UNIT-4

Computer numerical control Machines: Numerical control, computer numerical control, axis, co-ordinate system, types of slide control and control system.

Metal Joining Processes: Oxyacetylene welding, arc welding, electrodes, soldering and brazing.

Introduction to composites: Role of matrix and reinforcement, MMCs, PMCs and CMCs, advantages, limitations and applications.

5 NUMERICAL CONTROL OF MACHINE TOOL

History of numerical control

Numerical control is nothing new. As early as 1808 weaving machines utilized metal cards with holes punched in them to control the pattern of the cloth being produced. Each needle on the machine was controlled by the presence or absence of a hole on the punched cards. The punched cards were the program for the machine to get the desired pattern.

In the late 1940, Parasons conceived a method of using punched cards containing coordinate position data to control a machine tool. Parsons envisioned the following system.

A computer would calculate the path that the tool should follow and store that information on punched cards. A reader at the machine would then read the cards. The machine control would take the data from the reader and control the motors attached to each axis. The first machine produced by Parsons and MIT (Massachusetts Institute of Technology) was demonstrated in 1952. It was a three-axis vertical spindle milling machine and vacuum tubes were used in machine control.

Up until about 1976 these machines were called NC machines. In 1976 CNC machines were produced. These machine controls utilized microprocessors to give them additional capability. The NC *machines typically read one short program step (block) at a time and executed it,* however, CNC machine could store whole programs. Improvements in computer technology in the late 1970s and 1980s brought the cost of numerical control machines very low.

Numerical control

Numerical control (NC) may be defined as a method of controlling the operation of a machine tool by a series of coded instructions, consisting of numbers, letters of alphabet and symbols that the machine control unit can understand. The numerical data required to produce a part is known as *part program* and is used to control the relative position of work-to-tool, tool selection, turning on cutting fluid, feeds and speeds, etc. A numerical control machine tool system consists of the following three components (fig. 5.1).

1. Program of instructions, 2. Machine control unit (MCU) and 3. Machine tool

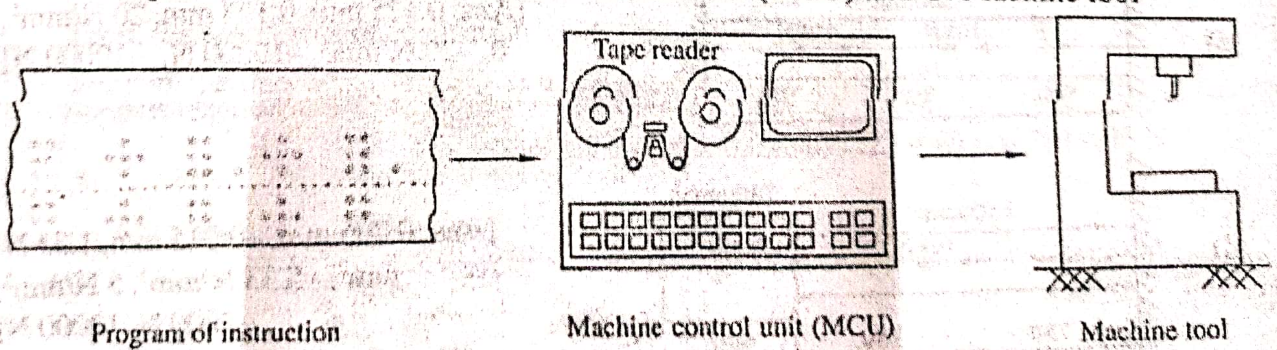


Fig. 5.1 Basic components of NC

Program of instructions: The part program (program of instructions) is the detailed step by step instructions by which the sequence of processing steps is to be performed. The programmer write the program on paper and recorded on a tape by means of tape punch. The most commonly used punched tape is 25 mm wide, 8 tracks, i.e., eight punched holes can be accommodated in one line across the width of tape. The tape is then played on a tape reader. The tape reader has the capacity of reading the punched holes either mechanically or electronically.

Machine control unit (MCU): The punched tape is played on a tape reader in the machine control unit. The controller unit interprets the program of instructions received from the tape reader and convert it into mechanical actions of machine tool, i.e., the signals are forwarded to servomotors which control the movement of the slides or spindle along X, Y and Z-axis. The controller unit controls the path to be followed by the cutting tool spindle speeds, feed rate, tool changes and several other functions of the machine tool.

Machine tool: The machine tool perform the machining operations. It consists of work table motors, spindle motors and controls. It also includes the cutting tools, fixtures and other auxiliary equipment needed in the machining operation. The machine tool has the capacity to change the tools automatically under tape command. The machine table can orient the job so that it can be machined on several surfaces as required.

NC procedure

The following steps must be accomplished to utilize the numerical control in manufacturing.

1. *Process planning:* In process planning, the work part drawing must be interpreted in terms of manufacturing processes to be used and to prepare route sheet. The route sheet is a listing of the sequence of operations which must be performed on the workpart.

2. *Part programming:* Part program is the procedure by which the sequence of processing steps to be performed on the NC Machine is planned and documented. There are two ways to program for NC. i) Manual part programming ii) Computer - assisted part programming.

The manual part programming consists of (i) calculating dimensional relationships of the tool and work piece, based on engineering drawings of the part, and (ii) the manufacturing operations to be performed and their sequence. A program sheet is then prepared, which consists of the necessary information to carry out the operation, such as cutting tools, spindle speeds, feeds, depth of cut cutting fluids, and tool or workpiece relative positions and movements.

Computer assisted part programming involves special symbolic programming languages that determine the coordinate points of corners, edges, and surfaces of the part. Thus the tedious computational work required in manual part programming is transferred to the computer.

3. *Tape preparation:* The program of instructions are placed on the NC tape by punching a specific pattern of holes. This is accomplished on a special typewriter tape punch machine. The typewriter keyboard operates in a similar manner as a standard typewriter. The tape punch is activated as each typewriter key is depressed. This produces a unique pattern of holes in the tape.

4. *Tape verification:* The typewriter tape punch also has a tape reading head. The reader is used to obtain a printed record of a punched tape. This is useful for verifying tape accuracy. If there is an error in the tape information, it can be detected and corrected. The typewriter reader is also used to duplicate tapes. The tape can also be checked by running it through computer program which plots the various tool movements.

5. Production: The final step in NC procedure is to use NC tape in production. The operator has to load new stock in the machine and play the tape in the tape reader usually found in the machine control unit. The NC system then takes over and machine the part according to the instructions on tape. When the part is completed, the operator remove the finished part from the machine and loads the next stock. Except for downtime due to re-sharpening of cutting tools or routine maintenance, the NC machine tool can function continuously.

Axes and coordinate system

In order for the part programmer to plan the sequence of positions and movements of the cutting tool relative to the workpiece, it is necessary to establish a standard axis system by which the relative positions can be specified. The machine tool motions are generally described in X-Y-Z Cartesian space. The axis of the spindle or the axis parallel to the spindle represented as Z-axis. The X-axis lies on a horizontal plane parallel to the work table. The positive or negative movement of the three axis is based on right hand rule.

Lathes or *turning center* typically use only X and Z axis as shown in fig. 5.2. The Z denotes the movement parallel to the spindle axis and controls the length of the part. The X-axis is perpendicular to the spindle and controls the diameter of the part.

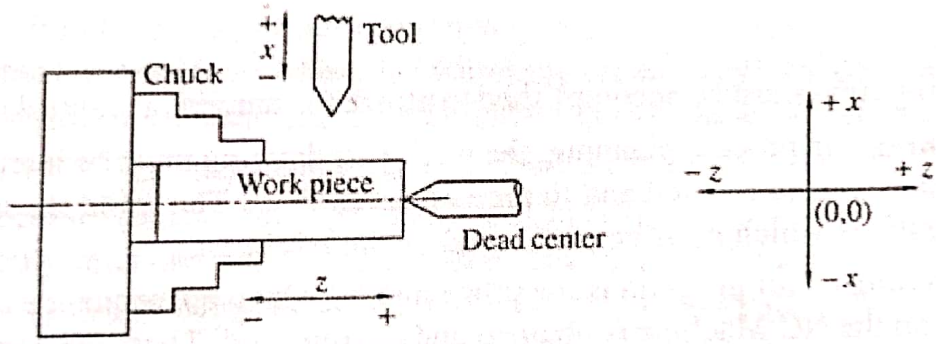


Fig. 5.2 Turning machine axis orientation

Milling machines or *machining center* use all the three axes as shown in fig. 5.3. On a vertical milling machine, the Z-axis denotes the movement parallel to the spindle axis, i.e., the up and down movement of the spindle or table. The X-axis (longest motion of the table) moves to the operator's left and right. The Y-axis moves toward and away from the operator. The Y-axis usually has the shortest travel.

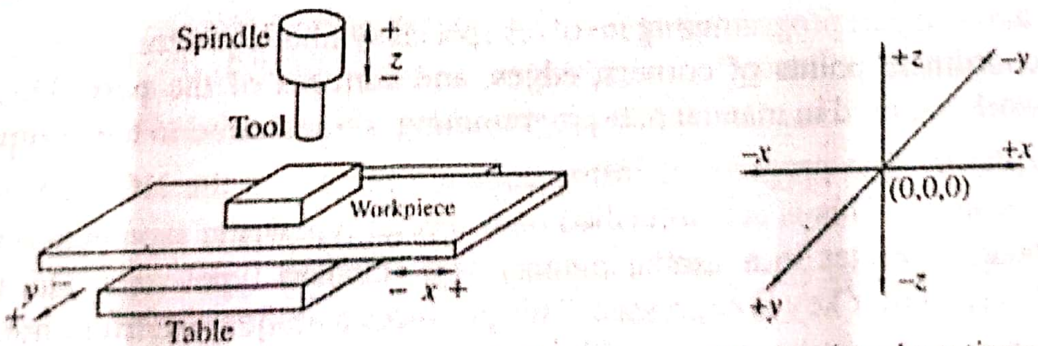


Fig. 5.3 Machining center (vertical milling machine) axis orientation

Fixed zero and floating zero (datum location): The programmer must determine the position machines are of an absolute type. The incremental programming implies that each move is specified as an incremental move from the previous position. An absolute and incremental measurement of a part are shown in fig. 5.6a and fig. 5.6b respectively.

Absolute positioning systems have a major advantage over incremental positioning. If the programmer makes a mistake when using absolute positioning, the mistake is isolated to the one location. When the programmer makes a positioning error using incremental positioning, all future positions are affected. Most NC machines allow the programmer to mix absolute and incremental programming.

Control-loops

Every control system, including NC systems may be designed as either an open loop or a closed-loop control system. Open loop systems provide no check or measurement to verify that a specific position has actually been reached. No feedback information is passed from the machine tool back to the controller. In an open loop system, a stepping motor is generally employed as the driving component to provide the machine-slide motion.

The program commands are converted into electric pulses or signals by the controller unit. These pulses are fed to the stepping motor. The stepping motor is an electromechanical device driven by an electrical pulse train to produce a sequence of angular movements corresponding to the number of pulses. Since there is no feedback from the slide position, the systems accuracy is solely a function of the motor's ability to step through the exact number of steps provided as its input. Fig. 5.7 shows an open-loop control system for a single axis of motion.

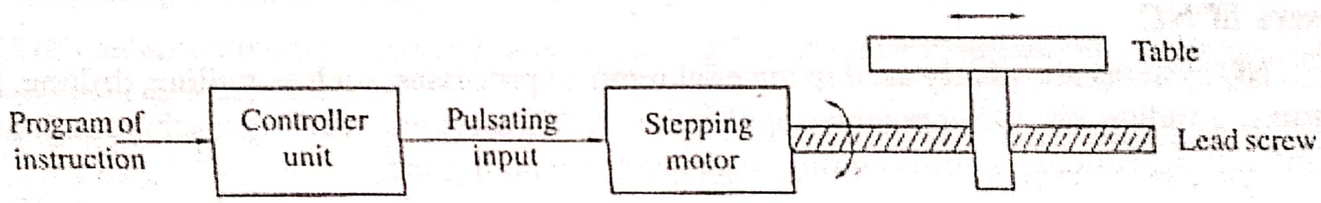
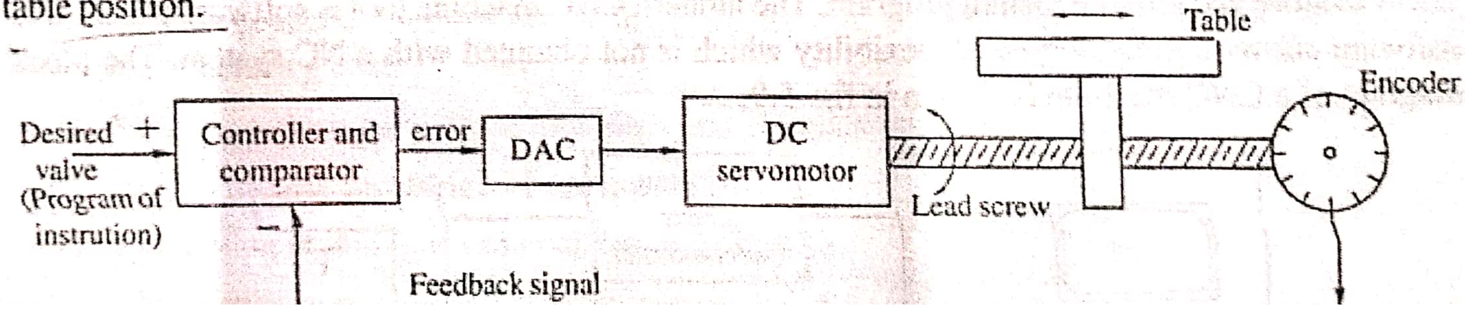


Fig. 5.7 Open-loop control in NC

One of the disadvantages of the stepping motor as the drive unit is the possible loss of one or more pulses when the motor is operating under heavy loads. This results in a loss in accuracy of table position.



Advantages and disadvantages of NC

Advantages:

1. Flexibility of operation is improved, as is the ability to produce complex shapes with good dimensional accuracy.
2. Reduced non machining and lead time.
3. Reduced inventory.
4. Reduced floor space requirements.
5. Reduced tool costs, since templates and other fixtures are not required.
6. High productivity.
7. High product quality.
8. Longer tool life.
9. Easy to modify the design of components.
10. Consistency using the correct speeds, feeds and tooling to achieve optimum productivity.

Disadvantages:

1. Relatively high initial cost of the equipment.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Users of NC

NC systems are widely used in material removal processes, such as milling, drilling, boring, turning, grinding, etc. Other potential applications of NC are, press working machine tool, welding, flame cutting, bending, plasma cutting, laser beam machining, etc.

Computer Numerical Control (CNC)

NC controls must read the program each time a part is run. They have no means of storing or editing the existing programs. In CNC machine, the control unit contains a computer which will allow to store and edit the loaded program. The modern CNC machine tool is software driven. The software allows a great degree of flexibility which is not obtained with a NC system. The block diagram of a CNC machine is shown in fig. 5.9.

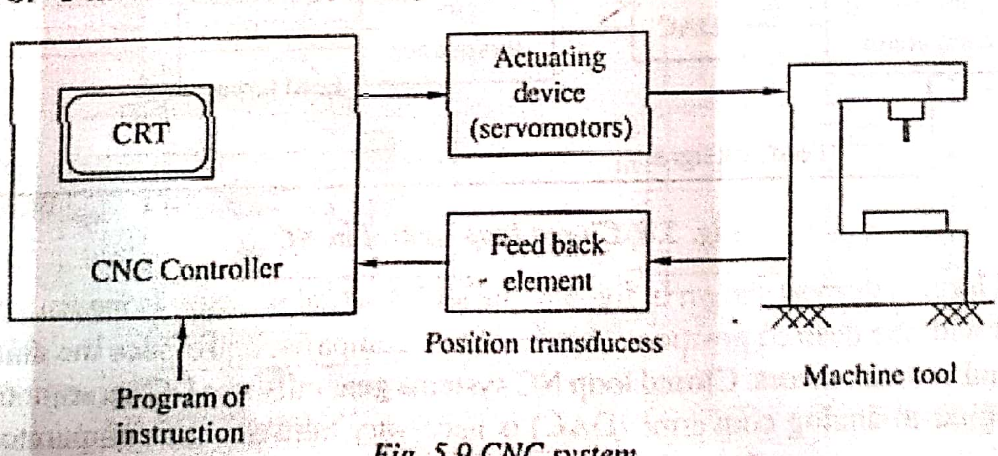


Fig. 5.9 CNC system

can see the loaded program, tool and cutter offsets, machine position
tool path simulation, etc. The tool path simulation can be used to
program is run to eliminate programming errors that could damage to

The information for each operation is fed from the control unit
motors turn the ball screws, which in-turn drive the different axes of th
capability and speed of computers make it possible to continuously
and velocity while it is operating. CNC machine offers accuracy
productivity.

Advantages and disadvantages of CNC machines

Advantages:

1. Part program tape and tape reader are used only once to ent memory. This results in improved reliability.
2. Tape editing is possible at the machine site.
3. CNC can accommodate conversion of tapes prepared in units c system of units.
4. High degree of accuracy and reduction of scrap.
5. Greater flexibility and capabilities.
6. Reduced non-machining time and lead time for production.
7. Faster in operation and high productivity.
8. Easy to produce components of high quality and accuracy manufacturing cost.

... complex geometry.

Disadvantages:

1. High initial cost.
2. High maintenance cost.
3. Requires skilled programmers and operators.

Direct Numerical Control (DNC)

In direct numerical control, several machines are directly controlled step by step by a central mainframe computer. In this system, the operator has access to the central computer through a remote terminal. Thus handling tapes and need for computers on each machine are eliminated. The computer is designed to provide instructions to each machine tool on demand. With DNC, the status of all machines in a manufacturing plant can be monitored and assessed from the central computer. However, DNC has the disadvantage that if the computer goes down, all the machines become inoperative.

Components of DNC system

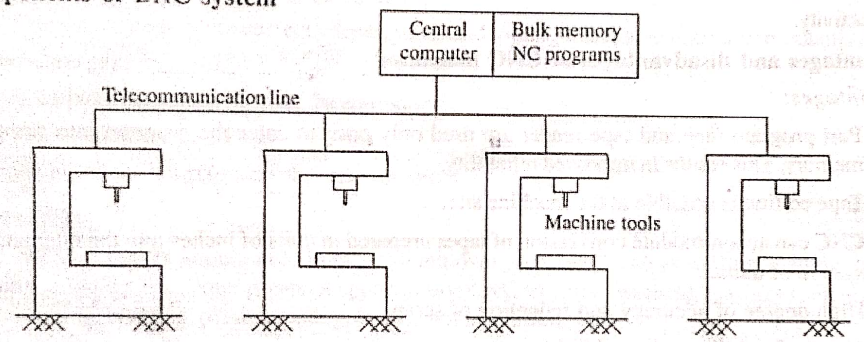


Fig. 5.10 DNC system

Fig. 5.10 illustrates the configuration of the basic DNC system. It consists of four basic components.

1. Central computer,
2. Bulk memory to store NC programs,
3. Telecommunication lines and
4. Machine tools.

The computer calls the part program instructions from the bulk storage and sends them to the individual machines as the need arises. The feature of DNC system is that the computer is servicing a large number of separate machine tools, all in real time.

A more recent DNC (Distributed Numerical Control) includes the use of central computer serving as the control system over a number of individual computer numerical control machines with onboard micro computers (fig. 5.11). This system provides large memory and computational capabilities, thus offering flexibility while overcoming the previous disadvantage of DNC. The central computer downloads complete programs to CNC machines as required. These machines may store one or more programs in their local storage, and they are thus independent of the central

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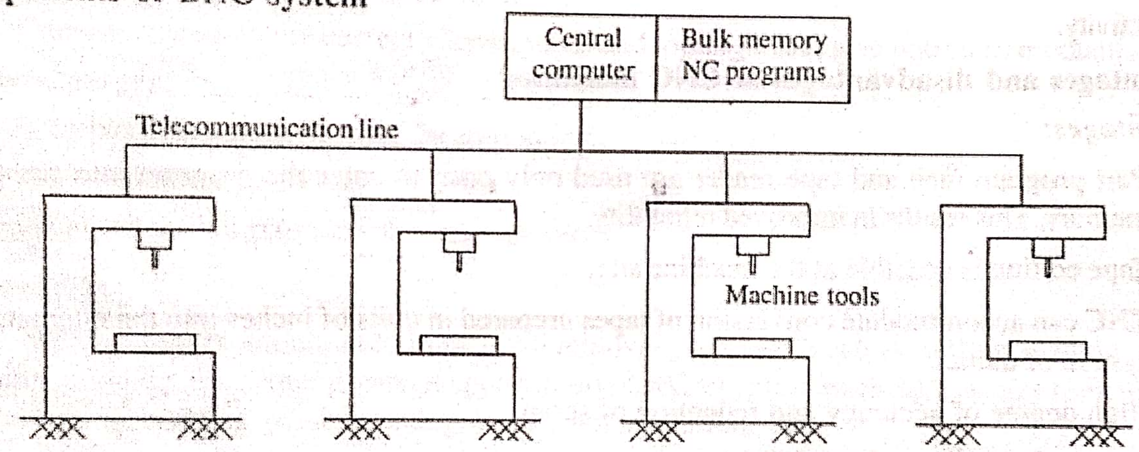

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METAL JOINING PROCESSES

SOLDERING, BRAZING AND WELDING:

SOLDERING:

Soldering is a method of joining two thin metal pieces using a dissimilar metal or an alloy by the application of heat.

- Temperature is range of 150 to 350 degree.
- Application of flux is externally, usually rosin or borax.
- Soldering application will be electronics circuits.

PRINCIPLE OF SOLDERING

Soldering is very much similar to brazing and its principle is same as that of brazing. The major difference lies with the filler metal, the filler metal used in case of soldering should have the melting temperature lower than 450oC. The surfaces to be soldered must be pre-cleaned so that these are faces of oxides, oils, etc. An appropriate flux must be applied to the faying surfaces and then surfaces are heated. Filler metal called solder is added to the joint, which distributes between the closely fitted surfaces. Strength of soldered joint is much lesser than welded joint and les than a brazed joint.

Advantages of soldering

1) Solder joints are easy to repair
2) Solder joints are corrosion resistance.
3) Low cost and easy to use.
4) Skilled operator is required.

BRAZING:

Brazing is a method of joining two similar or dissimilar metals using a special fusible alloy. The filler metal melts and diffuses over the joint placed.

- The filler metal is called as **Spelters.**
- The flux used is borax or boric acid.
- The brazing is used in copper alloys applications.

- The temperature range is 450 to 900 degree.

PRINCIPLE OF BRAZING

In case of brazing joining of metal pieces is done with the help of filler metal. Filler metal is melted and distributed by capillary action between the faying surfaces of the metallic parts being joined. In this case only filler metal melts. There is no melting of workpiece metal. The filler metal (brazing metal) should have the melting point more than 450^{o} C. Its melting point should be lesser than the melting point of workpiece metal. The metallurgical bonding between work and filler metal and geometric constrictions imposed on the joint by the workpiece metal make the joint stronger than the filler metal out of which the joint has been formed.

BRAZING PROCESSES

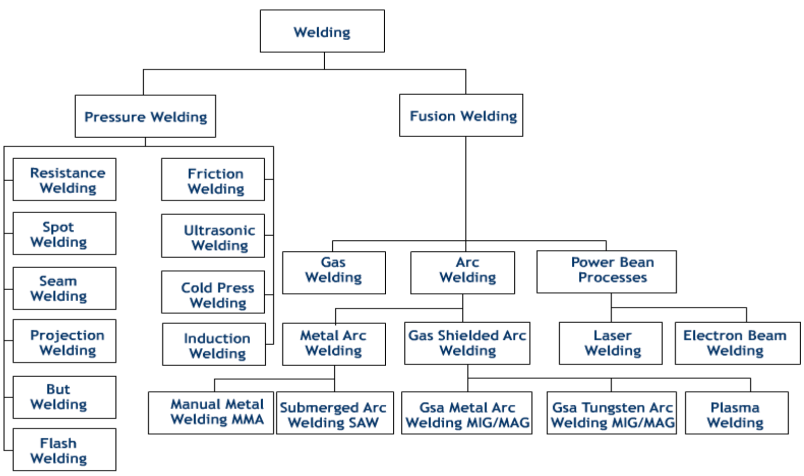
All the processes covered here can also be applied to soldering processes. These common processes are.

1. Torch Brazing
2. Furnace Brazing
3. Induction Brazing
4. Resistance Brazing
5. Dip Brazing
6. Infrared Brazing

WELDING

WELDING: Welding is a process of metallurgically joining two pieces of metals by the application of heat with or without the application of pressure and addition of filler metal. The joint formed is a permanent joint. Modern methods of welding may be classified under two broad headings.

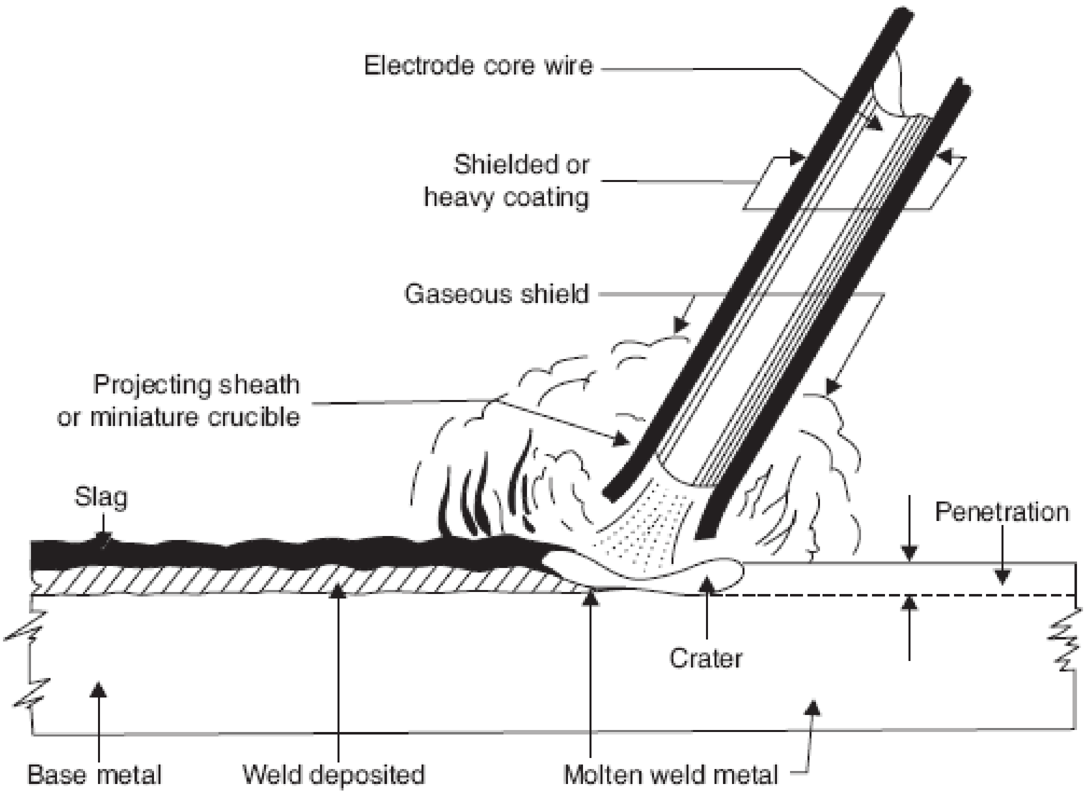
Classification of welding



Types of Welding

1) **Fusion Welding:** joining two metal pieces is heated up to molten state and allowed to solidify, also called as no-pressure welding.
   Ex- Arc welding and Gas welding
2) **Pressure welding:** joining parts to be heated up to plastic state and applying external pressure.
   Ex- Resistance welding and Forge welding.

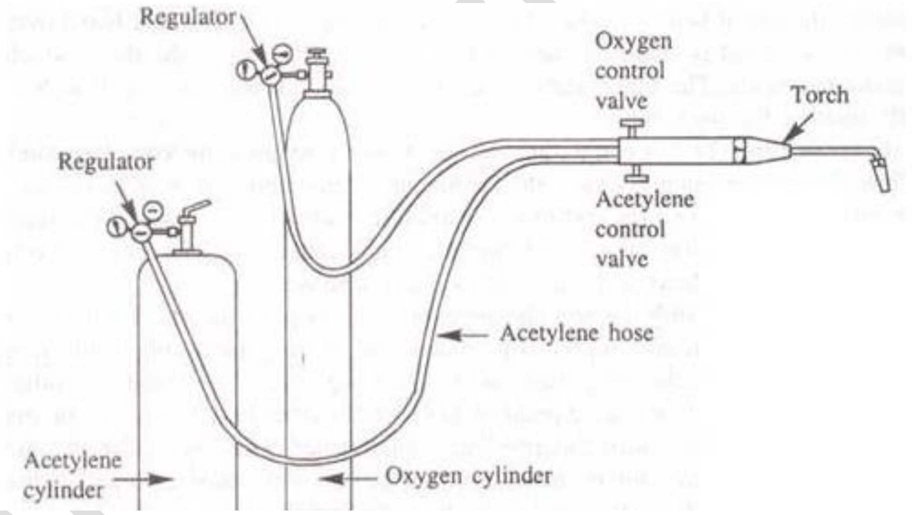
Electric Arc Welding



A typical arc welding setup is shown in Figure. Arc welding is a method of joining metals with heat produced by an electrical arc. In this process the heat necessary to melt the edges of the metal to be joined is obtained from an electric are struck between the electrode (filler rod) and the work, producing a temperature of 3000-4000^{O} C, in the welding zone. The heat of the arc melts the base metal or edges of the parts fusing them together. Filler metal, usually added melts and mixes with molten base metal to form the weld metal. The weld metal cools and solidifies to form the weld. In most cases, the composition of the filler material, known as welding rod, needed to provide extra metal to the weld, is same as that of the material being welded.

Oxy-Acetylene Welding

Gas welding is a fusion welding process, in which a flame produced by the combustion of gases is employed to melt the metal. The molten metal is allowed to flow together thus forming a solid continuous joint upon cooling. By burning pure oxygen in combination with other gases, in special torches, a flame upto 5000^{O}C can be attained. The gas is purchased in cylinder and connected through resulting valves and pressure gauges into flexible hoses attached to the nozzle. A typical arrangement is shown in Figure



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Types of flames:

1. **Neutral Flame**
2. **Carbonizing Flame**
3. **Oxidizing Flame**

1. Neutral Flame

The correct adjustment of the flame is very important for reliable works. When oxygen and acetylene are supplied to the torch in nearly equal volumes, a neutral flame is produced having a maximum temperature of 3200C. This neutral flame is desired for most welding operations. Neutral flame has little effect on the base metal and sound welds are produced when compared to other flames. Figure shows neutral flame.

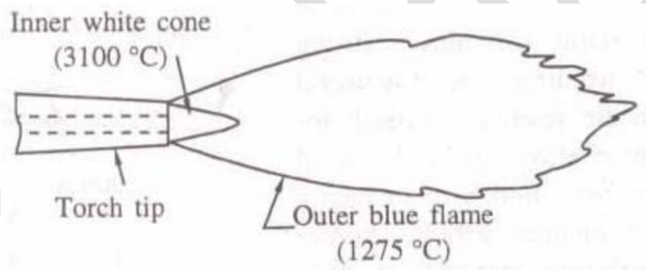

Fig : 1. **Neutral Flame**

2. Carbonizing Flame

In a carbonizing flame or reducing flame excess of acetylene is present. The temperature of this flame is low. The excess unburnt carbon is absorbed in ferrous metals, making the weld hard and brittle. In between the outer blue flame and inner white cone, an intermediate flame feather exists, which is reddish in colour. The length of the flame feather is an indication of the excess acetylene present. Figure shows a carbonizing flame. Carbonizing flame is used for welding high carbon steels and cast iron, alloy steel and for hard facing.

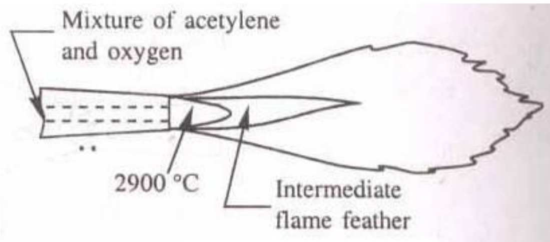

Figure : Carbonizing Flame

3. Oxidizing Flame

In an oxidizing flame excess of oxygen is present. The flame is similar to the neutral flame with the exception that the inner white cone is some what small, giving rise to higher tip temperatures. Excess of oxygen in the oxidizing flame causes the metal to burn or oxidize quickly. Oxidizing flame is useful for welding some nonferrous alloys such as copper and zinc base alloys. The Figure 7 shows the oxidizing flame.

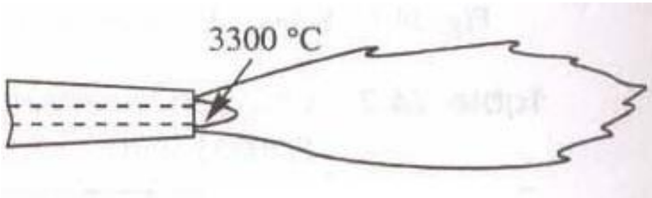

Figure : Oxidizing Flame

Differences between soldering, brazing and Welding

Sl. No.	Welding	Soldering	Brazing
1	These are the strongest joints used to bear the load. Strength of a welded joint may be more than the strength of base metal.	These are weakest joint out of three. Not meant to bear the load. Use to make electrical contacts generally.	These are stronger than soldering but weaker than welding. These can be used to bear the load up to some extent.
2	Temperature required is up to 3800°C of welding zone.	Temperature requirement is up to 450°C.	It may go to 600oC in brazing.
3	Work piece to be joined need to be heated till their melting point.	No need to heat the work pieces.	Work pieces are heated but below their melting point.
4	Mechanical properties of base metal may change at the joint due to heating and cooling.	No change in mechanical properties after joining.	May change in mechanical properties of joint but it is almost negligible.
5	Heat cost is involved and high skill level is required.	Cost involved and skill requirements are very low.	Cost involved and sill required are in between others two.
6	Heat treatment is generally required to eliminate undesirable effects of welding.	No heat treatment is required.	No heat treatment is required after brazing.
7	No preheating of work piece is required before welding as it is carried out at high temperature.	Preheating of work pieces before soldering is good for making good quality joint.	Preheating is desirable to make strong joint as brazing is carried out at relatively low temperature.

INTRODUCTION TO COMPOSITES

Fibers or particles embedded in **matrix** of another material are the best example of modern-day composite materials, which are mostly structural.

Laminates are composite material where different layers of materials give them the specific character of a composite material having a specific function to perform. **Fabrics** have no matrix to fall back on, but in them, fibers of different compositions combine to give them a specific character. **Reinforcing materials** generally withstand maximum load and serve the desirable properties.

Further, though composite types are often distinguishable from one another, no clear determination can be really made. To facilitate definition, the accent is often shifted to the levels at which differentiation take place viz., **microscopic** or **macroscopic**. In **matrix**-based structural composites, the matrix serves two paramount purposes viz., binding the **reinforcement phases** in place and deforming to distribute the stresses among the constituent **reinforcement materials** under an applied force.

The demands on matrices are many. They may need to temperature variations, be conductors or resistors of electricity, have **moisture sensitivity** etc. This may offer weight advantages, ease of handling and other merits which may also become applicable depending on the purpose for which matrices are chosen.

Solids that accommodate stress to incorporate other constituents provide strong bonds for the reinforcing phase are potential **matrix materials**. A few inorganic materials, polymers and metals have found applications as matrix materials in the designing of structural composites, with commendable success. These materials remain elastic till failure occurs and show decreased failure strain, when loaded in tension and compression.

A composite material is made by combining two or more materials – often ones that have very different properties. The two materials work together to give the composite unique properties. However, within the composite you can easily tell the different materials apart as they do not dissolve or blend into each other

1. Classification of Composites I (Based on Matrix Material)

1. Metal Matrix Composites (MMC)

Metal Matrix Composites are composed of a metallic matrix (aluminum, magnesium, iron, cobalt, copper) and a dispersed ceramic (oxides, carbides) or metallic (lead, tungsten, molybdenum) phase.

2. Ceramic Matrix Composites (CMC)

Ceramic Matrix Composites are composed of a ceramic matrix and embedded fibers of other ceramic material (dispersed phase)

3. Polymer Matrix Composites (PMC)

Polymer Matrix Composites are composed of a matrix from thermoset (Unsaturated Polyester (UP), Epoxy (EP)) or thermoplastic (Polycarbonate (PC),Polyvinylchloride, Nylon, Polystyrene) and embedded glass, carbon, steel or Kevlar fibers (dispersed phase).

2. Classification of composite materials II (based on reinforcing material structure)

1. Particulate Composites

Particulate Composites consist of a matrix reinforced by a dispersed phase in form of particles.

1.Composites with random orientation of particles.

2.Composites with preferred orientation of particles. Dispersed phase of these materials consists of two-dimensional flat platelets (flakes), laid parallel to each other.

2. Fibrous Composites

1. Short-fiber reinforced composites. Short-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of discontinuous fibers (length < 100*diameter).
   I. Composites with random orientation of fibers.
   II. Composites with preferred orientation of fibers.
2. Long-fiber reinforced composites. Long-fiber reinforced composites consist of a matrix reinforced by a dispersed phase in form of continuous fibers.
   I. Unidirectional orientation of fibers.
   II. Bidirectional orientation of fibers (woven).

3. Laminate Composites

When a fiber reinforced composite consists of several layers with different fiber orientations, it is called multilayer (angle-ply) composite.

Classification of Composites

Composite materials are commonly classified at following two distinct levels:

• The first level of classification is usually made with respect to the matrix constituent. The major composite classes include Organic Matrix Composites (OMCs), Metal Matrix Composites (MMCs) and Ceramic Matrix Composites (CMCs). The term organic matrix composite is generally assumed to include two classes of composites, namely Polymer Matrix Composites (PMCs) and carbon matrix composites commonly referred to as carbon-carbon composites.

• The second level of classification refers to the reinforcement form - fibre **reinforced composites**, **laminar composites** and **particulate composites**. Fibre Reinforced composites (FRP) can be further divided into those containing discontinuous or continuous fibres.

• **Fibre Reinforced Composites** are composed of fibres embedded in matrix material. Such a composite is considered to be a discontinuous fibre or short fibre composite if its properties vary with fibre length. On the other hand, when the length of the fibre is such that any further increase in length does not further increase, the elastic modulus of the composite, the composite is considered to be continuous fibre reinforced. Fibres are small in diameter and when pushed axially, they bend easily although they have very good tensile properties. These fibres must be supported to keep individual fibres from bending and buckling.

• **Laminar Composites** are composed of layers of materials held together by matrix. Sandwich structures fall under this category.

• **Particulate Composites** are composed of particles distributed or embedded in a matrix body. The particles may be flakes or in powder form. Concrete and wood particle boards are examples of this category

Polymer Matrix Composites (PMC)/Carbon Matrix Composites or Carbon-Carbon Composites

Polymers make ideal materials as they can be processed easily, possess lightweight, and desirable mechanical properties. It follows, therefore, that high temperature resins are extensively used in aeronautical applications.

Two main kinds of polymers are **thermosets** and **thermoplastics**. Thermosets have qualities such as a well-bonded three-dimensional molecular structure after curing. They decompose instead of melting on hardening. Merely changing the basic composition of the resin is enough to alter the conditions suitably for curing and determine its other characteristics. They can be retained in a partially cured condition too over prolonged periods of time, rendering Thermosets very flexible. Thus, they are most suited as matrix bases for advanced conditions fiber reinforced composites. Thermosets find wide ranging applications in the **chopped fiber composites** form particularly when a premixed or moulding compound with fibers of specific quality and aspect ratio happens to be starting material as in epoxy, polymer and phenolic polyamide resins.

Thermoplastics have one- or two-dimensional molecular structure and they tend to at an elevated temperature and show exaggerated melting point. Another advantage is that the process of softening at elevated temperatures can reversed to regain its properties during cooling, facilitating applications of **conventional compress techniques** to mould the compounds.

Resins reinforced with thermoplastics now comprised an emerging group of composites. The theme of most experiments in this area to improve the base properties of the resins and extract the greatest functional advantages from them in new avenues, including attempts to replace metals in die-casting processes. In crystalline thermoplastics, the reinforcement affects the **morphology** to a considerable extent, prompting the reinforcement to empower nucleation. Whenever **crystalline** or **amorphous**, these resins possess the facility to alter their **creep** over an extensive range of temperature. But this range includes the point at which the usage of resins is constrained, and the reinforcement in such systems can increase the failure load as well as creep resistance. Figure M1.2.1 shows kinds of thermoplastics

Metal Matrix Composites (MMC)

Metal matrix composites, at present though generating a wide interest in research fraternity, are not as widely in use as their plastic counterparts. High **strength**, **fracture toughness** and **stiffness** are offered by metal matrices than those offered by their polymer counterparts. They can withstand elevated temperature in corrosive environment than polymer composites. Most metals and alloys could be used as matrices and they require reinforcement materials which need to be stable over a range of temperature and non-reactive too. However the guiding aspect for the choice depends essentially on the matrix material. Light metals form the matrix for temperature application and the reinforcements in addition to the aforementioned reasons are characterized by high moduli.

Most metals and alloys make good matrices. However, practically, the choices for low temperature applications are not many. Only light metals are responsive, with their low density proving an advantage. Titanium, Aluminium and magnesium are the popular matrix metals currently in vogue, which are particularly useful for aircraft applications. If metallic matrix materials have to offer high strength, they require high modulus reinforcements. The strength-to-weight ratios of resulting composites can be higher than most alloys.

The melting point, physical and mechanical properties of the composite at various temperatures determine the service temperature of composites. Most metals, ceramics and compounds can be used with matrices of low melting point alloys. The choice of reinforcements becomes more stunted with increase in the melting temperature of matrix materials.

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