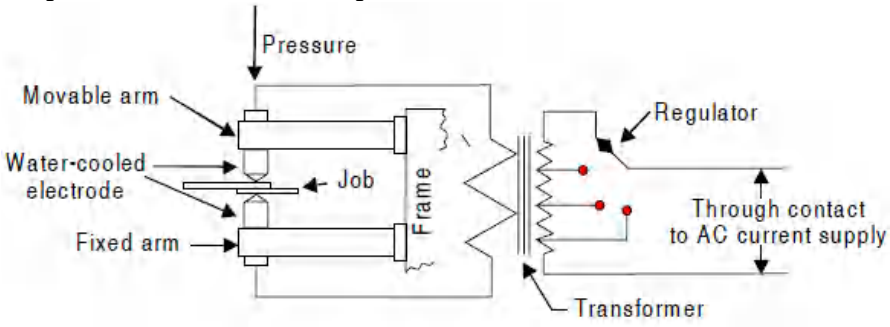


Fig. 8.1.1 Resistance spot welding machine setup

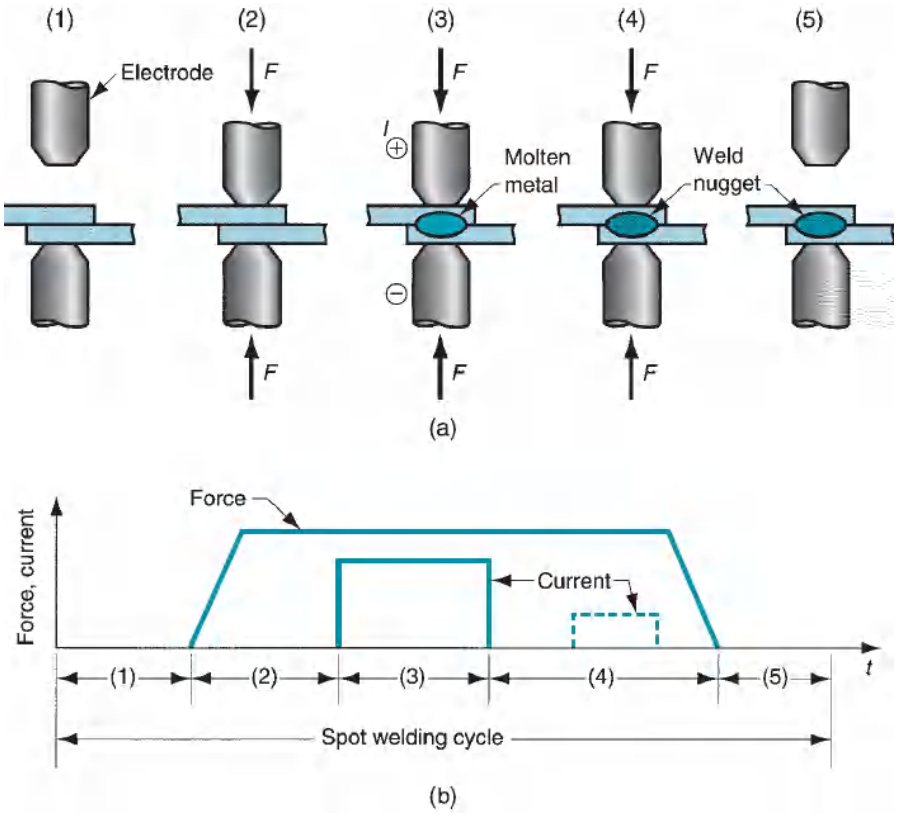


Fig 8.1.2 (a) Steps in a spot-welding cycle, and (b) plot of squeezing force and current during cycle.

The sequence is: (1) parts inserted between open electrodes, (2) electrodes close and force is applied, (3) weld time current is switched on, (4) current is turned off but force is maintained or increased (a reduced current is sometimes applied near the end of this step stress relief in the weld region), and (5) electrodes are opened, and the welded assembly is removed.
Before spot welding one must make sure that:-

(I) The job is clean, i.e., free from grease, dirt, paint, scale, oxide etc.

(II) Electrode tip surface is clean, since it has to conduct the current into the work with as little loss as possible. Very fine emery cloth may be used for routine cleaning.

(III) Water is running through the electrodes in order to

a) Avoid them from getting overheated and thus damaged,

b) Cool the weld.

(IV) Proper welding current has been set on the current selector switch.

(V) Proper time has been set on the weld-timer.

Spot welding electrodes

Spot welding electrodes are made of materials which have

1. Higher electrical and thermal resistivities, and
2. Sufficient strength to withstand high pressure at elevated temperatures.

Copper base alloys such as copper beryllium and copper tungsten are commonly used materials for spot welding electrodes. For achieving the desired current density, It is important to have proper electrode shape for which three main types of spot welding electrodes are used which are pointed, domed and flat electrodes.

Applications of Spot Welding

I. It has applications in automobile and aircraft industries

II. The attachment of braces, brackets, pads or clips to formed sheet-metal parts such as cases, covers or trays is another application of spot welding.

III. Spot welding of two 12.5 mm thick steel plates has been done satisfactorily as a replacement for riveting.

IV. Many assemblies of two or more sheet metal stampings that do not require gas tight or liquid tight joints can be more economically joined by spot welding than by mechanical methods.

V. Containers and boxes frequently are spot welded.

8.3.2 Resistance Seam Welding

It is a continuous type of spot welding wherein spot welds overlap each other to the desired extent. In this process coalescence at the faying surfaces is produced by the heat obtained from the resistance to electric current (flow) through the work pieces held together under pressure by circular electrodes. The resulting weld is a series of overlapping resistance-spots welds made progressively along a joint by rotating the circular electrodes. The principle of seam welding is shown in Fig.8.1.2 (a) and resistance seam welding process set up is shown in Fig. 8.1.3 (b). The seam welding is similar to spot welding, except that circular rolling electrodes are used to produce a continuous air-tight seam of overlapping welds. Overlapping continuous spot welds seams are produced by the rotating electrodes and a regularly interrupted current.

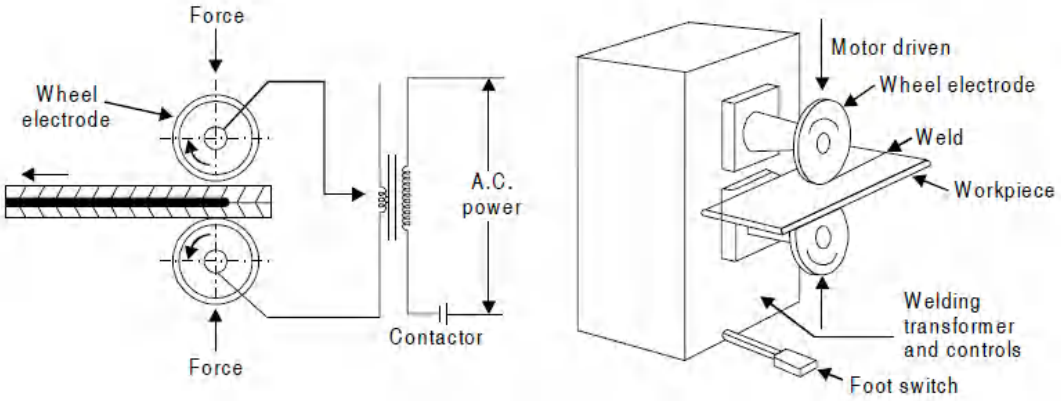


Fig. 8.1.3a) Principle of seam welding process, b) Resistance seam welding process setup

The spacing between the weld nuggets in resistance seam welding depends on the motion of the electrode wheels relative to the application of the weld current. In the usual method of operation, called continuous motion welding, the wheel is rotated continuously at a constant velocity, and current is turned on at timing intervals consistent with the desired spacing between spot welds

along the seam. Frequency of the current discharges is normally set so that overlapping weld spots are produced. But if the frequency is reduced sufficiently, then there will be spaces between the weld spots, and this method is termed roll spot welding. In another variation, the welding current remains on at a constant level (rather than being pulsed) so that a truly continuous welding seam is produced. These variations are depicted in Figure Fig. 8.1.3. An alternative to continuous motion welding is intermittent motion welding, in which the electrode wheel is periodically stopped to make the spot weld. The amount of wheel rotation between stops determines the distance between weld spots along the seam, yielding patterns similar to (a) and (b) in Figure 8.2. Seam-welding machines are similar to press-type spot welders except that electrode wheels are used rather than the usual stick-shaped electrodes. Cooling of the work and wheels is often necessary in RSEW, and this is accomplished by directing water at the top

Resistance Projection Welding

Fig.8.1.3 shows the projection welding.This process is a resistance welding process in which two or more than two spot welds are made simultaneously by making raised portions or projections on predetermined locations on one of the workpiece. These projections act to localize the heat of the welding circuit. The pieces to be welded are held in position under pressure being maintained by electrodes. The projected contact spot for welding should be approximately equal to the weld metal thickness. The welding of a nut on the automotive chasis is an example of projection welding.

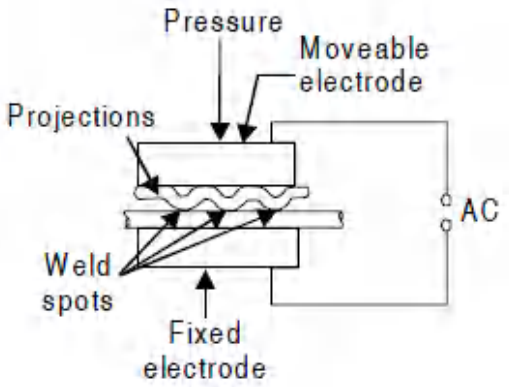


Fig. 8.1.3 Resistance projection welding

Resistance Upset Butt and Flash Butt Welding

This welding is also used for joining metal pieces end to end but it has largely replaced the butt-welding method for weld articles small cross-sections. It can be used for thick sections also. Initially the current is switched on and then one end the moveable part to be welded is brought gently closer to the fixed end of the other part to localize heat at the ends and thus raises the temperature of the ends quickly to the welding heat. On acquiring contact of fixed end and moveable end with each other, the moveable end is then pressed against one another by applying mechanical pressure. Thus the molten metal and slag to be squeezed out in the form of sparks enabling the pure metal to form the joint and disallowing the heat to spread back. The principle of upset butt welding and flash butt welding are depicted in Fig.8.1.4. (a, b). In this resistance welding single phase A.C. machines are commonly employed.

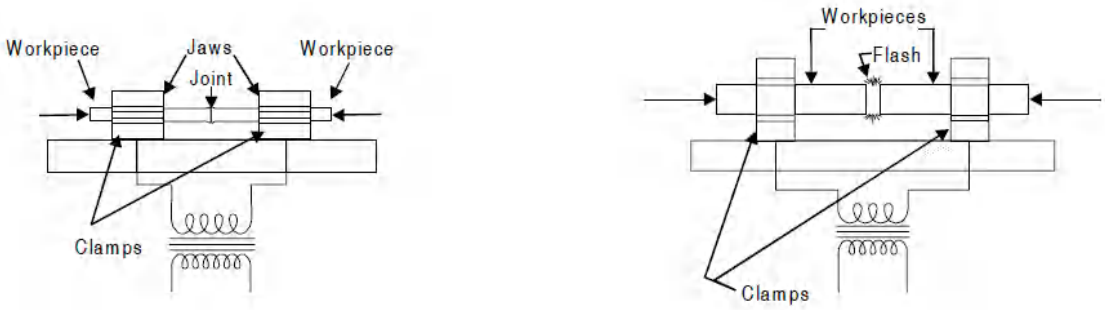


Fig. 8.1.4 Resistance upset butt welding

Advantages

1. It is comparatively much faster than butt welding.
2. This method utilizes less current in comparison to butt welding as the small portion of the metal is only being heated for getting a good weld
3. Created joint by this welding is much stronger than the butt welding joint. Also the strength of the weld produced is high even more than that of the base metal. The end of the metal pieces to be welded in this welding need not be squared as it is the basic requirement in butt-welding.
4. A high degree of accuracy can be easily achieved in terms of length alignment of weld.

Disadvantages

1. The periodic maintenance of machine and replacement of insulation is needed as flashing particles of molten metal are thrown out during welding which may enter into the slide ways and insulation of the set up.
2. Welder has to take enough care against possible fire hazard due to flashing during welding.
3. Additional stock has to be provided for compensating loss of metal during f1ashing and upsetting. This increases to the cost of weld.
4. Cost of removal of flash weld metal by trimming, chipping, grinding, etc. will increase to the welded product.
5. Surface of the jobs where they come in contact with the gripping surfaces, should be clean otherwise they will restrict the flow of electric current.
6. The available power, opening between the jaws of the gripping clamps and upsetting pressure of the welding set limit the size and cross sectional area of the jobs to be welded.

Applications

All conducting forged metals can be easily be flash welded. A number of dissimilar metals can also be welded by controlling the welding conditions carefully. Metals generally welded metal by the process involves lead, tin, antimony, zinc, bismuth and their alloys, low carbon steels, stainless steel, alloy steels, tool steels, copper alloys, aluminium alloys, magnesium alloys nickel alloys, molybdenum alloys, and titanium alloys. This process is used in automobile industry, welding of solid and tubular structural assemblies, etc. in air-craft industry, welding of band saw blades, welding of tool steel drills, reamers and taps etc. to mild steel or alloy steel shanks, welding of pipes and tubes.

High-frequency resistance welding

High-frequency resistance welding (HFRW) is a resistance-welding process in which a high-frequency alternating current is used for heating, followed by the rapid application of an upsetting force to cause coalescence, as in Fig. 8.1.5. The frequencies are 10 to 500 kHz, and the electrodes make contact with the work in the immediate vicinity of the weld joint. In a variation of the process, called high-frequency

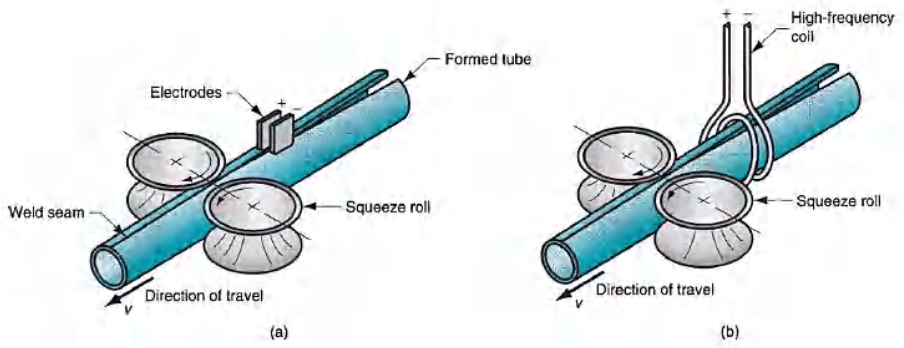


Fig. 8.1.5 Welding of tube seams by: (a) high-frequency resistance welding, and (b) high-frequency induction welding.

Induction welding (HFIW), the heating current is induced in the parts by a high frequency induction coil, as in Figure Fig. 8.1.5. The coil does not make physical contact with the work. The principal applications of both HFRW and HFIW are continuous butt

Name	Characteristic	Application
Resistance spot welding	Two pointed electrodes apply pressure and current to two or more thin workpieces	Automobile industry, Aerospace industry
Resistance seam welding	Two wheel-shaped electrodes roll along workpieces, applying pressure and current	Aerospace industry, steel drums, tubing
Projection welding	Semi-Automatic, Automatic, Welds are localized at predetermined points.	
Upset welding	Butt joint surfaces heated and brought together by force	

Sample question

1. The rate of heat energy supplied in a resistance spot welding operation is determined by which one of the following equations: (a)$R_H = ERt$, (b) $R_H = E^2R$, (c) $R_H = IR$, (d) $R_H = I^2R$, or (e) $R_H = I^2Rt$, where R_H = rate of heat energy, E = voltage, I = current, R = resistance, and t = time?
2. The fused zone between the two parts in a resistance spot welding operation is called which one of the following: (a) weld contact, (b) weld fillet, (c) weld nugget, (d) weld seam, or (e) weld spot?
3. Resistance welding is in the group of_____

   a) Fusion welding b) Solid-State welding
4. Describe in detail with set up process parameters, advantages, disadvantages and applications of resistance welding technology.
5. An RSW operation is used to join two pieces of sheet steel having a unit melting energy of 130 J/ mm^3. The sheet steel has a thickness of 2mm. The weld duration will be set at 0.25 sec with a current of 11,000 A. Based on the electrode diameter, the weld nugget will have a diameter of 0.30 in. Experience has shown that 50% of the supplied heat melts the nugget and the rest is dissipated by the metal. If the electrical resistance between the surfaces is 130 μV, what is the thickness of the weld nugget assuming it has a uniform thickness?

6. The unit melting energy for a certain sheet metal is 10.5 J/mm^3. The thickness of each of the two sheets to be spot welded is 3.5 mm. To achieve required strength, it is desired to form a weld nugget that is 5.5 mm in diameter and 5.0 mm thick. The weld duration will be set at 0.3 sec. If it is assumed that the electrical resistance between the surfaces is 140 μV, and that only one-third of the electrical energy generated will be used to form the weld nugget (the rest being dissipated), determine the minimum current level required in this operation.
7. A resistance seam-welding operation is performed on two pieces of 3.5-mm-thick austenitic stainless steel to fabricate a container. The weld current in the operation is 80,000 A, the weld duration is 0.3 sec, and the resistance at the interface is 90 μV. Continuous motion welding is used, with 200-mmdiameter electrode wheels. The individual weld nuggets formed in this RSEW operation have diameter is 6 mm and thickness is 3 mm (assume the weld nuggets are disc-shaped). These weld nuggets must be contiguous to form a sealed seam. The power unit driving the process requires an off-time between spot welds of 1.0 s. Given these conditions, determine (a) the unit melting energy of stainless steel using the methods of the previous chapter, (b) the proportion of energy generated that goes into the formation of each weld nugget, and (c) the rotational speed of the electrode wheels.

Chapter nine

9. Solid-State Welding Processes

Solid state welding is a group of welding processes which produces coalescence at temperatures essentially below the melting point of the base materials being joined, without the addition of brazing filler metal. Pressure may or may not be used. These processes are sometimes erroneously called solid state bonding processes: this group of welding processes includes cold welding, diffusion welding, explosion welding, forge welding, friction welding, hot pressure welding, roll welding, and ultrasonic welding.

In solid state welding the surfaces to be joined are **brought into close proximity** by:

- Heating the surfaces without causing melting and applying normal pressure.
- Providing relative motion between the two surfaces and applying light normal pressure.
- Applying high pressure without heating.

In these processes the materials remain in solid state and welding is achieved through the application of heat and pressure, or high pressure only. In all of these processes time, temperature, and pressure individually or in combination produce coalescence of the base metal without significant melting of the base metals.

Solid state welding includes some of the very oldest of the welding processes and some of the very newest. Some of the processes offer certain advantages since the base metal does not melt and form a nugget. The metals being joined retain their original properties without the heat-affected zone problems involved when there is base metal melting. When dissimilar metals are joined their thermal expansion and conductivity is of much less importance with solid state welding than with the arc welding processes.

Time, temperature, and pressure are involved; however, in some processes the time element is extremely short, in the microsecond range or up to a few seconds. In other cases, the time is extended to several hours. As temperature increases time is usually reduced. Since each of these processes is different each will be described. 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.

Cold Welding (CW)

Cold welding is a solid state welding process which uses pressure at room temperature to produce coalescence of metals with substantial deformation at the weld.

Welding is accomplished by using extremely high pressures on extremely clean interfacing materials. Sufficiently high pressure can be obtained with simple hand tools when extremely thin materials are being joined. When cold welding heavier sections a press is usually required to exert sufficient pressure to make a successful weld.

Indentations are usually made in the parts being cold welded. The process is readily adaptable to joining ductile metals. Aluminum and copper are readily cold welded. Aluminum and copper can be joined together by cold welding.

Diffusion Welding (DFW)

Diffusion welding is a solid state welding process which produces coalescence of the faying surfaces by the application of pressure and elevated temperatures. The process does not involve microscopic deformation melting or relative motion of the parts. Filler metal may or may not be used. This may be in the form of electroplated surfaces.

The process is used for joining refractory metals at temperatures that do not affect their metallurgical properties. Heating is usually accomplished by induction, resistance, or furnace. Atmosphere and vacuum furnaces are used and for most refractory metals a protective inert atmosphere is desirable.

Successful welds have been made on refractory metals at temperatures slightly over half the normal melting temperature of the metal. To accomplish this type of joining extremely close tolerance joint preparation is required and a vacuum or inert atmosphere is used. The process is used quite extensively for joining dissimilar metals. The process is considered diffusion brazing when a layer of filler material is placed between the faying surfaces of the parts being joined. These processes are used primarily by the aircraft and aerospace industries.

Explosion Welding (EXW)

Explosion welding is a solid state welding process in which coalescence is affected by high-velocity movement together of the parts to be joined produced by a controlled detonation. Even though heat is not applied in making an explosion weld it appears that the metal at the interface is molten during welding.

This heat comes from several sources, from the shock wave associated with impact and from the energy expended in collision. Heat is also released by plastic deformation associated with jetting and ripple formation at the interface between the parts being welded. Plastic interaction between the metal surfaces is especially pronounced when surface jetting occurs. It is found necessary to allow the metal to flow plastically in order to provide a quality weld.

Explosion welding creates a strong weld between almost all metals. It has been used to weld dissimilar metals that were not weldable by the arc processes. The weld apparently does not disturb the effects of cold work or other forms of mechanical or thermal treatment. The process is self-contained, it is portable, and welding can be achieved quickly over large areas. The strength of the weld joint is equal to or greater than the strength of the weaker of the two metals joined.

Explosion welding (EXW) is 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 form king 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 Inter locking that results from a rippled or wavy interface between the metals. The process for cladding one metal plate on another can be described with reference to Fig. 9.1. In this setup, the two plates are in a parallel configuration, separated by a certain gap distance, with the explosive charge above the upper plate, called the flyer plate. A buffer layer (e.g., rubber, plastic) is often used between the explosive and the flyer plate to protect its surface. The lower plate, called the backer metal, rests on an anvil for support. When detonation is initiated, the explosive charge propagates from one end of the flyer plate to the other, caught in the stop-action view shown in Fig. 9.1(2). One of the difficulties in comprehending what happens in EXW is the common misconception that an explosion occurs instantaneously; it is actually a progressive reaction, although admittedly very rapid propagating at rates as high as 8500m/s (28,000 ft/sec).The resulting high-pressure zone propels the flyer plate to collide with the backer metal progressively at high velocity, so that it takes on an angular shape as the explosion advances, as illustrated in our sketch. The upper plate remains in position in the region where the explosive has not yet detonated. The high-speed collision, occurring in a progressive and angular fashion as it does, causes the surfaces at the point of contact to become fluid, and any surface films are expelled forward from the apex of the angle. The colliding surfaces are thus chemically clean, and the fluid behavior of the metal, which involves some interfacial melting, provides intimate contact between the surfaces, leading tome tallurgical bonding. Variations in collision velocity and impact angle during the process can result in a wavy or rippled interface between the two metals. This kind of interface strengthens the bond because it increases the contact area and tends to mechanically interlock the two surfaces.

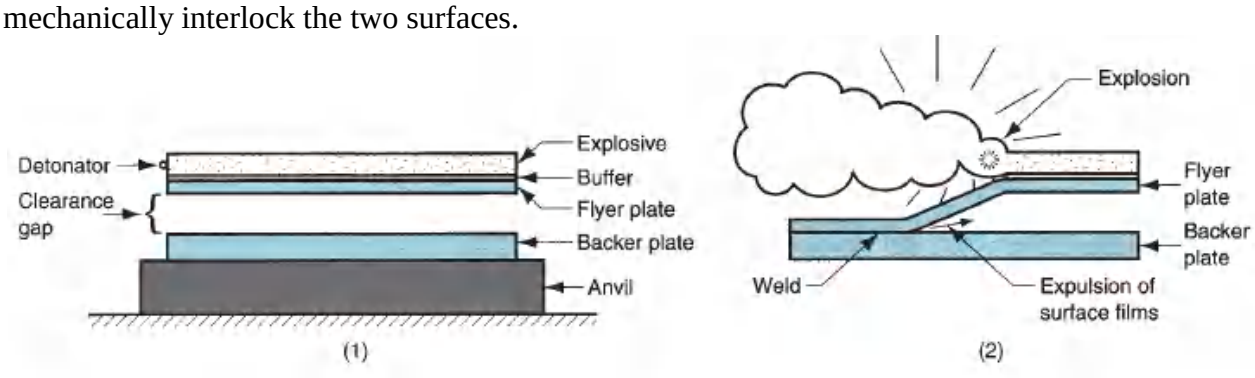


Fig. Explosive welding process (step ways (1) and (2))

Explosion welding has not become too widely used except in a few limited fields. One of the most widely used applications of explosion welding has been in the cladding of base metals with thinner alloys. Another application for explosion welding is in the joining of tube-to-tube sheets for the manufacture of heat exchangers. The process is also used as a repair tool for repairing leaking tube-to-tube sheet joints. Another and new application has been the joining of pipes in a socket joint. This application will be of increasing importance in the future.

Forge Welding (FOW)

Forge welding is a solid state welding process which produces coalescence of metals by heating them in a forge and by applying pressure or blows sufficient to cause permanent deformation at

the interface. This is one of the older welding processes and at one time was called hammer welding. Forge welds made by blacksmiths were made by heating the parts to be joined to a red heat considerably below the molten temperature. Normal practice was to apply flux to the interface. The blacksmith by skillful use of a hammer and an anvil was able to create pressure at the faying surfaces sufficient to cause coalescence. This process is of minor industrial significance today.

Friction Welding (FRW)

Friction welding is a solid state welding process which produces coalescence of materials by the heat obtained from mechanically-induced sliding motion between rubbing surfaces. The work parts are held together under pressure. This process usually involves the rotating of one part against another to generate frictional heat at the junction. When a suitable high temperature has been reached, rotational motion ceases and additional pressure is applied and coalescence occurs.

There are two variations of the friction welding process. In the original process one part is held stationary and the other part is rotated by a motor which maintains an essentially constant rotational speed. The two parts are brought in contact under pressure for a specified period of time with a specific pressure. Rotating power is disengaged from the rotating piece and the pressure is increased. When the rotating piece stops the weld is completed. This process can be accurately controlled when speed, pressure, and time are closely regulated.

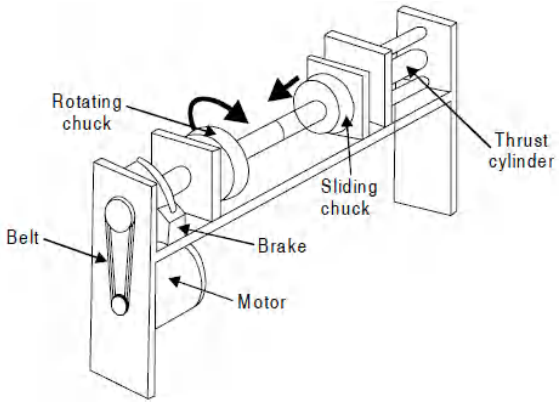


Fig. 9.1.2 Friction welding process

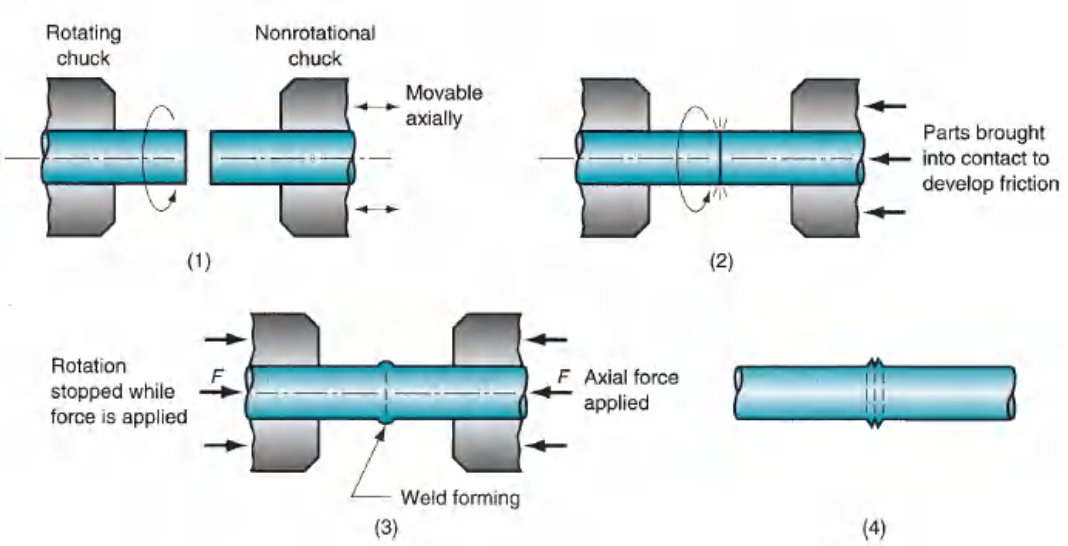


Fig. 9.1.3 Friction welding (FRW): (1) rotating part, no contact; (2) parts brought into contact to generate

friction heat; (3) rotation stopped and axial pressure applied; and (4) weld created.The total cycle for these operations is about 20 seconds. Machines used for friction welding have the appearance of an engine lathe. They require a powered spindle to turn one part at high speed, and a means of applying an axial force between the rotating part and the non rotating part. With its short cycle times, the process lends itself to mass production. It is applied in the welding of various shafts and tubular parts in industries such as automotive, aircraft, farm equipment, petroleum, and natural gas. The process yields a narrow wheat-affected zone and can be used to join dissimilar metals. However, at least one of the parts must be rotational; flash must usually be removed, and upsetting reduces the part lengths (which must be taken into consideration in product design). The conventional friction welding operations discussed above utilize a rotary motion to develop the required friction between faying surfaces. A more recent version of the process is linear friction welding, in which a linear reciprocating motion is used to generate friction heat between the parts. This eliminates the requirement for at least one of the parts to be rotational (e.g., cylindrical, tubular).

Among the advantages of friction welding is the ability to produce high quality welds in a short cycle time. No filler metal is required and flux is not used. The process is capable of welding most of the common metals. It can also be used to join many combinations of dissimilar metals.

Friction welding requires relatively expensive apparatus similar to a machine tool. There are three important factors involved in making a friction weld:

1. The rotational speed which is related to the material to be welded and the diameter of the weld at the interface.
2. The pressure between the two parts to be welded. Pressure changes during the weld sequence. At the start it is very low, but it is increased to create the frictional heat. When the rotation is stopped pressure is rapidly increased so that forging takes place immediately before or after rotation is stopped.
3. The welding time. Time is related to the shape and the type of metal and the surface area. It is normally a matter of a few seconds. The actual operation of the machine is automatic and is controlled by a sequence controller which can be set according to the weld schedule established for the parts to be joined.

Normally for friction welding one of the parts to be welded is round in cross section; however, this is not an absolute necessity. Visual inspection of weld quality can be based on the flash, which occurs around the outside perimeter of the weld. Normally this flash will extend beyond the outside diameter of the parts and will curl around back toward the part but will have the joint extending beyond the outside diameter of the part. If the flash sticks out relatively straight from the joint it is an indication that the time was too short, the pressure was too low, or the speed was too high. These joints may crack. If the flash curls too far back on the outside diameter it is an indication that the time was too long and the pressure was too high. Between these extremes is the correct flash shape. The flash is normally removed after welding.

Friction Stir Welding

Friction stir welding (FSW), illustrated in Fig. 9.1.3, is a solid state welding process in which a rotating tool is fed along the joint line between two work pieces, generating friction heat and mechanically stirring the metal to form the weld seam. The process derives its name from this stirring or mixing action. FSW is distinguished from conventional FRW by the fact that friction heat is generated by a separate wear-resistant tool rather than by the parts themselves. FSW was developed in 1991 at The Welding Institute in Cambridge, UK. The rotating tool is stepped, consisting of a cylindrical shoulder and a smaller probe projecting beneath it. During welding, the shoulder rubs against the top surfaces of the two parts, developing much of the friction heat,

while the probe generates additional heat by mechanically mixing the metal along the butt surfaces. The probe has a geometry designed to facilitate the mixing action. The heat produced by the combination of friction and mixing does not melt the metal but softens it to a highly plastic condition. As the tool is fed forward along the joint, the leading surface of the rotating probe forces the metal around it and into its wake, developing forces that forge the metal into a weld seam. The shoulder serves to constrain the plasticized metal flowing around the probe. The FSW process is used in the aerospace, automotive, railway, and shipbuilding industries. Typical applications are butt joints on large aluminum parts. Other metals, including steel, copper, and titanium, as well as polymers and composites have also been joined using FSW. Advantages in these applications include (1) good mechanical properties of the weld joint, (2) avoidance of toxic fumes, warping, shielding issues, and other problems associated with arc welding, (3) little distortion or shrinkage, and (4) good weld appearance. Disadvantages include (1) an exit hole is produced when the tool is withdrawn from the work, and (2) heavy-duty clamping of the parts is required.

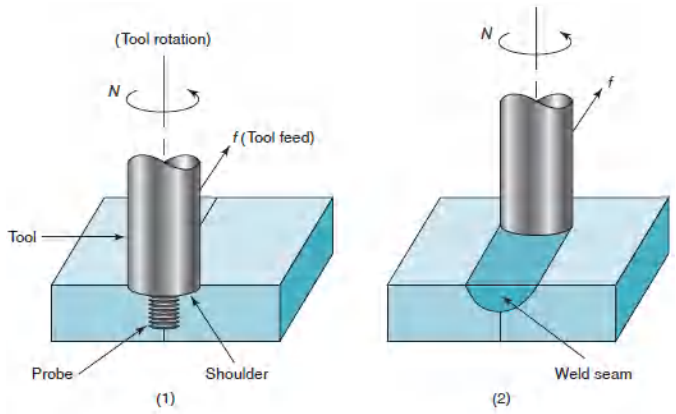


Figure 9.1.3 Friction stir welding (FSW): (1) rotating tool just prior to feeding into joint and (2) partially completed weld seam. N =tool rotation, f=tool feed.

Hot Pressure Welding (HPW)

Hot pressure welding is a solid state welding process which produces coalescence of materials with heat and the application of pressure sufficient to produce macro-deformation of the base metal. In this process coalescence occurs at the interface between the parts because of pressure and heat which is accompanied by noticeable deformation. The deformation of the surface cracks the surface oxide film and increases the areas of clean metal. Welding this metal to the clean metal of the abutting part is accomplished by diffusion across the interface so that coalescence of the faying surface occurs. This type of operation is normally carried on in closed chambers where vacuum or a shielding medium may be used. It is used primarily in the production of weldments for the aerospace industry. A variation is the hot isostatic pressure welding method. In this case, the pressure is applied by means of a hot inert gas in a pressure vessel.

Roll Welding (ROW)

Roll welding is a solid state welding process which produces coalescence of metals by heating and by applying pressure with rolls sufficient to cause deformation at the faying surfaces. This process is similar to forge welding except that pressure is applied by means of rolls rather than by means of hammer blows. Coalescence occurs at the interface between the two parts by means of diffusion at the faying surfaces.

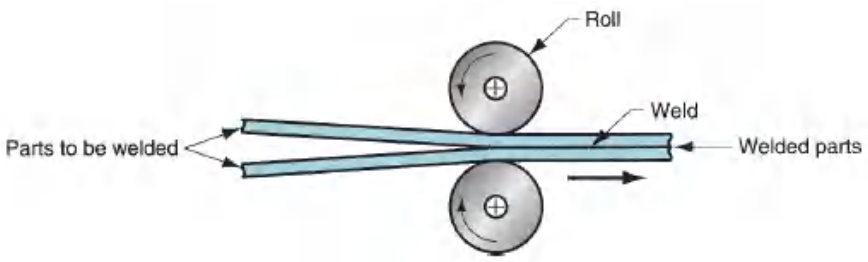


Fig. 9.1.4 Roll welding (ROW).

One of the major uses of this process is the cladding of mild or low-alloy steel with a high-alloy material such as stainless steel. It is also used for making bimetallic materials for the instrument industry.

Ultrasonic Welding (USW)

Ultrasonic welding is a solid state welding process which produces coalescence by the local application of high-frequency vibratory energy as the work parts are held together under pressure. Welding occurs when the ultrasonic tip or electrode, the energy coupling device, is clamped against the work pieces and is made to oscillate in a plane parallel to the weld interface.

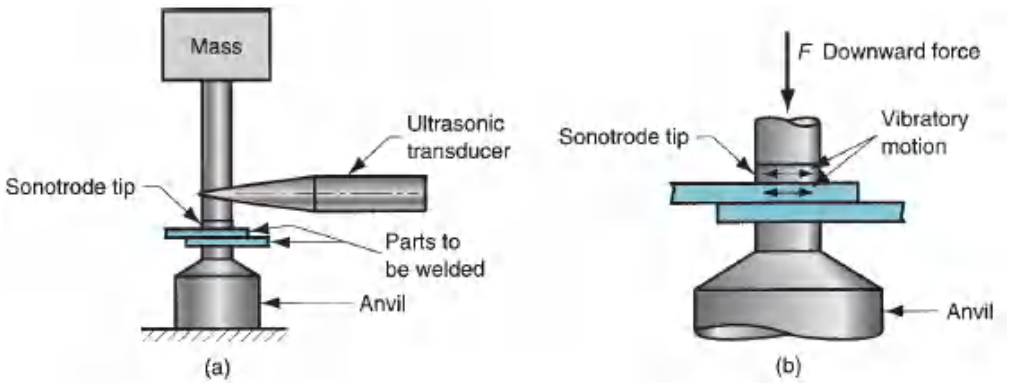


FIG. 9.1.5 Ultrasonic welding (USW): (a) general setup for a lap joint; and (b) close-up of weld area

The combined clamping pressure and oscillating forces introduce dynamic stresses in the base metal. This produces minute deformations which create a moderate temperature rise in the base metal at the weld zone. This coupled with the clamping pressure provides for coalescence across the interface to produce the weld. Ultrasonic energy will aid in cleaning the weld area by breaking up oxide films and causing them to be carried away. The vibratory energy that produces the minute deformation comes from a transducer which converts high-frequency alternating electrical energy into mechanical energy. The transducer is coupled to the work by various types of tooling which can range from tips similar to resistance welding tips to resistance roll welding electrode wheels. The normal weld is the lap joint weld.

The temperature at the weld is not raised to the melting point and therefore there is no nugget similar to resistance welding. Weld strength is equal to the strength of the base metal. Most ductile metals can be welded together and there are many combinations of dissimilar metals that can be welded. The process is restricted to relatively thin materials normally in the foil or extremely thin gauge thicknesses.

This process is used extensively in the electronics, aerospace, and instrument industries. It is also used for producing packages and containers and for sealing them.

Self Test

1. The feature that distinguishes fusion welding from solid-state welding is that melting of the faying surfaces occurs during fusion welding but not in solid-state welding: (a) true or (b) false?
2. Friction stir welding is a fusion welding process in which a rotating tool is fed along the joint line between two workpieces, generating friction heat and mechanically stirring the metal to form the weld seam: (a) true or (b) false?
3. Which of the following solid-state welding processes applies heat from an external source (two best answers): (a) diffusion welding, (b) forge welding, (c) friction welding, and (d) ultrasonic welding?
4. Explosive welding is primarily used for bonding sheets of corrosion- resistant metal to _____, particularly for_____
5. The Friction Welding (FRW) is a _____ process that produces a weld under _____.
6. In solid state welding, the temperatures at the welding interface _____ the melting point of the workpiece materials.
   a) will not exceed
   b) will be higher than
7. Which of the following processes are classified as fusion welding (three correct answers):
   a) Electrogas welding
   b) Electron-beam welding
   c) Explosion welding
   d) (d) forge welding
   e) laser-beam welding, and f) ultrasonic welding

Chapter Ten

10. Brazing, Soldering, And Adhesive Bonding

In this chapter, we consider three joining processes that are similar to welding in certain respects: brazing, soldering, and adhesive bonding. Brazing and soldering both use filler metals to join and bond two (ormore) metal parts to provide a permanent joint. It is difficult, although not impossible; to disassemble the parts after a brazed or soldered joint has been made. In the spectrum of joining processes, brazing and soldering lie between fusion welding and solid-state welding (solid / liquid state).

A filler metal is added in brazing and soldering as in most fusion-welding operations; however, no melting of the base metals occurs, which is similar to solid-state welding. Despite these anomalies, brazing and soldering are generally considered to be distinct from welding. Brazing and soldering are attractive compared to welding under circumstances where:

1. the metals have poor weldability
2. Dissimilar metals are to be joined
3. The intense heat of welding may damage the components being joined
4. The geometry of the joint does not lend itself to any of the welding methods, and/or
5. High strength is not a requirement.

Adhesive bonding shares certain features in common with brazing and soldering. It utilizes the forces of attachment between a filler material and two closely spaced surfaces to bond the parts. The differences are that the filler material in adhesive bonding is not metallic, and the joining process is carried out at room temperature or only modestly above.

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.

10.1 Brazed Joints

Brazed joints are commonly of two types: butt and lap However, the two types have been adapted for the brazing process in several ways. The conventional butt joint provides a limited area for brazing, thus jeopardizing the strength of the joint. To increase the faying areas in brazed joints, the mating parts are often scarfed or stepped or otherwise altered, as shown in Fig. 10.1.1 Of course, additional processing is usually required in the making of the parts for these special joints. One of the particular difficulties associated with a scarfed joint is the problem of maintaining the alignment of the parts before and during brazing. Lap joints are more widely used in brazing, since they can provide a relatively large interface area between the parts. An overlap of at least three times the thickness of the thinner part is generally considered good design practice. Some adaptations of the lap joint for brazing are illustrated in Figure 31.2. An advantage of brazing over welding in

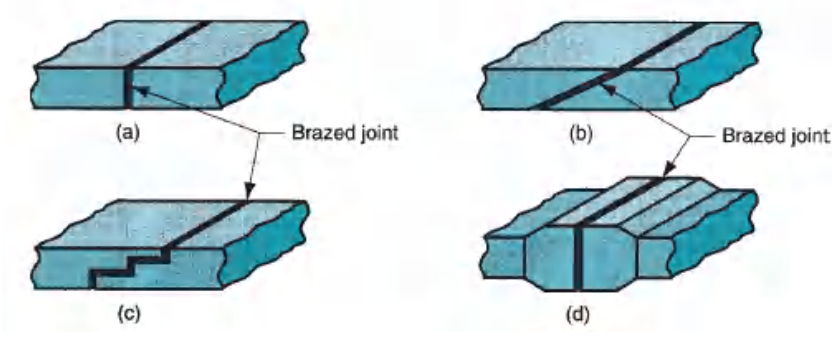


Fig. 10.1.1 (a) Conventional butt joint, and adaptations of the butt joint for brazing: (b) scarf joint, (c) stepped butt joint, (d) increased cross section of the part at the joint.

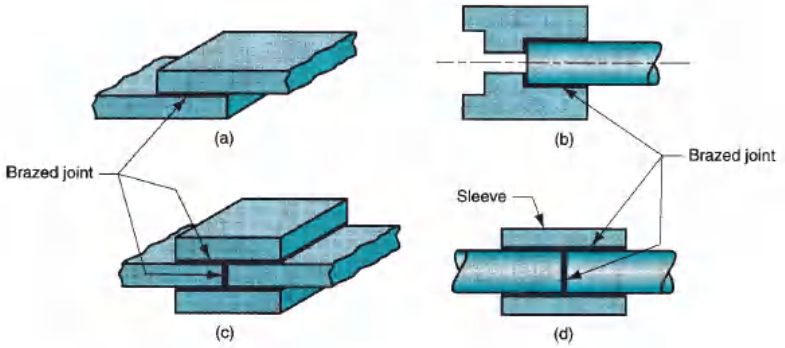


Fig. 10.1.2 (a) Conventional lap joint, and adaptations of the lap joint for brazing: (b) cylindrical parts, (c) sandwiched parts, and (d) use of sleeve to convert butt joint into lap joint.

lap joints is that the filler metal is bonded to the base parts throughout the entire interface area between the parts, rather than only at the edges (as in fillet welds made by arc welding) or at discrete spots (as in resistance spot welding). Clearance between mating surfaces of the base parts is important in brazing. The clearance must be large enough so as not to restrict molten filler metal from flowing throughout the entire interface. Yet if the joint clearance is too great, capillary action will be reduced and there will be areas between the parts where no filler metal is present. Joint strength is affected by clearance, as depicted in Fig. 10.1.3. There is an optimum clearance value at which joint strength is maximized. The issue is complicated by the fact that the optimum depends on base and filler metals, joint configuration, and processing conditions. Typical brazing clearances in practice are 0.025 to 0.25mm. These values represent the joint clearance at the brazing temperature, which may be different from room temperature clearance, depending on thermal expansion of the base metal(s). Cleanliness of the joint surfaces prior to brazing is also important. Surfaces must be free of oxides, oils, and other contaminants in order to promote wetting and capillary attraction during the process, as well as bonding across the entire interface.

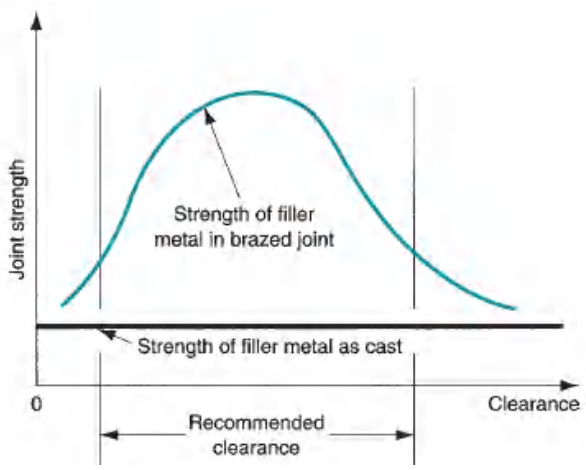


Fig. 10.1.3 Joint strength as a function of joint clearance

Filler Metals and Fluxes

Common filler metals used in brazing are listed in Table 31.1 along with the principal base metals on which they are typically used. 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.

Filler metals are applied to the brazing operation in various ways, including wire, rod, sheets and strips, powders, pastes, preformed parts made of braze metal designed to fit a particular joint configuration, and cladding on one of the surfaces to be brazed. Several of these techniques are illustrated in Fig. 10.1.4. Braze metal pastes, shown in Fig. 10.1.5, consist of filler metal powders mixed with fluid fluxes and binders. 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.
5. 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. Alternatives to using a flux are to perform the operation in a vacuum or a reducing atmosphere that inhibits oxide formation.

Brazing Methods

There are various methods used in brazing. Referred to as brazing processes, they are differentiated by their heating sources.

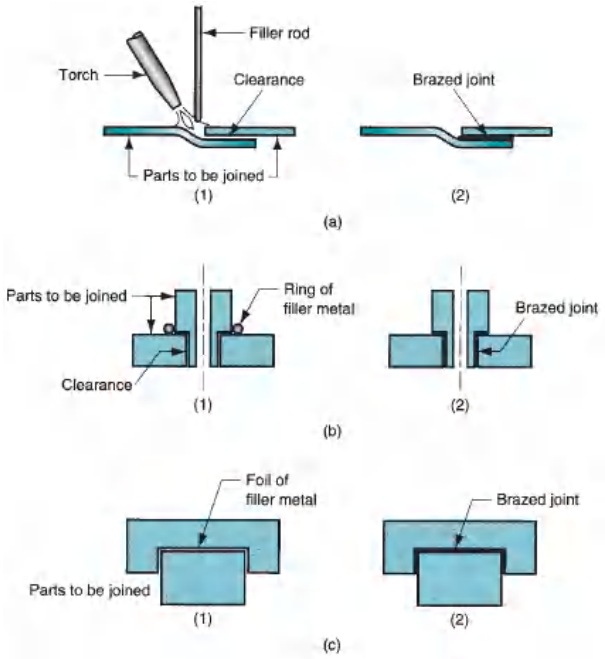


Fig 10.1.4 several techniques for applying filler metal in brazing: (a) torch and filler rod; (b) ring of filler metal at entrance of gap; and (c) foil of filler metal between flat part surfaces. Sequence: (1) before, and (2) after.

Fig.10.1.5 Application of brazing paste to joint by dispenser. (Courtesy of Fusion, Inc., Willoughby, Ohio.)

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. Areducing 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 a 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 lower 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 Fig 10.1.6, 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.

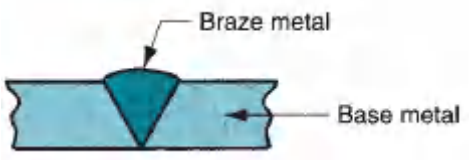


Fig 10.1.6 Braze welding. The joint consists of braze (filler) metal; no base metal is fused in the joint.

Soldering welding Technology

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 filler 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 pre cleaned 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. In some applications, the solder is pre-coated onto one or both of the surfaces-a process called tinning, irrespective of whether the solder contains any tin. Typical clearances in soldering range from 0.075 to 0.125 mm, except when the surfaces are tinned, in which case a clearance of about 0.025 mm is used. After solidification, the flux residue must be removed. As an industrial process, soldering is most closely associated with electronics assembly. It is also used for mechanical joints, but not for joints subjected to elevated stresses or temperatures.

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,
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.

Joint Designs in Soldering

As in brazing, soldered joints are limited to lap and butt types, although butt joints should not be used in load-bearing applications. Some of the brazing adaptations of these joints also apply to soldering, and soldering technology has added a few more variations of its own to deal with the

special part geometries that occur in electrical connections. In soldered mechanical joints of sheet-metal parts, the edges of the sheets are often bent over and interlocked before soldering, as shown in Fig 10.1.7, to increase joint strength. For electronics applications, the principal function of the soldered joint is to provide an electrically conductive path between two parts being joined. Other design considerations in these types of soldered joints include heat generation (from the electrical resistance of the joint) and vibration. Mechanical strength in a soldered electrical connection is often.

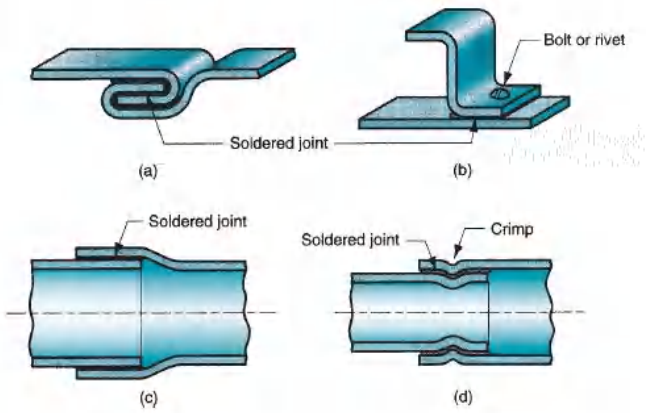


Fig 10.1.7 Mechanical interlocking in soldered joints for increased strength: (a) flat lock seam; (b) bolted or riveted joint; (c) copper pipe fittings lap cylindrical joint; and (d) crimping (forming) of cylindrical lap joint.

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. In soldering copper, common in electrical connections, intermetallic compounds of copper and tin are formed that strengthen the bond. Silver and antimony are also sometimes used in soldering

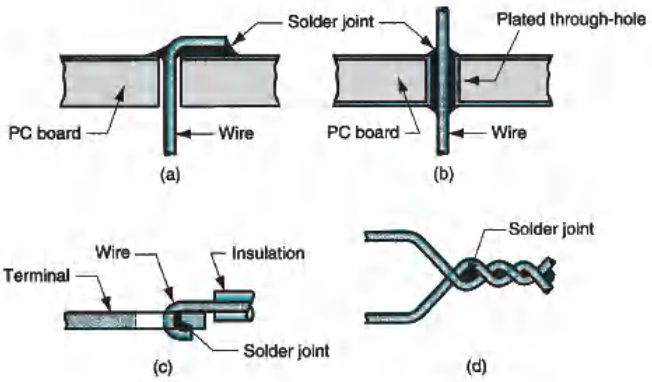


Fig 10.1.8 Techniques for securing the joint by mechanical means prior to soldering in electrical connections: (a) crimped lead wire on printed circuit board (PCB); (b) plated through hole on PCB to maximize solder contact surface; (c) hooked wire on flat terminal; and (d) twisted wires.

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.

Unfortunately, there is no single flux that serves all of these functions perfectly for all combinations of solder and base metals. The flux formulation must be selected for a given application. 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 at room temperatures. Inorganic fluxes consist of inorganic acids (e.g., muriatic acid) and salts (e.g., combinations of zinc and ammonium chlorides) and are used to achieve rapid and active fluxing where oxide films are a problem. The salts become active when melted, but are less corrosive than the acids. When solder wire is purchased with an acid core it is in this category. Both organic and inorganic fluxes should be removed after soldering, but it is especially important in the case of inorganic acids to prevent continued corrosion of the metal surfaces. Flux removal is usually accomplished using water solutions except in the case of rosins, which require chemical solvents. Recent trends in industry favor water-soluble fluxes over rosins because chemical solvents used with rosins are harmful to the environment and to humans.

Soldering Methods

Many of the methods used in soldering are the same as those used in brazing, except that less heat and lower temperatures are required for soldering. 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 hand 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. Some are designed as fast-heating soldering guns, which are popular in electronics assembly for intermittent (on/off) operation actuated by a trigger. They are capable of making a solder joint in about a second. 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 PCBon 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.

This third step is illustrated in Fig 10.1.9. The board is often inclined slightly, as depicted in the sketch, and special tinning oil is mixed with the molten solder to lower its surface tension. Both of these measures help to inhibit buildup of excess solder and formation of ‘‘icicles’’ on the bottom of the board. Wave soldering is widely applied in electronics to produce printed circuit

board assemblies. 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. Heating methods for reflow soldering include vapor phase reflow and infrared reflow. In vapor phase reflow soldering, an inert fluorinated hydrocarbon liquid is vaporized by heating in an oven; it subsequently condenses on the board surface where it transfers its heat of vaporization to melt the solder paste and form solder joints on the printed circuit boards. In infrared reflow soldering, heat from an infrared lamp is used to melt the solder paste and form joints between component leads and circuit areas on the board. Additional heating methods to reflow the solder paste include use of hot plates, hot air, and lasers.

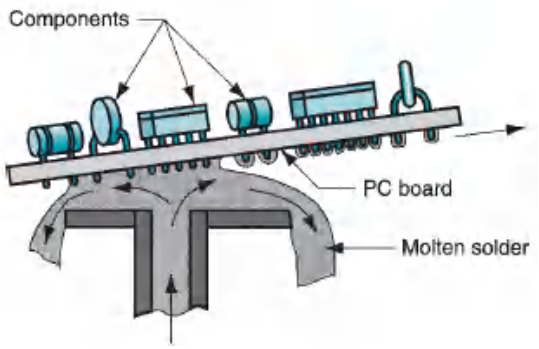


Fig 10.1.9 Wave soldering, in which molten solder is delivered up through a narrow slot onto the underside of a printed circuit board to connect the component lead wires.

Adhesive Bonding

Use of adhesives dates back to ancient times (Historical Note 31.1) and adhesive bonding was probably the first of the permanent joining methods. Today, adhesives are used in a wide range of bonding and sealing applications for joining similar and dissimilar materials such as metals, plastics, ceramics, wood, paper, and cardboard. Although well-established as a joining technique, adhesive bonding is considered a growth area among assembly technologies because of the tremendous opportunities for increased applications. Adhesive bonding is a joining process in which a filler material is used to hold two (or more) closely spaced parts together by surface attachment. The fillermaterial that binds the parts together is the adhesive. It is a nonmetallic substance—usually a polymer. The parts being joined are called adherends. Adhesives of greatest interest in engineering are structural adhesives, which are capable of forming strong, permanent joints between strong, rigid adherends. A large number of commercially available adhesives are cured by various mechanisms and suited to the bonding of various materials. Curing refers to the process by which the adhesive's physical properties are changed from a liquid to a solid, usually by chemical reaction, to accomplish the surface attachment of the parts. The chemical reaction may involve polymerization, condensation, or vulcanization. Curing is often motivated by heat and/or a catalyst, and pressure is sometimes applied between the two parts to activate the bonding process. If heat is required, the curing temperatures are relatively low, and so the materials being joined are usually unaffected; an advantage for adhesive bonding. The curing or hardening of the adhesive takes time, called curing time or setting time. In some cases this time is significant, generally a disadvantage in manufacturing.

Joint strength in adhesive bonding is determined by the strength of the adhesive itself and the strength of attachment between adhesive and each of the adherends. One of the criteria often used to define a satisfactory adhesive joint is that if a failure should occur due to excessive

stresses, it occurs in one of the adherends rather than at an interface or within the adhesive itself. The strength of the attachment results from several mechanisms, all depending on the particular adhesive and adherends: (1) chemical bonding, in which the adhesive unites with the adherends and forms a primary chemical bond upon hardening; (2) physical interactions, in which secondary bonding forces result between the atoms of the opposing surfaces; and (3) mechanical interlocking, in which the surface roughness of the adherend causes the hardened adhesive to become entangled or trapped in its microscopic surface asperities. For these adhesion mechanisms to operate with best results, the following conditions must prevail: (1) surfaces of the adherend must be clean—free of dirt, oil, and oxide films that would interfere with achieving intimate contact between adhesive and adherend; special preparation of the surfaces is often required; (2) the adhesive in its initial liquid form must achieve thorough wetting of the adherend surface; and (3) it is usually helpful for the surfaces to be other than perfectly smooth; a slightly roughened surface increases the effective contact area and promotes mechanical interlocking. In addition, the joint must be designed to exploit the particular strengths of adhesive bonding and avoid its limitations.

Joint Design

Adhesive joints are not generally as strong as those by welding, brazing, or soldering.
Accordingly, consideration must be given to the design of joints that are adhesively bonded.
The following design principles are applicable:

1. Joint contact area should be maximized
2. Adhesive joints are strongest in shear and tension as in Fig 10.1.10 (a) and (b), and joints should be designed so that the applied stresses are of these types.
3. Adhesive bonded joints are weakest in cleavage or peeling as in Fig 10.1.10 (c) and (d), and adhesive bonded joints should be designed to avoid these types of stresses.

Typical joint designs for adhesive bonding that illustrate these design principles are presented in Fig 10.1.11. Some joint designs combine adhesive bonding with other joining methods to increase strength and/or provide sealing between the two components. Some of the possibilities are shown in Fig 10.1.12. For example, the combination of adhesive bonding and spot welding is called weld bonding.

In addition to the mechanical configuration of the joint, the application must be selected so that the physical and chemical properties of adhesive and adherends are compatible under the service conditions to which the assembly will be subjected. Adherend materials include metals, ceramics, glass, plastics, wood, rubber, leather, cloth, paper, and cardboard. Note that the list includes materials that are rigid and flexible, porous and nonporous, metallic and nonmetallic and those similar or dissimilar substances can be bonded together.

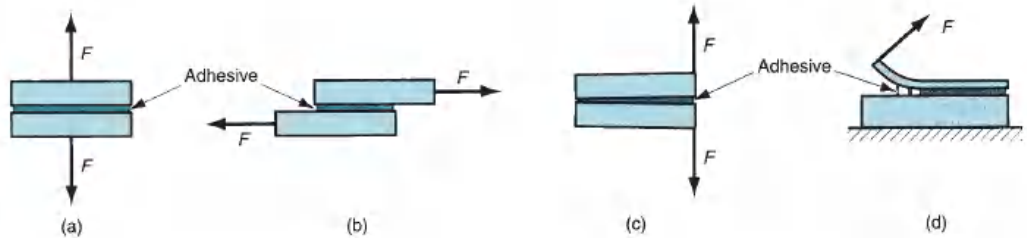


Fig 10.1.10 Types of stresses that must be considered in adhesive bonded joints: (a) tension, (b) shear, (c) cleavage, and (d) peeling.

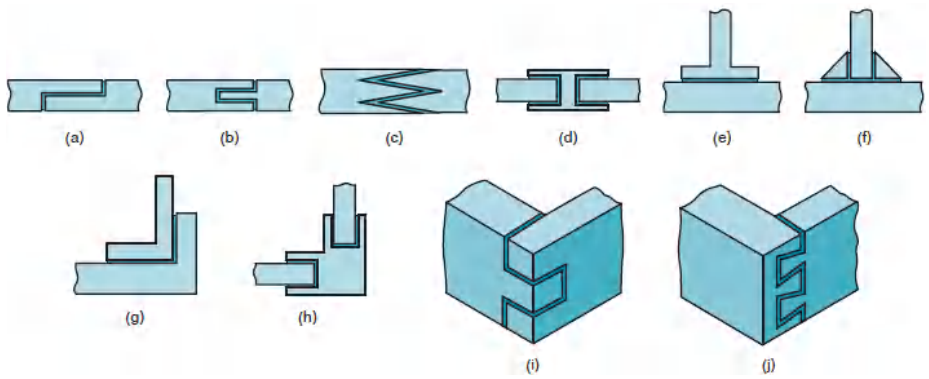


Fig 10.1.11 some joint designs for adhesive bonding: (a) through (b) butt joints; (c) and (d) T-joints; and (e) through (f) corner joints.

31.3.2 **Adhesive Types**

A large number of commercial adhesives are available. They can be classified into three categories:

1. Natural
2. Inorganic
3. Synthetic.

Natural adhesives are derived from natural sources (e.g., plants and animals), including gums, starch, dextrin, soy flour, and collagen. This category of adhesive is generally limited to low-stress applications, such as cardboard cartons, furniture, and bookbinding; or where large surface areas are involved (e.g., plywood). Inorganic adhesives are based principally on sodium silicate and magnesium oxchloride. Although relatively low in cost they are also low in strength-a serious limitation in a structural adhesive. Synthetic adhesives constitute the most important category in manufacturing. They are cured by various mechanisms, such as adhesion. For nonmetallic parts, solvent cleaning is generally used, and the surfaces are sometimes mechanically abraded or chemically etched to increase roughness. It is desirable to accomplish the adhesive bonding process as soon as possible after these treatments, since surface oxidation and dirt accumulation increase with time.

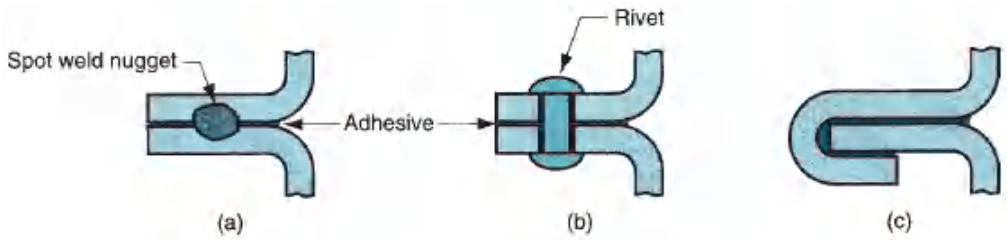


Fig 10.1.12 Adhesive bonding combined with other joining methods: (a) Weld bonding-spot welded and adhesive bonded; (b) riveted (or bolted) and adhesive bonded; and (c) formed plus adhesive bonded.

The actual application of the adhesive to one or both part surfaces is accomplished in a number of ways. The following list, though incomplete, provides a sampling of the techniques used in industry:

- Brushing, performed manually, uses a stiff-bristled brush. Coatings are often uneven.
- Flowing, using manually operated pressure-fed flow guns, has more consistent control than brushing.
- Manual rollers, similar to paint rollers, are used to apply adhesive from a flat container.
- Silk screening involves brushing the adhesive through the open areas of the screen onto the part surface, so that only selected areas are coated.

- Spraying uses an air-driven (or airless) spray gun for fast application over large or difficult-to-reach areas.
- Automatic applicators include various automatic dispensers and nozzles for use on medium- and high-speed production applications.

Roll coating is a mechanized technique in which a rotating roller is partially submersed in a pan of liquid adhesive and picks up a coating of the adhesive, which is then transferred to the work surface. Fig 10.1.13 shows one possible application, in which the work is a thin, flexible material (e.g., paper, cloth, and leather, plastic). Variations of the method are used for coating adhesive onto wood, wood composite, cardboard, and similar materials with large surface areas.

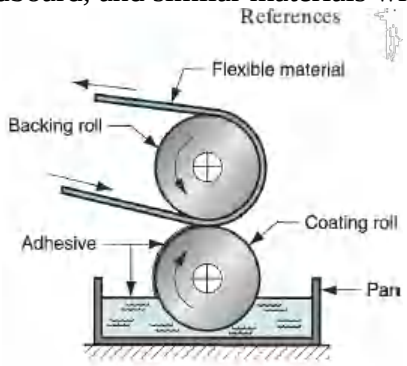


Fig 10.1.13 Roll coating of adhesive onto thin, flexible material such as paper, cloth, or flexible polymer.

Advantages and Limitations Advantages of adhesive bonding are:-

1. The process is applicable to a wide variety of materials;
2. Parts of different sizes and cross sections can be Joined-fragile parts can be joined by adhesive bonding
3. Bonding occurs over the entire surface area of the joint, rather than in discrete spots or along seams as in fusion welding, There by distributing stresses over the entire area
4. Some adhesives are flexible after bonding and are thus tolerant of cyclical loading and differences in thermal expansion of adherends
5. Low temperature curing avoids damage to parts being joined
6. Sealing as well as bonding can be achieved; and
7. Joint design is often simplified (e.g., two flat surfaces can be joined without providing special part features such as screw holes).

Principal limitations of this technology include

1. Joints are generally not as strong as other joining methods
2. Adhesive must be compatible with materials being joined;
3. Service temperatures are limited;
4. Cleanliness and surface preparation prior to application of adhesive are important;
5. Curing times can impose a limit on production rates; and
6. Inspection of the bonded joint is difficult.

Review Questions

1. Certain changes in joint configuration are usually made to improve the strength of brazed joints. What are some of these changes?
2. What are the two most common alloying metals used in solders?
3. What are the two most common alloying metals used in solders?
4. Certain changes in joint configuration are usually made to improve the strength of brazed joints. What are some of these changes?
5. What is the technical difference between brazing and soldering?
6. List the advantages often attributed to soldering as an industrial joining process?

7. What is wave soldering?
8. In brazing, the base metals melt at temperatures above 840_F (450_C) while in soldering they melt at 840_F (450_C) or below: (a) true or (b) false?
9. Which one of the following is not a function of a flux in brazing or soldering:
    a) chemically etch the surfaces to increase roughness for better adhesion of the filler metal
    b) promote wetting of the surfaces,
    c) protect the faying surfaces during the process
    d) Remove or inhibit formation of oxide films
10. In adhesive bonding, which one of the following is the term used for the parts that are joined:
    a) Adherend
    b) Adherent
    c) Adhesive
    d) Adhibit,
    e) Ad infinitum?

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Chapter Eleven

11. Introduction to Thermit, Electron-Beam and Laser-Bear Welding Technology

Electron-Beam Welding Electron-beam welding (EBW) is a fusion-welding process in which the heat for welding is produced by a highly focused, high-intensity stream of electrons impinging against the work surface. The equipment is similar to that used for electron-beam machining. The electron beam gun operates at high voltage to accelerate the electrons (e.g., 10–150 kV typical), and beam currents are low (measured in milliamps). The power in EBW is not exceptional, but power density is. High power density is achieved by focusing the electron beam on a very small area of the work surface, so that the power density PD is based on

$$PD = \frac{F_{1EI}}{A} \quad (11.1)$$

Where PD= power density, W/mm^2 f1 = heat transfer factor (typical values for EBW range from 0.8–0.95; E= accelerating voltage, V; I= beam current, A; and A= the work surface area on which the electron beam is focused, mm^2. Typical weld areas for EBW range from$13\ x10^{-3}\ to\ 2000x10^{-3}mm^2$. The process had its beginnings in the 1950s in the atomic power field. When first developed, welding had to be carried out in a vacuum chamber to minimize the disruption of the electron beam by air molecules. This requirement was, and still is, a serious inconvenience in production, due to the time required to evacuate the chamber prior to welding. The pump-down time, as it is called, can take as long as an hour, depending on the size of the chamber and the level of vacuum required. Today, EBW technology has progressed to where some operations are performed without a vacuum. Three categories can be distinguished:

1. High-vacuum welding (EBW-HV), in which welding is carried out in the same vacuum as beam generation;
2. Medium-vacuum welding (EBW-MV), in which the operation is performed in a separate chamber where only a partial vacuum is achieved; and
3. Non vacuum welding (EBW-NV), in which welding is accomplished at or near atmospheric pressure.

The pump-down time during workpart loading and unloading is reduced in medium-vacuum EBW and minimized in nonvacuum EBW, but there is a price paid for this advantage. In the latter two operations, the equipment must include one or more vacuum dividers (very small orifices that impede air flow but permit passage of the electron beam) to separate the beam generator (which requires a high vacuum) from the work chamber. Also, in nonvacuum EBW, the work must be located close to the orifice of the electron beam gun, approximately 13 mm or less. Finally, the lower vacuum processes cannot achieve the high weld qualities and depth-to-width ratios accomplished by EBW-HV. Any metals that can be arc welded can be welded by EBW, as well as certain refractory and difficult-to-weld metals that are not suited to AW. Work sizes range from thin foil to thick plate. EBW is applied mostly in the automotive, aerospace, and nuclear industries. In the automotive industry, EBW assembly includes aluminum manifolds, steel torque converters, catalytic converters, and transmission components. In these and other

applications, electron-beam welding is noted for high-quality welds with deep and/ or narrow profiles, limited heat-affected zone, and low thermal distortion. Welding speeds are high compared to other continuous welding operations. No filler metal is used, and no flux or shielding gases are needed. Disadvantages of EBW include high equipment cost, need for precise joint preparation and alignment, and the limitations associated with performing the process in a vacuum, as we have already discussed. In addition, there are safety concerns because EBW generates X-rays from which humans must be shielded.

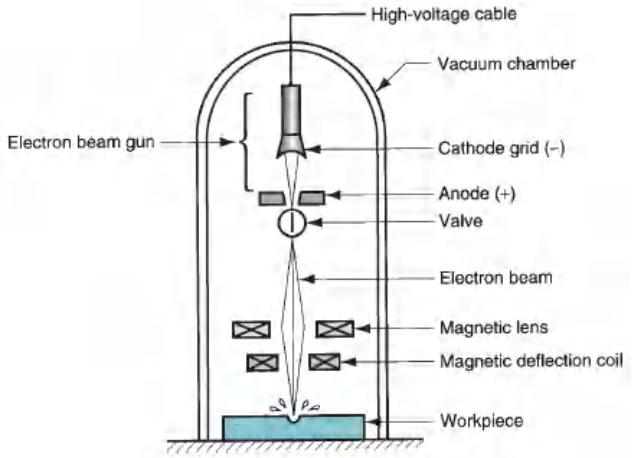

Fig.11.1.1 Electron beam machine

Laser-Beam Welding

Laser-beam welding (LBW) is a fusion-welding process in which coalescence is achieved by the energy of a highly concentrated, coherent light beam focused on the joint to be welded. The term laser is an acronym for light amplification by stimulated emission of radiation. This same technology is used for laser-beam machining. LBW is normally performed with shielding gases (e.g., helium, argon, nitrogen, and carbon dioxide) to prevent oxidation. Filler metal is not usually added. LBW produces welds of high quality, deep penetration, and narrow heat-affected zone. These features are similar to those achieved in electron-beam welding, and the two processes are often compared. There are several advantages of LBW over EBW: no vacuum chamber is required, no X-rays are emitted, and laser beams can be focused and directed by optical lenses and mirrors. On the other hand, LBW does not possess the capability for the deep welds and high depth-to-width ratios of EBW. Maximum depth in laser welding is about 19 mm, whereas EBW can be used for weld depths of
50 mm (2 in) or more; and the depth-to-width ratios in LBW are typically limited to around 5:1. Because of the highly concentrated energy in the small area of the laser beam, the process is often used to join small parts.

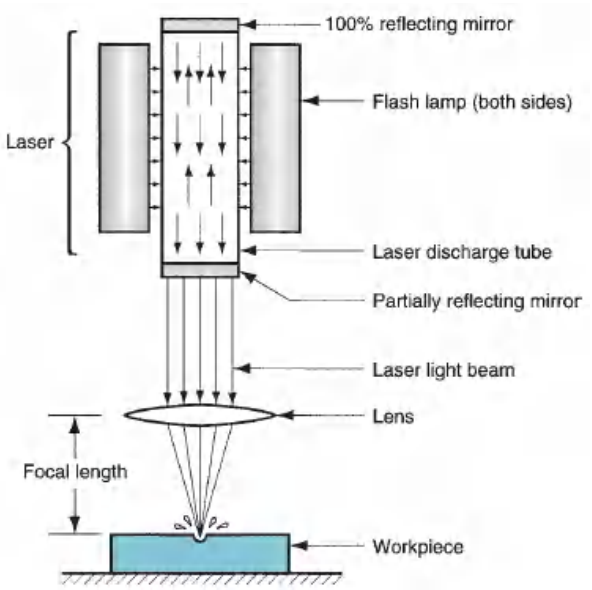

Fig.11.1.2 Laser beam machine (LBM)

Thermit Welding

Thermit is a trademark name for Thermite, a mixture of aluminum powder and iron oxide that produces an exothermic reaction when ignited. It is used in incendiary bombs and for welding. As a welding process, the use of Thermit dates from around 1900. Thermit welding (TW) is a fusion-welding process in which the heat for coalescence is produced by superheated molten metal from the chemical reaction of Thermit. Filler metal is obtained from the liquid metal; and although the process is used for joining, it has more in common with casting than it does with welding. Finely mixed powders of aluminum and iron oxide (in a 1:3 mixture), when ignited at a temperature of around 1300^0C (2300^0F), produce the following chemical reaction:

$$8Al + 3Fe_3O_4 \rightarrow 9Fe + 4Al_2O_3 + \text{heat} \quad (11.2)$$

The temperature from the reaction is around 2500_C (4500_F), resulting in superheated molten iron plus aluminum oxide that floats to the top as a slag and protects the iron from the atmosphere. In Thermit welding, the superheated iron (or steel if the mixture of powders is formulated accordingly) is contained in a crucible located above the joint to be welded, as indicated by our diagram of the process in Fig.11.1.2. After the reaction is complete (about 30 s, irrespective of the amount of Thermit involved), the crucible is tapped and the liquid metal flows into a mold built specially to surround the weld joint. Because the entering metal is so hot, it melts the edges of the base parts, causing coalescence upon solidification. After cooling, the mold is broken away, and the gates and risers are removed by oxyacetylene torch or other method. Thermit welding has applications in joining of railroad rails (as pictured in our figure), and repair of cracks in large steel castings and forgings such as ingot molds, large diameter shafts, frames for machinery, and ship rudders. The surface of the weld in these applications is often sufficiently smooth so that no subsequent finishing is required.

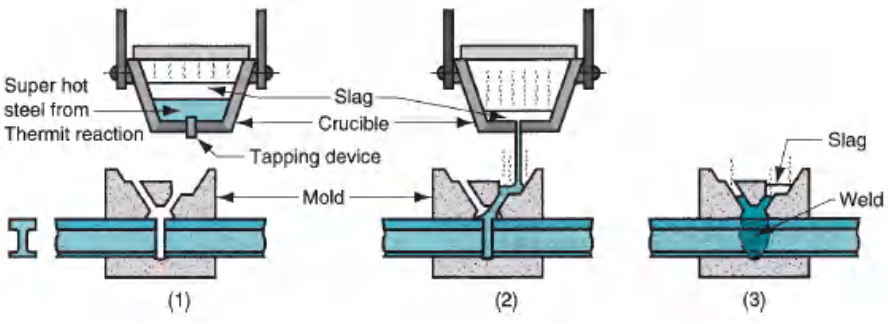

Fig.11.1.2 Thermit welding: (1) Thermit ignited; (2) crucible tapped, superheated metal flows into mold; (3) metal solidifies to produce weld joint.

Exercise

1. The term ‘‘laser’’ stands for ‘‘light actuated system for effective reflection’’: (a) true or (b) false?
2. The voltage in an EBW operation is 45 kV. The beam current is 60 milliamp. The electron beam is focused on a circular area that is 0.25 mm in diameter. The heat transfer factor is 0.87. Calculate the average power density in the area in watt/mm^2.
3. Thermit Welding uses what to work?
    a) Oxygen and acetylene gasses combined to form a flame
    b) Resistance of two metal held under pressure
    c) Enveloping tungsten using hydrogen gas
    d) An exothermic reaction between aluminum powder and metal oxides
4. Electron-beam welding has a significant disadvantage in high-production applications. What is that disadvantage?
5. Laser-beam welding and electron-beam welding are often compared because they both produce very high power densities. LBW has certain advantages over EBW. What are they?