# Chapter 3

# Sheet Metal Working Joining Processes

CHAPTER HIGHLIGHTS

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- Shearing Action
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## Sheet Metal Working

Sheet metal working or press working of sheet metals is a chipless manufacturing method producing various components using sheet metal. The operations are generally carried out by punches and dies. These can be grouped into two categories.

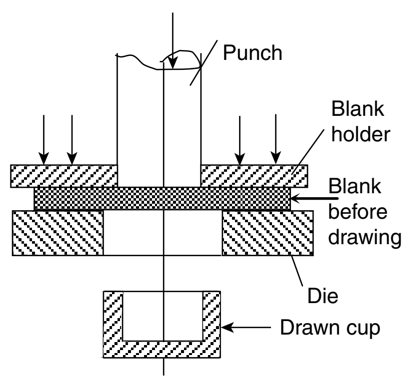
1. Cutting or shearing operations
2. Forming operations

Cutting/shearing operations involve shearing action and include blanking, piercing, punching, notching, perforating, trimming, shaving, slitting, lancing, slotting, parting etc.

Forming operations include bending, drawing, squeezing, spinning etc.

### Drawing

Drawing is the process of shaping a flat or hollow blank into a three dimensional hollow component without any appreciable change in sheet thickness. Considerable compressive stresses appear in the flange portion of the blank drawn and this causes wrinkling if the blank thickness is small. To prevent wrinkling, a blank holder is used. The portion of blank between the die wall and the punch surfaces is under tension.




In a single drawing operation the diameter of the blank can be reduced 1.8 to 2 times less than that of the initial blank. If a further reduction is required the blank is to be redrawn.

$$\therefore \frac{D}{d} = 1.8 \text{ to } 2$$

$$\% \text{ Reduction} = \frac{D-d}{D} \times 100$$

Where $D$ = blank diameter
$d$ = cup diameter

## Blank Size

Blank diameter, $D$ can be estimated using the formulae given below.

Let $h$ = height of cup
$r$ = corner radius of cup
$d$ = outside diameter of cup

If $\frac{d}{r} \geq 20$,

$$D = \sqrt{d^2 + 4dh}$$

If $15 \leq \frac{d}{r} \leq 20$

$$D = \sqrt{d^2 + 4dh - 0.5r}$$

If $10 \leq - \leq 15$, $D = \sqrt{d^2 + 4dh - r}$

If $\frac{d}{r} \leq 10$

$$D = \sqrt{(d - 2r)^2 + 4d(h - r) + 2\pi r(d - 0.7r)}$$

If the depth to diameter ratio (i.e, $h/d$) is greater than 0.4 drawing is called **deep drawing** otherwise it is **shallow drawing.**

### Solved Examples

**Example 1:** A cup of 10 cm height and 5 cm diameter with 2.5 mm corner radius is to be made from a metal sheet of 3 mm thickness by drawing. Determine the number of draws required.

**Solution:** $h = 10$ cm $= 100$ mm
$d = 5$ cm $= 50$ mm
$t = 3$ mm
$r = 2.5$ mm

$$\frac{d}{r} = \frac{50}{2.5} = 20$$

If $\frac{d}{r} \geq 20$

Blank radius $D = \sqrt{d^2 + 4dh}$

$$= \sqrt{50^2 + 4 \times 50 \times 100}$$

$$= 150 \text{ mm}$$

$$\frac{D}{d} = \frac{150}{50} = 3$$

For a single draw blank diameter should not be greater than twice the drawn diameter.

∴ Number of draws required is 2.

## Ironing

Ironing is the deep drawing operation in which the shell wall thickness is reduced and surface is made smooth.

## Re-drawing

When the blank diameter and the final cut diameter is very large, the drawing operation requires more than one stage. The drawings after the first stage is called re-drawings.

## Reverse Drawing

When a cup is drawn reverse to the original direction of drawing it is called reverse drawing. Reverse drawing helps strain softening.

## Defects in Deep Drawing

Bulging, buckling, earing and surface scratch are some defects noticed in deep drawing.

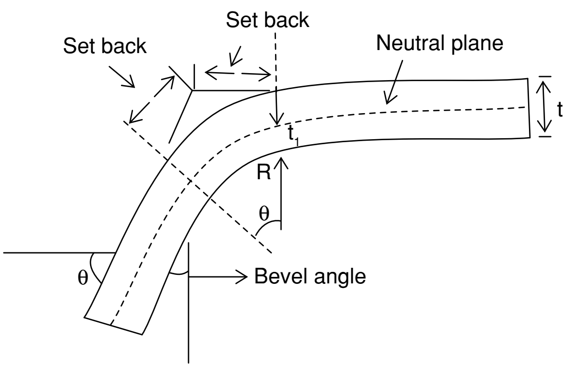
Bulging happens when the outer diameter of a cylindrical shell or outer walls of a box shaped shell expands from the straight shape.

Excessive compressive stress causes uncontrolled deformation pattern perpendicular to the surface of the sheet. As a result, a bend, kink or wavy condition is formed on the surface This is called buckling.

Edges formed around the top of a drawn sheet is called earing.

**Bending:** It is the operation in which a flat sheet or strip is uniformly strained in a linear axis, which lies in the neutral plane and perpendicular to the length wise direction.

In bending a straight length is transformed into a curved length. The strain in the bent material increases when the radius of curvature decreases. The neutral axis of the section moves towards the inner surface. Distance of neutral axis from inside surface is $0.3t$ to $0.5t$ depending upon the radius of curvature, where $t$ is the thickness of the part.




Stretch factor or $k$ factor $k = \frac{t_1}{t}$

$= 0.33$ when $R < 2t$

$= 0.5$ when $R > 2t$

Where $R$ = inside bend radius
$t$ = material thickness
$t_1$ = distance of neutral plane from inside surface

Bend allowance BA $= \frac{\theta\pi}{180°}(R + kt)$

Where $\theta$ = bend angle in degrees

(Bend allowance is the distance along the neutral plane corresponding to bend angle).

**Example 2:** A 3 mm thick metal sheet is to be bent at an angle of 1.5 radian with a radius of 150 mm. If the *k*-factor is 0.5, the bend allowance is

**Solution:** $t = 3$ mm

$\theta = 1.5$ radian

$R = 150$ mm

$k = 0.5$

Bend allowance

$$= (R + kt)\theta$$
$$= (150 + 0.5 \times 3) \text{ x } 1.5$$
$$= 227.25 \text{ mm}$$

**Notching:** It is the operation in which metal pieces are cut from the edge of a sheet, strip or blank.

**Perforating:** It means cutting very small holes which are very close, in a sheet metal.

**Trimming:** It is the cutting and removal of unwanted excess material from the periphery of a previously by formed component.

**Shaving:** It is Removal of thin strip of metal from a blanked part to make it dimensionally accurate and smooth is called shaving.

**Slitting:** It is the operation of cutting a sheet metal along the length.

## Slotting

Cutting of elongated holes or slots is called slotting.

## Parting

Shearing of a sheet metal into two or more pieces is called parting.

**Lancing:** It is a cutting operation in which a hole is partially cut and the cut portions is bent.

**Nibbling:** It is removing metal in small increments. When a specified contour is to be cut in a sheet metal a small punch is used to punch repeatedly by along the contour.

**Squeezing:** In this operation, metal is caused to flow to all portions of die cavity under the action of compressive forces.

**Spinning:** It is the operation of shaping of thin metal by pressing it against a form, while it is rotating. Spinning is done on lathe like machines.

**Stretch forming:** is the process of producing contoured parts by stretching metal sheets over a shaped form block.

**Embossing:** It is the operation of producing raised or depressed impression of figures, letter or design on sheet metal parts.

**Coining**: It refers to the cold squeezing of metal under compressive forces, while all the surfaces are confined within a set of dies. Used for production of coins, medals etc. The pressure required is 5 to 6 times the strength of the material, in order to produce fine details.

**Blanking**: It is the operation of cutting a flat piece of required shape from a sheet using a punch and a die. The metal punched out is the required product and it is called a blank.

**Piercing/punching:** It is the production of a hole in a sheet metal by the punch and die. The operation is same as blanking. But here, the material punched out constitute the waste and the sheet with hole is the required product. In punching the hole produced is circular. In piercing it can be of any shape.

## Shearing Action

When the sheet metal is placed between two shearing blades and pressed the metal is brought to plastic stage and fracture is initiated at the cutting edges. The fracture on either side of the sheet further progress with the movement of the upper shear and finally separates the slug from the parent sheet.

Metal under the upper shear is subjected to both tensile and compressive stresses. The upper shear pushes the metal about one third of the thickness in an ideal shearing operation. The area of cross section between the cutting edges gets reduced and facture is initiated. If the clearance is sufficient, further movement of the upper shear will cause the fractures to meet and complete the shearing action.

## Clearance

Clearance between the shears is an important factor which controls the shearing process. The clearance can be approximated as.

$$C = 0.0032 \times t \times \sqrt{\tau} \text{ mm}$$

Where $t$ = sheet thickness in mm

$\tau$ = material shear stress in MPa

## Punching Force

The force required on a punch in order to shear out the blank from the stock is given by the formula.

$$F = Lt\tau$$

Where $L$ = length (perimeter)

$t$ = thickness

$\tau$ = shear strength

Punching force for holes with diameter less than the thickness may be estimated as,

$$F = \frac{dts}{\sqrt[3]{\frac{d}{t}}}$$

Where $d$ = diameter of punch, mm

$s$ = tensile strength of stock, MPa

## Provision of Shear

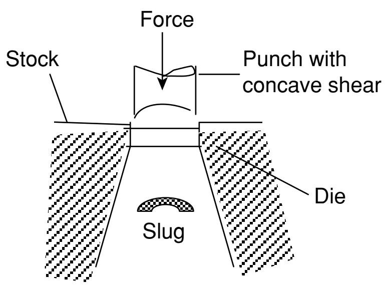
Shear is provided on a punch or die to reduce the required shearing force. For example, this may be required to accommodate a component on a smaller capacity punch press. Shear is ground on the face of die or punch. This distributes cutting force over a period of time depending on the amount of shear provided. This reduces the maximum force to be applied, but does not alter the total work done.

Provision of shear on the punch will change the slug and shear provided on the die will change the stock. So shear is provided on the die for blanking and on the punch for piercing. Therefore for blanking operations,

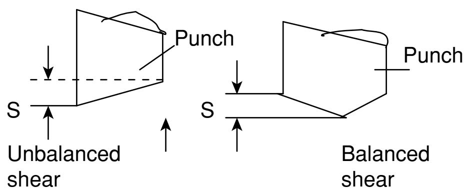
blank size = die size

And for piercing/punching operation,

blank size = punch size




Piercing operation




**Example 3:** Calculate the die and punch sizes for blanking a circular disc of 22 mm diameter from a *C* 20 steel sheet with thickness 1.5 mm. Determine also the punching force (Shear strength for *C* 20 steel = 294 MPa).

**Solution:** Clearance

$C = 0.0032 \times t \times \sqrt{\tau}$

$= 0.0032 \times 1.5 \times \sqrt{294}$

$= 0.0823 \text{ mm} \simeq 0.10 \text{ mm}$

For blanking operation,

Die size = blank size

= 22 mm

Punch size = blank size – 2*C*

= 22 – 0.2 = 21.8 mm

For piercing operations,

Punch size = hole size = 22 mm

Die size = hole size + 2*C*

= 22 + 0.2 = 22.2 mm

Punching force = $Lt\tau$

$= \pi \times 22 \times 1.5 \times 294 \times 10^{-3}$

= 30.4 kN.

## Energy in Presswork

Energy or work done to make a cut is given as

$$E = F_{max} \times \text{punch travel}$$

$$= F_{max} \times k \times t$$

Where $k$ = percentage of penetration required to cause rupture.

$t$ = thickness of sheet

$F_{max} = Lt\tau$

To account for energy lost in machine friction the energy equation may be modified as

$$T = F_{max} \times k \times t \times C$$

where $C$ = factor to account for machine friction.

When shear is provided, let $F$ be the punching force required

Then $E = F(kt + S)$

Where $S$ = shear

$$F(kt + S) = F_{max}\, kt$$

$$\text{or } F = \frac{F_{max} kt}{kt + S}$$

**Example 4:** 12 mm diameter holes are to be punched in a steel plate of 3 mm thickness and shear strength 400 MPa. Shear provided on the punch is 2 mm and penetration is 40%. Determine the blanking force required for the operation.

**Solution:** $d = 12$ mm

$t = 3$ mm

$\tau_u = 400 \text{ MPa} = 400 \text{ N/mm}^2$

Penetration = 40% = 0.4

Shear $S = 2$ mm

$F_{max} = \pi dt\, \tau_u$

$= \pi \times 12 \times 3 \times 400$

= 45,239 N

$F_{max}\, kt = F(kt + S)$

$$\text{or } F = \frac{F_{max} kt}{kt + S}$$

$$= \frac{45239(0.4 \times 3)}{(0.4 \times 3) + 2}$$

= 16965 N.

## Powder Metallurgy

Powder metallurgy is a process of making reliable ferrous and non-ferrous components from ferrous and non-ferrous powders. Originally it was used to replace castings of metals of very high melting point. The development of the technique made it possible to produce the product economically and now a days it occupies and important place in the metal processing field.

## Basic Steps of the Process

Basic steps of the manufacturing of parts by powder metallurgy are

1. Production of metal powders
2. Blending and mixing of powders
3. Compaction
4. Sintering
5. Finishing operations

## Production of Metal Powders

Depending on the type and nature of the metal, various methods are available for production of metal powders. Some of the methods are

1. Atomization
2. Machining
3. Crushing and milling
4. Reduction
5. Electrolytic deposition
6. Shotting
7. Condensation

In atomization, molten metal is forced through a small orifice and is broken into the form of small particles by a powerful jet of compressed air, inert gas or water. These particles are allowed to solidify to get the powder. This method is used for low melting point alloys.

In machining, metal chips produced by filing, turning etc are pulverized by crushing and milling. The powders obtained are coarse and irregular in shape. This method is mainly used for production of magnesium powder.

Crushing and milling methods are used for brittle materials. Ceramic powder is produced by this method. It is also used for powders of some metals and alloys.

In the method of reduction pure metal is produced by the reduction of metallic oxides using suitable reducing gas at high temperature before melting point. Later this reduced product is crushed and milled to powder.

Electrolytic deposition method is mainly used for production of iron and copper powders. Metallic powder deposited on cathode plates are scrapped off, washed, dried and pulverized to produce powder of the required grain size.

Shotting is used for metals of low melting points. Molten metal is poured through a sieve or orifice and cooled by dropping into water. This produces larger size spherical particles. This is used for low melting point metals.

In the method of condensation metals are boiled to produce vapour and condensed to obtain powder. Powders of volatile metals like zinc, magnesium and cadmium are produced by this method.

## Blending and Mixing

In the blending and mixing process metallic powders in the required proportion are mixed uniformly. Binders are added to develop the required green strength. Lubricants are added to reduce inter particle friction and to reduce die wall friction.

## Compaction

Compaction is the process of pressing the blended powder to shape in dies. A green compact of accurate size and shape is obtained in this process. Pressing, centrifugal compacting, slip casting, extrusion, gravity sintering, rolling, explosive moulding etc are some of the compacting methods.

## Sintering

Sintering is the process of heating the green compact at high temperatures below melting point in a controlled atmosphere. Sintering increases the bond between particles and increases strength of the powder metal compact. Sintering temperature is usually 0.6 to 0.8 times the melting point of the powder. If powders of different melting points are used, the sintering temperature is above the melting point of one of the low melting point consistent.

## Finishing Operations

Finishing operations are secondary operations intended for providing dimensional tolerances, better surface finish etc. Finishing operations are

1. Coining: It is the repressing of the sintered component in the die to increase density and to provide the required surface details.
2. Forging or hot densification: It is the method in which desired shape is given to the sintered part at elevated temperature and pressure in dies.
3. Machining: Machining is the operation carried out on the sintered part for making threads, holes slots etc, which cannot be provided during the powder metallurgy process.
4. Sizing: It is the process in which the sintered component is repressed to achieve the required accuracy.
5. Heat treatment: It is the heating and cooling treatment done on the part to achieve wear resistance, grain structure and strength.
6. Plating: Plating is done on the parts to attain surface finish and colour, protection from corrosion and to improve electrical conductivity etc.
7. Infiltration: In this process pores of the part are filled with molten metal to improve physical properties.
8. Stream treating: In this process sintered part is given oxide coating.
9. Joining: Two sintered parts are joined by welding, brazing etc.
10. Impregnation: It is the process in which the sintered part is filled with lubricants such as oil, greeze etc for using as bearings.
11. Repressing: By repressing, density of the sintered part is increased. It also improves the mechanical properties.

## Joining Processes

Joining two or more elements to make a single part is termed as a joining or fabrication process. Joining process include mechanical joining by means of bolts, screws or rivets; adhesive bonding by employing synthetic glues such as epoxy resins, welding, brazing and soldering .

Choice of a particular process depends on type of assembly (permanent, semi-permanent or temporary); materials, economy, type of service (heavy loading, light loading, high temperature etc.)

Joining by adhesive bonding is done using adhesives such as thermosetting resins, thermoplastic resins, silicone resins and elastomers. Elastomers such as natural rubbers when mixed with thermosetting resins reduce brittleness and provide toughness for shock resistance.

## Welding

Welding is the most extensively used joining method. In welding, the joining takes place through atomic bonding. Atomic bonding may be solid state, liquid state or solid liquid state.

For the bonding to take place heat or pressure or both heat and pressure are to be applied at the joints.

In fusion welding heat is applied at the joints and in pressure type welding pressure also applied apart from heat.

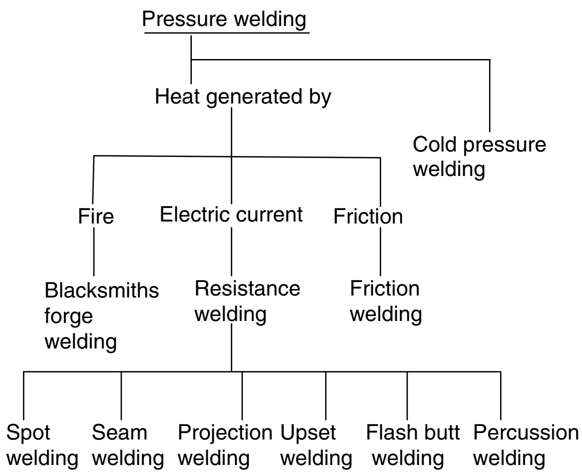
In all welding process, except cold welding process, heat is applied for the bonding to take place. Therefore there should be one heat source.

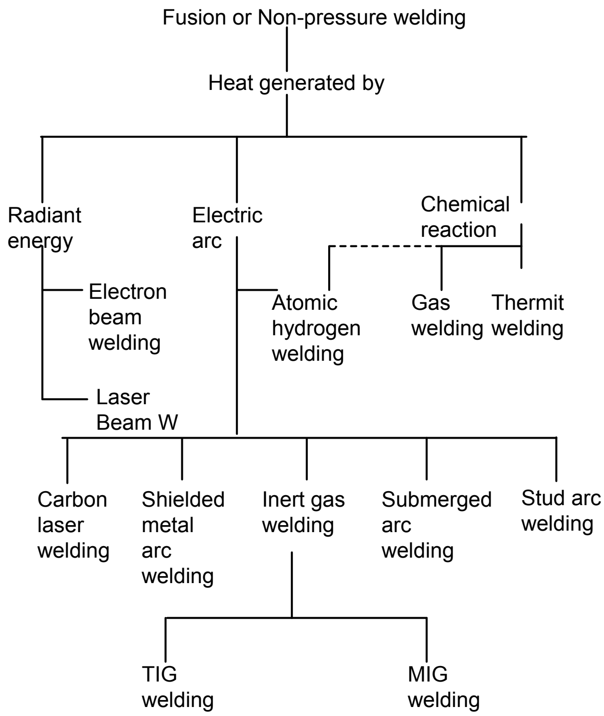
Fusion welding is a non pressure liquid state welding Bonding takes place in a metallurgical fusion process where interface of two parts are brought above melting point and then allowed to solidify.

Electric arc welding, Induction welding, gas welding, thermit welding etc are examples of fusion welding.

Forge welding, resistance welding, friction welding and cold pressure welding are examples of pressure type welding.

Classifications of welding processes are shown in the figures.




## Solid State Welding

Cold welding, friction welding, diffusion welding, forge welding etc are examples of solid state welding. Cold welding includes pressure welding, ultrasonic welding, and explosive welding.

In fusion welding process melting of metal takes place. Therefore there should be a source of heat. In electric arc welding, electric resistance welding and induction welding heat is generated by thermo chemical actions.

In gas welding and thermit welding heat is generated by thermo chemical actions.

In new generation welding processes such as electron beam welding, laser beam welding etc radiant energy is the source of heat for welding.

## Electric Arc Welding

Electric arc welding is a fusion welding process. Welding heat is obtained from an electric arc between the work (or base metal) and electrode.

Electric arc is produced when two conductors in an electric circuit, which are touched together are separated by a small distance, such that there is sufficient voltage in the circuit to maintain the flow of current through the gaseous medium. Temperature produced is 6000°C to 7000°C.

The depression created on the base metal due to the arc is called crater.

DC or AC current can be used for arc welding. DC voltage required is 60 to 80 V for striking the arc and 15 to 25 V for maintaining the arc. For AC current they are 80 to 100 V and 30 to 40 V respectively.

An arc is a sustained electric discharge through the ionized gas column, called plasma between the electrodes. When electrons hit the anode at high velocity, kinetic energy is converted producing a large amount of heat. Similarly positively charged ions hitting the cathode also produces heat. 65 to 75% of the total heat generated is at the anode. So work is connected as anode if it is required to generate more heat at anode. This is called straight polarity or DCEN (direct current electrode negative) DCEN is required for thicker plate and materials of higher thermal conductivity. For thinner plates reverse polarity or DCEP (Direct current electrode positive) is used. Weld penetration is more in DCEN. Weld penetration for AC is between DCEP and DCEN.

## Ac Welding Equipment

1. AC Machines
   (i) Transformer
   (ii) Alternater engine driven by motor or engines
2. DC Machines
   (i) Transformer with rectifier
   (ii) DC generator driven by motor or engine

Transformer sets are more commonly used in AC welding. As there is no moving parts power consumed and noise are less. Also maintenance cost is low and efficiency is more.

## Specification of Arc Welding Machines

1. Maximum rated open circuit voltage
2. Rated current in amperes
3. Duty cycle

American welding society (AWS) defines duty cycle as the percentage time in a ten minute period that a welding machine can be used at its rated output without overloading. Normally 40% duty cycle is suggested (Indian standard specifies 5 minutes as the cycle time.)

## Types of Welding Electrodes

1. Non consumable
2. Consumable

Non consumable type of electrodes are made of carbon, graphite or tungsten. Carbon and graphite electrodes are used in DC welding only tungsten can be used for both AC and DC welding. As this electrode is not consumed arc length is constant and it is stable and easy to maintain. Separate filler rods are used in this case.

There are three types of consumable electrodes

1. Bare electrodes
2. Fluxed or lightly coated electrodes
3. Coated or extruded/shielded electrodes

Bare electrodes may be used for welding mild steel and wrought iron.

Primary function of a light coating is to increase the arc stability. These are also called ionizing coatings.

Coated electrodes contain arc stabilizing ingredients, slag forming ingredients, binding materials, alloying constituents etc. Some times iron powder is added to improve deposition rate.

## Types of Electric Arc Welding Process

1. Carbon arc welding
2. Shielded metal arc welding
3. Flux cored arc welding
4. Gas metal arc welding
5. Gas tungsten arc welding
6. Submerged arc welding
7. Atomic hydrogen welding
8. Plasma arc welding
9. Stud welding
10. Electro slag welding

## Carbon Arc Welding

In carbon arc welding carbon or graphite electrodes are used. If required filler material also is used. Shielding is not generally used. So carbon arc welding is used in metals that are not sufficiently contaminated by oxygen and nitrogen in the atmosphere (copper alloys, brass, bronze, Aluminium alloys etc.).

## Shielded Metal Arc Welding (SMAW)

This method is also known as manual metal arc welding. This is the most generally used welding type. Coated electrodes are used in this type of welding. Shielding is obtained from the decomposition of the coating. The ingredients in the vaporized coating creates a protective gas atmosphere over the weld puddle. As the coating melts at a slower rate than the metal this welding rod will be having a concave end. This helps to concentrates the heat from the arc. The flux coating helps removal of impurities through formation of slag. The electrode diameter depend upon the thickness of the metal being welded and the type of the joint.

Welding current is determined on the basis of the electrode diameter.

Welding current = $k.d$ amperes

Where $d$ is diameter in mm.

$K$ = constant

= 45 to 60 for ordinary steel electrodes

= 18 to 22 for graphite

= 5 to 8 for carbon

Voltage depends only on the arc length. It is given by, $V = k_1 + k_2$ volts

Where $k_1$ = 10 to 12 and $k_2$ = 2 to 3

$L$ = arc length in mm.

Minimum arc voltage, $V_{min} = (20 + 0.04I)$ volts.

Arc length depends upon the kind of electrodes used, its coating, its diameter, current used and position of welding. Shorter arc lengths are used for overhead and vertical positions.

An arc length of 0.6 to 0.8 times the electrode diameter can produce stable arcs and high quality welding.

## Flux Cored Arc Welding

In this method a hollow tubular electrode inside which the flux is provided, is used. Continuous welding is possible as the electrode can be supplied in coils.

## Gas Metal Arc Welding (GMAW)

This is also known as metal inert gas (MIG) welding. In this method an inert gas such as Argon is used for shielding the welding area. Consumable electrode is fed through a welding gun through which the inert gas also is supplied for shielding weld area. Electrode is supplied in coils and continuous welding is possible. Other inert gases are helium and carbon dioxide.

## Gas Tungsten Arc Welding (GTAW)

This process is also known as tungsten inert gas welding (TIG welding). This is similar to mig welding. But a non-consumable electrode of tungsten is used. For shielding, inert gas such as argon is used. A filler metal may or may not be used. In the tungsten electrode 1 to 2% thorium and zirconium are added improve electron emission, arc stability, arc striking and current carrying capacity etc. TIG welding was originally developed for welding magnesium which is highly oxidizing. Now it is used for welding, aluminium and its alloys, stainless steel, cast iron, silicon bronze, titanium, nickel, copper and carbon steels. This method is suitable for welding thinner metals, below 6 mm thick. Both AC and DC can be used. DCEP is not used as this tend to melt electrode due to overheating. For more penetration DCEN is preferable. For metals like magnesium and aluminium high frequency AC supply is used which break up the surface oxides.

## Submerged Arc Welding (SAW)

Submerged arc welding is generally used for welding thick plates which require straight welds in flat position. In this method arc electrode is continuously fed from reals. The arc and the welding occurs inside a blanket of granular flux which is continuously fed ahead of the electrode. The granular flux shields the weld area from atmosphere. Molten flux acts as a cleanser, absorbing impurities from the molten metal and producing the slag which floats on top of molten metal. The flux may also contain powder metal alloying elements, In order to prevent molten metal running out of the joints, water cooler backup plates are used.

## Atomic Hydrogen Welding

In atomic hydrogen welding arc is produced between two tungsten electrodes. A stream of hydrogen passes to the weld area through nozzles through which the electrodes are held. High temperature of the arc breaks up the hydrogen molecules into hydrogen atoms absorbing heat from the arc (421.2 KJ/mol). The hydrogen atoms are highly reactive. They combine with atmospheric oxygen to form water vapor and form hydrogen molecule at the surface to be welded releasing intense heat necessary for melting of the metal. Because of its reactivity hydrogen atoms also breaks the oxides on the base metals allowing formation of a clean weld. Hydrogen also acts as a shielding gas. As the molten metals becomes highly fluid atomic hydrogen welding is used only for flat positions. The main advantage of this process is its ability to provide high heat concentration. Thin metal sheets or smaller diameter wires can be welded using this method because of its lower thermal efficiency compared to direct arc processes. Aluminium, stainless steel sheets etc are welded using this method.

## Plasma Arc Welding

In plasma arc welding, welding is done using a plasma jet. Plasma is a gas sufficiently ionized, containing positive and negative ions and with very high temperature and conducts current freely. In plasma welding argon gas and tungsten electrode is used. Argon gas is used for producing the plasma jet as well as acting as a shielding gas. Plasma jet is created when the arc is passed through a constrictive nozzle. As a result of this, the plasma jet will take a narrow columnar shape with unique properties ideal for welding. The plasma welding torch has passages for orifice gas, shield gas and water for cooling.

There are two methods of plasma welding

1. Transferred plasma arc
2. Non-transferred plasma arc

In both cases electrode is negative. In transferred arc work is positive and in non-transferred arc the nozzle is connected as positive.

## Stud Arc Welding

Stud arc welding is an arc welding process used for welding studs to flat metal surfaces. A stud welding gun is used for this, purpose. An arc is produced between the work and end of the stud held in the gun. When the stud end and work spot melts the stud is pressed and allowed to cool. The whole cycle of operations are automatically controlled.

## Electro Slag Welding

Electro slag welding is used for welding thick plates, structures for turbine shafts, boiler parts etc. In this process the plates to be welded are held in a vertical position with a gap of 15 to 30 mm. Filler wires and flux are fed automatically into the gap. Filler wires are used as electrodes. Initially an arc is produced melting the flux into slag. The arc is stopped, and the slag is maintained in the molten state by the heat produced by the resistance. The molten metal in the gap is held by water cooled copper shoes (dams). As the cooling rate of molten metal is low course grains are formed and a further heat treatment is required to restore the strength.

## Electro Gas Welding

This process is a development of electro-slag welding. The main difference with the electro-slag welding is that no flux is fed into the joint and the heat is produced by electric arc through out. An inert gas is fed into the joint for shielding the arc. This process is used for welding 20 to 80 mm thickness plates.

## Non-conventional Welding

Cold welding, diffusion welding explosion welding, resistance welding etc can be grouped under non-conventional welding.

## Cold Welding

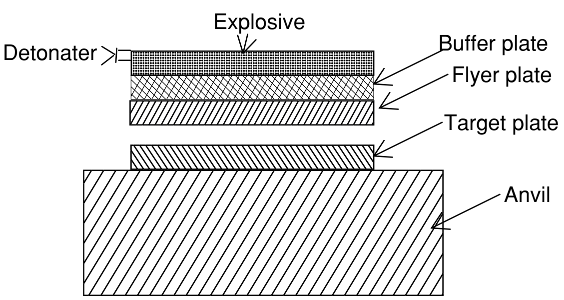
Cold welding is a solid state welding done at room temperature under pressure. Coalescence of the metal parts occur due to the deformation under the great pressure applied by roller or die.

## Diffusion Welding

In diffusion welding process, strength of the joint is obtained primarily from diffusion of the atoms across the interface. It is a solid state welding process where coalescence of the parts occur by the application of pressure under elevated temperatures. Generally the temperature is above 0.5 times the melting point.

## Explosion Welding

Explosion welding or explosive welding is a solid state welding where the parts are joined by high velocity movements produced by a controlled detonation.




When the explosive is detonated, the flyer plate moves to the target plate under great velocity and bonding occurs with the target plate or base plate. This method is used for metal cladding of heat exchanger tube plates etc. Dissimilar metals can be welded using this method. For example aluminium or copper to stainless steel.

## Electric Resistance Welding

In resistance welding heat required for welding is produced by means of electrical resistance at the joint of two parts to be joined. Low voltage (4 to 12 V) and high current is applied. Heat generated during time, $t$ is given by

$$H = I^2 R t k$$

When $I$ = current in amperes
$R$ = resistance in ohms
$t$ = time in secs
$k$ = constant to account for loss by conduction and radiation

Types of resistance welding

1. Spot welding
2. Seam welding
3. Projection welding
4. Butt welding
5. Percussion welding

In **spot welding** the tips of two solid cylindrical electrodes are placed on either side of the lap joint of two sheet metals and high current is passed across the point of contact. Heat generated melts the metals locally at the point of contact when pressure is applied. Low voltage and high current is applied during a very short time.

**Seam welding** is a specialized case of spot welding. In this case rotating disc type electrodes are used. Therefore a continuous weld is obtained. The seam is made of continuous overlapping spot welds. If the spot welds are spaced it is known as **roll spot welding.**

**Projection welding** is another variation of spot welding. One sheet is provided with a number of projections to help to locate the current at predetermined spots. These projections are obtained by embossing.

**Upset butt welding** is a butt joint welding. Heat is generated at the contact area between the two plates. The joint get slightly upset due to the pressure applied. It is used for joining ends of rods or similar pieces.

**Flash butt welding** is another butt welding process. But here heat is generated by an arc. Two pieces to be welded arc brought together and power supply is switched on. Momentarily the pieces are separated a little to produce an arc due to which the ends get melted. They are pressed together and power is switched off.

**Percussion welding** is a recent development. The welding heat is obtained from the arc produced by a rapid discharge of stored electric energy. One piece is held in a fixed clamp and other in a spring loaded movable clamp. When movable clamp is released discharge occurs when the gap is about 1.5 mm. The arc is extinguished by the percussion blow of the moving part coming with sufficient force and the weld is effected.

## Welding Defects

For a strong welding joint the welding should have minimum defects.

The following defects are noticed in welding

1. Porosity
2. Slag inclusions
3. Incomplete penetration
4. Underfilling
5. Undercutting
6. Inclusions
7. Cracks
8. Lamellar tears

**Porosity** is caused by the gases such as oxygen, nitrogen and hydrogen absorbed during melting.

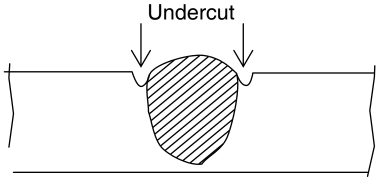
As the molten metal is cooled solubility of the gases is decreased and they try to escape. If escaping is not possible they remain with in the weld causing porosity.

In **inclusions** slag, scale or dirt may get entrapped in the weld deposit during welding. Contaminated base plate, non-uniform melting of electrode coating, high melting point or high viscosity of slag or insufficient deoxidizing of the metal in the weld etc can cause inclusions. Slag inclusion can occur in a multipass welding if the slag solidified in the previous pass is not cleaned before the next pass.

**Incomplete fusion** or lack of fusion may occur if the temperature of the base metal is not raised to its melting point and due to faulty welding conditions. When the gap is not totally filled by molten metal, it leads to incomplete fusion.

**Underfilling** occurs when proper amount of molten metal is fed to the gap.

In **Undercutting** An undercut is a groove formed adjacent to the toe of the weld. Under cutting may be caused by excessive heating, improper positions of electrode or torch tip or non-uniform feed of filler rod. Undercutting reduces fatigue strength of the joint




## Cracks

Cracks may occur in or near the weld. Cracks can be micro cracks, macro cracks or wide cracks (fissures) depending upon the size. Micro cracks will be visible only through a microscope. Macro cracks can be seen by unaided eye or through a low power magnifier. Cracks that occur at low temperature (around 200 °C) is known as cold cracks.

Cracks that occur when the metal is very hot is known as hot cracks. Depending upon location and direction, cracks can be toe crack, under bead crack, longitudinal crack, transverse crack etc.

## Lamellar Tears

Lamellar tears are caused by non-metallic inclusion such as sulphides and oxides. These inclusions are elongated by rolling process. This generally happens in plates of low ductility in the thickness direction.

Lamellar tears are more dominant in T and corner joints where fusion boundary is parallel to the rolling plane.

## Welding Equations

1. Voltage–arc length characteristic of DC $V = A + BL$
   Where $V$ = voltage drop across the arc
   $A$ = electrode drop
   $BL$ = column drop
2. Power source characteristic equation

$$V = \text{OCV} - \frac{\text{OCV} \cdot I}{\text{ISC}}$$

Where OCV = open circuit voltage
ISC = short circuit current
$I$ = arc current
$V$ = arc voltage

3. Power, $P = V.I$

   For maximum power, $\frac{\delta P}{\delta I} = 0$

## Heat Flow Characteristics

In welding processes heat source may be moving or stationary. For example in fusion welding processes like arc welding heat source is moving and in spot welding the heat source is stationary. For analysing purpose moving heat source is treated as stationary and work piece is treated as moving with the same velocity in opposite direction. This speed is called welding speed. Heat source can be a point source of three dimensional heat flow or a line source as in the case of butt welding of thin plates. For three dimensional heat source,

Rate of heat input

$$Q = \frac{5}{4}\pi wk\theta_m\left(\frac{2}{5} + \frac{vw}{4\alpha}\right)$$

Where $w$ = width of the weld
$k$ = thermal conductivity of the work piece
$\theta_m$ = difference between melting point and initial temperature of the work material
$v$ = welding speed
$\alpha$ = thermal diffusivity $= \frac{k}{\rho c}$
$\rho$ = density
$c$ = specific heat

For two dimensional heat source the equation is

$$Q = 8k\theta_m h\left(\frac{1}{5} + \frac{vw}{4\alpha}\right)$$

Where $h$ = thickness of plate

In arc welding heat input rate is given by $Q = C\,VI$

where $V$ = arc voltage

$I$ = arc current

$C$ = fraction of total time during which the arc acts

**Example 5:** The voltage–arc length characteristic of DC arc is given by $V = 20 + 40L$ where $L$ = arc length in cm. The power source characteristic can be approximately a straight line. Open circuit voltage is 80. and short circuit current is 1000 A k. Determine optimum arc length.

**Solution:** For welding arc,

$$V = 20 + 40L \quad (1)$$

For power source

$$\text{V} = 80 - \frac{80}{1000}I \quad (2)$$

For stable arc,

(1) = (2)

$$20 + 40L = 80 - \frac{80}{1000}I$$

$$\frac{80}{1000}I = 60 - 40L$$

$I = 750 - 500\ L$

Power, $VI = (20 + 40L)\ (750–500L)$

$1000\ (15 + 20L - 20L^2)$

For optimum arc length, $\dfrac{\delta p}{\delta I} = 0$

i.e. $20 - 40L = 0$

i.e. $L = 0.5$ cm

## Heat Input and Heat Flow in Welding

### *Heat Input*

For arc welding, $P = VI$ Watts or J/s.

Let $v$ = the travel speed of electrode in mm/s

Heat input is given by

$$H = \frac{P}{v}\ \text{J/mm}$$

$$= \frac{VI}{v}\ \text{J/mm}$$

$$H_{\text{net}} = f_1\frac{VI}{v}\ \text{J/mm}$$

Where $f_1$ = a factor for heat transfer efficiency.

All the $H_{\text{net}}$ is not available for melting as part of it is conducted away by the base metal. Considering this another efficiency factor $f_2$ is used.

$$f_2 = \frac{\text{Heat required to melt the joint}}{\text{Net heat supplied}}$$

Values of $f_1$ for various processes are,

GTAW 0.21 to 0.48

SMAW and GMAW 0.66 to 0.85

SAW 0. 90 to 0.99

For resistance welding, $H = I^2\ Rt$.

### *Heat Flow*

For relatively thick plates, cooling rate is given by,

$$R = \frac{2\rho k(T_c - T_o)^2}{H_{net}}$$

Where $T_0$ = initial plate temperature °C

$k$ = thermal conductivity of base metal J/mm s °C

$T_c$ = temperature at which cooling rate is calculated ~ 550°C for most steels.

$R$ = cooling rate at the weld centre line.

If the plates are relatively thin requiring less than 3 passes, the following equation can be used.

$$R = \pi k\rho c\left(\frac{}{\text{net}}\right)(T_c - T_o)$$

Where $h$ = thickness of base metal, mm

$\rho$ = density of base metal gm/mm$^3$

$C$ = sp. heat J/g °C

**Example 6:** Calculate the melting efficiency, in the case of arc welding of steel with a potential of 20 V. and a current of 220 A. Travel speed is 5 mm/s and cross sectional area of the joint is 24 mm$^2$. Heat required to melt steel may be taken as 12 J/mm$^3$ and the heat transfer efficiency 0.85.

**Solution:** Net heat supplied = $0.85 \times 20 \times 220 = 3740$ W

Volume of base metal melted = $24 \times 5 = 120$ mm$^3$/s

Heat required for melting = $120 \times 12$

= 1440 J/s

Melting efficiency

$$= \frac{1440}{3740}$$

$= 0.385$

$= 38.5\%$.

**Example 7:** Two steel sheets of 1.2 mm thickness are resistance welded in a Lap joint with a current of 10000 A for 0.1 second. The effective resistance of the joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of 6 mm diameter and 1.5 mm height. The density of steel is 0.00786 g/mm$^3$. Calculate heat lost to surroundings.

**Solution:** Heat supplied

$= (10000)^2 \times 100 \times 10^{-6} \times 0.1$

= 1000 J.

Volume of the joint $= \dfrac{\pi \times 6^2 \times 1.5}{4}$

= 42.412 mm$^3$

Heat required for melting = $412 \times 10$

= 424 J

Heat lost to surroundings = 1000 − 424
= 576J = 57.6%.

**Example 8:** If the two sheets in the above problem is resistance welded in a projection welding with a current of 30,000 A for 0.005 seconds. The effective resistance of the joint can be taken as 100 micro ohms. The joint can be considered as a cylinder of 5 mm diameter and 1.5 mm height. Calculate heat lost to surroundings.

**Solution:** Heat supplied

$$= 30{,}000^2 \times 100 \times 10^{-6} \times 0.006$$
$$= 540 \text{ J}$$

$$\text{Volume of the joint} = \frac{\pi \times 6^2}{4} \times 1.5 = 42.412 \text{ mm}^3$$

Heat required for melting = 42.412 × 10 = 424 J
Heat lost to surroundings = 540 – 424 = 116 J
= 21.48%.

## Gas Welding

It is a fusion welding process in which heat is generated by combustion of a fuel gas. Oxy-acetylene gas welding is the most commonly used. Oxygen and acetylene are the gases used in this case.

Various gas welding methods with their flame temperature are as follows.

1. Oxy-acetylene, 3200°C
2. Oxy-hydrogen, 2400°C
3. Oxy-propane, 2200°C
4. Oxy-town gas, 2100°C
5. Air-acetylene, 2400°C
6. Air-town gas, 1800°C
7. Air-propane, 1750°C

## Oxy-acetylene Gas Welding

Equipment for oxy-acetylene welding consists oxygen and acetylene cylinders, welding torch, pressure regulator hose and hose fittings etc.

Combustion of acetylene with pure oxygen at the tip of the welding torch takes place in two steps. Acetylene reacts with oxygen from the oxygen cylinder to form carbon monoxide and hydrogen. i.e, $C_2H_2 + O_2 = 2\ CO + H_2$

This reaction takes place with in the white inner cone of the flame.

In the second stage, carbon monoxide and hydrogen produced in the first reaction reacts with oxygen from the atmosphere to form carbon dioxide and water vapor. i.e.,

$$4\ CO + 2H_2 + 3O_2 = 4\ CO_2 + 2H_2O$$

These reactions take place in the larger blue flame which surrounds the white inner cone. This larger blue flame contributes to a preheating effect in welding. It also protects the molten metal from oxidation.

Three types of flames can be set is oxy-acetylene welding

1. Neutral
2. Carburizing
3. Oxidizing

**Neutral flame** is obtained when equal amounts of oxygen and acetylene are mixed. The flame is recognized by the inner white luminous cone and outer blue flame envelope.

**Carburizing flame or reducing flame** is obtained when an excess of acetylene is supplied than theoretically required. Oxygen to acetylene ratio may be 0.85 to 0.95. There are three zones in carburizing flame. In between the inner cone (not sharply defined) and outer bluish envelope a white zone appears. This is called intermediate flame feather or acetylene feather. Its length is an indication of the amount of excess acetylene.

For obtaining a neutral flame, first carburizing flame is obtained. Then supply of oxygen is increased till the intermediate feather disappears.

Intermediate feather can be adjusted by the amount of acetylene imbalance induced at the torch. If inner cone length is $x$ and intermediate feather length is $3x$, it is called a $3x$ flame.

**Oxidizing flame** has excess oxygen than required for a neutral flame. Oxygen acetylene ratio may be 1.15 to 1.50. To get an oxidizing flame acetylene supply is reduced in a neutral flame. Inner cone is slightly shorter and more pointed in this case. An oxidizing flame has a harsh sound and outer envelop is short and narrow.

## Flame Temperatures

In a neutral flame, inner cone temperature is around 3100°C and outer blue envelope is around 1275°C. In a reducing flame the inner cone temperature is about 2900°C and in an oxidizing flame it is about 3300°C.

## Oxygen and Acetylene Cylinders

Oxygen for gas welding is stored in steel cylinder, 7 $M^3$ capacity and painted black for easy identification. Right Hand threads are used in cylinder valves and regulators etc. for oxygen. It is stored under a pressure of 13.8 to 18.2 MPa (about 150 kg/cm$^2$).

Acetylene cylinder is made of steel and painted in maroon colour. They and their valves, regulators etc are left hand threaded to avoid wrong usage of oxygen valves, regulators etc. Acetylene is stored around 1.5 MPa.

Free acetylene is highly explosive if stored at a pressure more than 200 kPa. So it is used dissolved in acetone. Acetone can absorb 420 times its volume of acetylene at a pressure of 1.75 MPa. Acetylene molecules fit in between acetone molecules, thus storing at a higher pressure is made possible.

Acetylene cylinder is filled with 80 to 85% porous material (calcium silicate) and then filled with acetone.

Acetylene is released from acetone at a slow rate.

## *Application of Different Flames in Gas Welding*

If possible, the welding should be done with a neutral flame as it has minimum chemical effect on most heated metals.

Neutral flame is used for welding of steel, cast iron, copper and aluminium.

Materials that tend to absorb Carbon should not be welded using reducing flame. Reducing flame can be used for materials that oxidizes rapidly like steel and aluminium.

Reducing flame can also be used for non-ferrous materials that do not absorb carbon.

Oxidizing flame has limited use. The presence of excess oxygen with oxidizing flame causes an oxide film to form quickly which provides a protective cover over the base metal pool. Due to this it is used in materials like brass and Zinc which have a tendency to separate and fume away.

## *Oxy-fuel Gas Cutting (OFC)*

In cutting of metals using gas, the torch tip differs from that of welding, For gas cutting, the torch tip has two sets of orifices–an inner orifice for oxygen jet and surrounding it, the outer orifices for oxygen-acetylene mixture.

It is possible to rapidly oxidize (burn) iron and steel when heated to a temperature of 800°C to 1000°C. Metal burnt is blown off by the high pressure oxygen jet causing the cut. The cut formed is known as Kerf.

Chemical reactions

$3Fe + 20_2 = Fe3O_4 + Heat$

$2Fe + O_2 = 2\ FeO + Heat$

$4\ Fe + 3O_2 = 2Fe_2O_3 + Heat$

The heat from the above exothermic reactions is not sufficient to maintain the kindling temperature. So the pre heating flames through the outer orifices are continued at a lower rate. In the gas cutting process, about 30 to 40% of iron is simply blown off without forming oxides.

## *Brazing, Braze Welding and Soldering*

Brazing, braze welding and soldering are metal joining processes by atomic bonding in which a filler material of lower melting point than the parent metal is used to make the bond. In these processes the parent metal is not melting as in the case of welding. Joint is obtained by means of diffusion of filler metal into the base metal and by surface alloy formation.

**Brazing** is the coalescence of a joint with the help of a filler metal whose liquids temperature is above 427°C and below the solids temperature of the base metal. Filler metal is drawn into the joint by capillary action. Flux usually used is borax. Due to the many advantages over welding, brazing is very widely used in industries. Brazing can join almost all metals. Dissimilar metals can be brazed. For example cast iron to stainless steel.

As temperature is less, there is less distortion in brazed joints.

**Braze welding** is similar to brazing in the matter of temperature. The main difference is that the filler metal reaches the joint by gravity instead of capillary action as the joint gap is bigger. Thick layers of filler metal are deposited in the joint.

Braze welding is also known as bronze welding. The filler rod usually consists of 60% copper and 40% Zinc, with small amounts deoxidizers such as silicon and tin. Metals with high melting point such as steel, cast iron, copper etc are braze welded.

**Soldering** is the process of joining two metal pieces by means of heat and a filler metal whose melting point is below 427°C and below the solids temperature of the metals to be joined. The filler metal known as solder is an alloy of lead and tin. Higher Tin solders have greater strength and silvery appearance. The joint is filled by capillary action as in the case of brazing. Fluxes used are rosin and rosin plus alcohol based fluxes for electrical soldering. Other fluxes used are zinc chloride and ammonium chloride.

# Exercises

## Practice Problems I

**1.** A 4 mm thick circular blank is used to make a cylindrical cup of outside diameter 105 mm and height 25 mm. The corner radius is 6 mm. The trimming allowance provided is 3 mm. The blank diameter is
(A) 140 mm (B) 147 mm
(C) 150 mm (D) 145 mm

**2.** 10 mm diameter holes are to be punched in a steel sheet of 4 mm thickness. Shear strength of the materials is 450 $N/mm^2$ and penetration is 40%. Shear provided on the punch is 2 mm. The blanking force during the operation is
(A) 26.8 kN (B) 45.2 kN
(C) 33.9 kN (D) 35.7 kN

**3.** In arc welding of steel, voltage and current are 20 V and 200 A respectively. Travel speed is 5 mm/s and cross sectional area of joint is 20 $mm^2$. Heat required to melt steel is 10 $J/mm^3$ and heat transfer efficiency is 0.85. The melting efficiency in the welding is
(A) 29.4% (B) 35.2%
(C) 27.5% (D) 22.7%

**4.** The spot welding of sheets of 1 mm thickness, a current of 10000 A was required for 8 seconds. Heat generated in joules, assuming effective resistance as 10 mW, is
(A) 1000 J (B) 800 J
(C) 900 J (D) 700 J

**5.** In the above problem, if 5 mm diameter electrodes are used the temperature rise will be (assume heat generated is confined to the volume of material directly between the two electrodes and temperature is distributed uniformly and sp. Heat of steel is 0.46)
(A) 5397°C (B) 6492°C
(C) 6860°C (D) 5574°C

**6.** In a DC arc welding operation, the voltage–Arc length characteristic was obtained as $V_{arc} = 20 + 5$ L where the arc length $L$ was varied between 5 mm and 7 mm. Here $V_{arc}$ denotes the arc voltage in volts. The arc current was varied from 400 A to 500 A. Assuming linear power source characteristic, the open circuit voltage and short circuit current for the welding operation are
(A) 45 V, 450 A (B) 75 V, 750 A
(C) 95 V, 950 A (D) 150 V, 1500 A

**7.** Two sheets of low carbon steel 1.5 mm thick each are spot welded by passing a current of 10,000 amp for 5 Hz to 50 Hz supply. The maximum intendation is 10% of sheet thickness and density of spot weld nugget is 8 gm/mm$^3$. If 1380 J are required to melt one gram of steel. Find the percentage of heat actually utilized in making the spot weld. assume effective resistance as 200 mΩ and $d = 6\sqrt{t}$ to determine nugget diameter. Also assume the nugget size to be equal to metal between the two electrodes
(A) 72.13% (B) 63.24%
(C) 58.73% (D) 66.91%

**8.** A metal disc of 20 mm dia is to be punched from a sheet of 3 mm thickness. The punch and die clearance is 3%. The required punch diameter will be
(A) 19.88 mm (B) 20.06 mm
(C) 19.82 mm (D) 20.12 mm

**9.** A 25 mm square hole is to be cut in sheet metal 1 mm thick. Shear strength of the material is 2900 kg/cm$^2$ The cutting force in kN is
(A) 21.45 (B) 28.42
(C) 32.12 (D) 25.31

**10.** A cup of 75 mm diameter and 40 mm deep in to be drawn in 2 mm thick material. The maximum drawing force, if the ultimate tensile stress of the material is 3000 kg/cm$^2$, will be
(A) 138.7 kN (B) 142.8 kN
(C) 141.4 kN (D) 135.3 kN

**11.** A blank of 2.5 mm diameter is to be made from a sheet of 2 mm thickness. Shear strength of sheet material is 295 MPa. The size of the punch will be
(A) 24.3 mm (B) 25.2 mm
(C) 24.8 mm (D) 24.4 mm

**12.** A 100 mm diameter hole is to be punched in a steel plate of 6 mm thickness. Shear strength of the plate is 550 N/mm$^2$. Cutting is complete at 40% penetration of the punch with normal clearance.If a 250 kN press is to be used for this work, what is the shear angle to be provided on this punch, assuming a balanced shear.
(A) 8.59°C (B) 9.23°C
(C) 11.35°C (D) 7.62°C

**13.** In blanking operations 'shear' is provided on
(A) Punch
(B) Both punch and die
(C) Not provided
(D) Die

**14.** In piercing operation, the clearances is provided on
(A) Punch
(B) Die
(C) Half on punch and half on die
(D) Either on punch or die (designer's divia)

**15.** In gas welding, neutral flame inner cone has a temperature about
(A) 3200°C
(B) 2100°C
(C) 1000°C
(D) 1250°C

**16.** Carburising flame is used to weld
(A) Steel, cast iron etc.
(B) Brass and bronze
(C) Hard surfacing materials such as stellite
(D) All of the above

**17.** In arc welding temperature of heat produced by the electric arc is of the order of
(A) 3000°C – 4000°C
(B) 4000°C – 5000°C
(C) 5000°C – 6000°C
(D) 6000°C – 7000°C

**18.** In DC arc welding when work is connected to the positive terminal it is called a
(A) Straight polarity
(B) Reversed polarity
(C) Cross polarity
(D) None of the above

**19.** In resistance welding, the voltage required for heating is
(A) 1 to 5 V (B) 11 to 20 V
(C) 6 to 10 V (D) 50 to 100 V

**20.** The welding process used in joining mild steel shanks to high speed drills is
(A) Spot welding
(B) Flash butt welding
(C) Seam welding
(D) Projection welding

## Practice Problems 2

**1.** Blanking and piercing operation can be performed simultaneously in a
(A) Simple die
(B) Progressive die
(C) Combination die
(D) Compound die

**2.** The operation of cutting a triangular hole in a sheet metal using a punch and die is under the process
(A) Shearing (B) Piercing
(C) Punching (D) Blanking

**3.** Cutting a sheet metal through part of its length and then bending the cut portion is called
(A) Stitting (B) Lancing
(C) Nibbling (D) Notching

**4.** Two one mm thick sheets are to be spot welded at a current of 4500 A. Assuming effective resistance as 250 micro ohms and current flow time as 0.2 second, heat generated during the process will be
(A) 1013 J (B) 1020 J
(C) 1000 J (D) 955 J

**5.** Which one of the following is a solid state welding process
(A) Electrons beam welding
(B) Friction welding
(C) Thermit welding
(D) Percussion welding

**6.** Which of the following use non-consumable electrode
(A) GMAW (B) SAW
(C) GTAW (D) SMAW

**7.** Match the correct combination:

| | |
|---|---|
| P Blanking | 1. Tension |
| Q Stretch forming | 2. Compression |
| R Coining | 3. Shear |
| S Deep drawing | 4. Tension and compression |
| | 5. Tension and shear |

(A) P-2, Q-1, R-3, S-4
(B) P-3, Q-4, R-1, S-5
(C) P-3, Q-1, R-2, S-4
(D) P-5, Q-3, R-3, S-1

**8.** A shell of 100 mm diameter and 90 mm height with corner radius of 4 mm is to be produced by cup drawing. The required blank diameter in mm is
(A) 228 (B) 224
(C) 232 (D) 215

**9.** In an arc welding process, voltage and current are 25 V and 300 A respectively. The arc heat transfer efficiency is 0.90 and welding speed is 8 mm/s. The net heat input in J/mm is
(A) 797.2 (B) 822.3
(C) 843.8 (D) 861.1

**10.** A DC welding machine with a linear power source characteristic provides open circuit voltage of 80 V and short circuit current of 800 A. During welding with the machine the measured arc current is 500 A. corresponding to an arc length of 5 mm. and the measured arc current is 460 A corresponding to an arc length of 7 mm. The voltage–arc length characteristic can be given as
(A) 20 + 8 L (B) 80 + 2 L
(C) 20 + 2 L (D) 80 + 8 L

**11.** The force requirement in a blanking operation of low carbon steel sheet is 6 kN. If the diameter of the blanked part is increased to 1.5 times and thickness of the sheet is reduced to 0.4 times. The blanking force in kN will be
(A) 3.6 (B) 3.3
(C) 3.0 (D) 2.8

**12.** A contour having a perimeter of 250 mm is pierced out from a 3 mm sheet having an ultimate shear strength of 250 N/mm$^2$. What will be the amount of shear, if the punch force is to be reduced to 60%. Assume a penetration of 30%.
(A) 0.3 mm (B) 0.6 mm
(C) 3 mm (D) 6 mm

**13.** Estimate reduction in piercing load for producing circular hole of 50 mm diameter in a 3 mm thick steel strip when the punch was provided with a shear of 1 mm. Assume 30% penetration and shear strength of steel as 400 N/mm$^2$
(A) 48.34% (B) 52.63%
(C) 45.83% (D) 47.91%

**14.** The voltage arc length characteristic of a power source is $V$ = 20 + 40 L. Where $V$ = operating voltage and L = arc length. Determine the open circuit voltage and short circuit current for arc length varying from 3 to 5 mm and current from 400 to 500 amp during welding operation
(A) 540 V, 675 A (B) 560 V, 695 A
(C) 520 V, 720 A (D) 580 V, 710 A

**15.** A circular piece of 25 mm diameter is to be blanked from a sheet of thickness 2 mm. Radial clearance in the punch and die is 0.06 mm. Die allowance is 0.05 mm. The punch size in mm will be
(A) 25.01 mm (B) 24.89 mm
(C) 25.17 mm (D) 24.83 mm

**16.** A hole of 25 mm diameter is to be punched in a sheet of 2 mm thickness, the shear strength of which is 290 MPa. Estimate the size of the die required
(A) 25.22 mm (B) 25.42 mm
(C) 24.88 mm (D) 24.78 mm

**17.** In arc welding of steel with a potential of 20 V and a current 230 A; travel speed of the rod is 4 mm/s. Cross sectional area of the joint is 20 mm$^2$. Heat requirement for melting is 12 J/mm$^3$ and melting efficiency is 40%. The heat transfer efficiency in the welding is
(A) 48% (B) 52%
(C) 46% (D) 56%

**18.** In a spot welding, two 1 mm thick plates in a lap joint are welded using a current of 10000 A for 0.1 sec. The effective resistance of the joint is 100 mW. The joint can be considered as a cylinder of 5 mm diameter and 1.5 mm height. Assuming density of steel as 0.0079 gm/mm$^3$ and heat required for melting steel as 1380 J/gm efficiency of the welding is
(A) 36.2% (B) 52.3%
(C) 32.1% (D) 41.8%

**19.** Two 1 mm thick sheets are spot welded by passing current for 0.1 sec through the electrodes. The resultant weld nugget formed is 5 mm in diameter and 1.5 mm thick. If the latent heat of fusion of steel is 1400 kJ/kg and the effective resistance is 200 micro ohms, the current passed through was (assume steel density – 8000 kg/m$^3$)
(A) 1480 A (B) 3300 A
(C) 4060 A (D) 9400 A

**20.** In arc welding process of a butt joint area of cross section of weld is 5 mm$^2$ and unit energy required to melt the metal is 10 J/mm$^3$. If welding input power is 2 kW, and melting and heat transfer efficiency are 0.5 and 0.7 respectively the welding speed will be
(A) 14 mm/s (B) 34 mm/s
(C) 24 mm/s (D) 4 mm/s

**21.** Two metallic sheets of 2 mm thickness each are spot welded in a lap joint with a welding current of 10000 A and welding time of 10 milli second. A spherical fusion zone of radius 2 mm is formed. If melting temperature is 1793 K, density is 7000 kg/m$^3$, latent heat of fusion = 300 kJ/kg, specific heat = 800 J/kg K and ambient temperature = 293 K, the melting efficiency of the process is (assume contact resistance = 500 mW)
(A) 50.38%
(B) 70.38%
(C) 60.38%
(D) 80.38%

**22.** A blank holder is used in deep drawing to
(A) Guide the punch through the die
(B) Exactly locate the blank on the die
(C) Avid wrinkles
(D) None of the above

**23.** Spinning operation is carried out on
(A) Hydraulic press
(B) Mechanical press
(C) Lathe
(D) Milling machine

**24.** Cutting and forming operations are performed in single operation in
(A) Simple die (B) Combination die
(C) Progressive die (D) Compound die

**25.** In progressive dies
(A) Two or more cutting operation can be performed simultaneously
(B) Cutting and forming operations can be combined and carried in simple operations
(C) Work piece moves from one station to other with separates operations performed at each station
(D) All of the above

**26.** Gases used in TIG welding are
(A) Hydrogen and oxygen
(B) $CO_2$ and $H_2$
(C) Argon and neon
(D) Argon and helium

**27.** Temperature of plasma torch is the order of
(A) 1000°C (B) 5000°C
(C) 10000°C (D) 10 – 100 A

**28.** Current range in SMAW is
(A) 10 – 500 A (B) 10 – 50 A
(C) 100 – 200 A (D) 10 – 100 A

**29.** The flux commonly used in brazing is
(A) Rosin plus alcohol
(B) Zinc chloride
(C) Copper
(D) Tin and lead alloys

**30.** In hard soldering filler material used is
(A) Aluminium alloys
(B) Silver alloys
(C) Copper
(D) Tin and lead alloys

## Previous Year's Questions

**1.** Two 1 mm thick steel sheets are to be spot welded at a current of 5000 A. assuming effective resistance to be 200 micro-ohms and current flow time of 0.2 second, heat generated during the process will be **[2004]**
(A) 0.2 J (B) 1 J
(C) 5 J (D) 1000 J

**2.** 10 mm diameter holes are to be punched in a steel sheet of 3 mm thickness. Shear strength of the material is 400 N/mm$^2$ and penetration is 40%. Shear provided on the punch is 2 mm. The blanking force during the operation will be **[2004]**
(A) 22.6 kN (B) 37.7 kN
(C) 61.6 kN (D) 94.3 kN

**3.** Spot welding of two 1 mm thick sheets of steel (density = 8000 kg/m$^3$) is carried out successfully by passing a certain amount of current of 0.1 second through the electrodes. The resultant weld nugget formed is 5 mm in diameter and 1.5 mm thick. If the latent heat of fusion of steel is 1400 kJ/kg and the effective resistance in the welding operation is 200 mW, the current passing through the electrodes is approximately **[2005]**

(A) 1480 A (B) 3300 A
(C) 4060 A (D) 9400 A

**4.** Match the items in columns I and II. **[2006]**

| Column I | Column II |
|---|---|
| P Wrinkling | 1. Yield point elongation |
| Q Orange peel | 2. Anisotropy |
| R Stretcher strains | 3. Large grain size |
| S Earing | 4. Insufficient blank holding force |
| | 5. Fine grain size |
| | 6. Excessive blank holding force |

(A) P-6 Q-3 R-1 S-2
(B) P-4 Q-5 R-6 S-1
(C) P-2 Q-5 R-3 S-4
(D) P-4 Q-3 R-1 S-2

**5.** In an arc welding process, the voltage and current are 25 V and 300 A respectively. The arc heat transfer efficiency is 0.85 and welding speed is 8 mm/sec. The net heat input (in J/mm) is **[2006]**
(A) 64
(B) 797
(C) 1103
(D) 79700

**6.** Which one of the following is a solid state joining process? **[2007]**
(A) Gas tungsten arc welding
(B) Resistance spot welding
(C) Friction welding
(D) Submerged arc welding

**7.** A direct current welding machine with a linear power source characteristic provides open circuit voltage of 80 V and short circuit current of 800 A. During welding with the machine, the measured arc current is 500 A corresponding to an arc length of 5.0 mm and the measured arc current is 460 A corresponding to an arc length of 7.0 mm. The linear voltage ($E$)–arc length ($L$) characteristic of the welding arc can be given as (where $E$ is in Volt and $L$ is in mm) **[2007]**
(A) $E = 20 + 2L$
(B) $E = 20 + 8L$
(C) $E = 80 + 2L$
(D) $E = 80 + 8L$

**8.** Two metallic sheets, each of 2.0 mm thickness, are welded in a lap joint configuration by resistance spot welding at a welding current of 10 kA and welding time of 10 ms. A spherical fusion zone extending up to the full thickness of each sheet is formed. The properties of the metallic sheets are given as:

Ambient temperature = 293 K

Melting temperature = 1793 K

Latent heat of fusion = 300 kJ/kg

Density = 7000 kg/m$^3$

Specific heat = 800 J/kgK

Assume: (i) contact resistance along sheet-sheet interface is 500 micro-ohm and along electrode-sheet interface is zero; (ii) no conductive heat loss through the bulk sheet materials; and (iii) the complete weld fusion zone is at the melting temperature.

The melting efficiency (in%) of the process is **[2007]**
(A) 50.37
(B) 60.37
(C) 70.37
(D) 80.37

**9.** Match the correct combination for following metal working processes. **[2007]**

| Processes | Associated state of stress |
|---|---|
| P Blanking | 1. Tension |
| Q Stretch forming | 2. Compression |
| R Coining | 3. Shear |
| S Deep drawing | 4. Tension and compression |
| | 5. Tension and Shear |

(A) P-2, Q-1, R-3, S-4
(B) P-3, Q-4, R-1, S-5
(C) P-5, Q-4, R-3, S-1
(D) P-3, Q-1, R-2, S-4

**10.** The force requirement in a blanking operation of low carbon steel sheet is 5.0 kN. The thickness of the sheet is '$t$' and diameter of the blanked part is '$d$'. For the same work material, if the diameter of the blanked part is increased to 1.5 $d$ and thickness is reduced to 0.4 $t$, the new blanking force in kN is **[2007]**
(A) 3.0 (B) 4.5
(C) 5.0 (D) 8.0

**11.** In arc welding of a butt joint, the welding speed is to be selected such that highest cooling rate is achieved. Melting efficiency and heat transfer efficiency are 0.5 and 0.7, respectively. The area of the weld cross section is 5 mm$^2$ and the unit energy required to melt the metal is 10 J/mm$^3$. If the welding power is 2 kW, the welding speed in mm/s is closest to **[2008]**
(A) 4 (B) 14
(C) 24 (D) 34

**12.** In the deep drawing of cups, blanks show a tendency to wrinkle up around the periphery (flange). The most likely cause and remedy of the phenomenon are, respectively **[2008]**

(A) Buckling due to circumferential compression; increase blank holder pressure
(B) High blank holder pressure and high friction; reduce blank holder pressure and apply lubricant
(C) High temperature causing increase in circumferential length; apply coolant to blank
(D) Buckling due to circumferential compression; decrease blank holder pressure

**13.** The operation in which oil is permeated into the pores of a powder metallurgy product is known as **[2011]**

(A) Mixing
(B) Sintering
(C) Impregnation
(D) Infiltration

**14.** Which one among the following welding processes uses non-consumable electrode? **[2011]**

(A) Gas metal arc welding
(B) Submerged arc welding
(C) Gas tungsten arc welding
(D) Flux coated arc welding

**15.** The shear strength of a sheet metal is 300 MPa. The blanking force required to produce a blank of 100 mm diameter from a 1.5 mm thick sheet is close to **[2011]**

(A) 45 kN (B) 70 kN
(C) 141 kN (D) 3500 kN

**16.** Match the following metal forming processes with their associated stresses in the work piece. **[2012]**

| Metal forming process | Type of stress |
|---|---|
| 1. Coining | P Tensile |
| 2. Wire drawing | Q Shear |
| 3. Blanking | R Tensile and compressive |
| 4. Deep drawing | S Compressive |

(A) 1-S, 2-P, 3-Q, 4-R
(B) 1-S, 2-P, 3-R, 4-Q
(C) 1-P, 2-Q, 3-S, 4-R
(D) 1-P, 2-R, 3-Q, 4-S

**17.** Calculate the punch size in mm, for a circular blanking operation for which details are given below: **[2012]**

| | |
|---|---|
| Size of the blank | 25 mm |
| Thickness of the sheet | 2 mm |
| Radial clearance between punch and die | 0.06 mm |
| Die allowance | 0.05 mm |

(A) 24.83 (B) 24.89
(C) 25.01 (D) 25.17

**18.** In a DC arc welding operation, the voltage-arc length characteristic was obtained as $V_{arc} = 20 + 51$ where the arc length $l$ was varied between 5 mm and 7 mm. Here $V_{arc}$ denotes the arc voltage in Volts. The arc current was varied from 400 A to 500 A. Assuming linear power source characteristic, the open circuit voltage and the short circuit current for the welding operation are **[2012]**

(A) 45 V, 450 A (B) 75 V, 750 A
(C) 95 V, 950 A (D) 150 V, 1500 A

**19.** Match the pairs: **[2013]**

| Processes | Characteristics/Applications |
|---|---|
| P Friction welding | 1 Non-consumable electrode |
| Q Gas metal arc welding | 2 Joining of thick plates |
| R Tungsten inert gas welding | 3 Consumable electrode wire |
| S Electroslag welding | 4 Joining of cylindrical dissimilar materials |

(A) P-4, Q-3, R-1, S-2
(B) P-4, Q-2, R-3, S-1
(C) P-2, Q-3, R-4, S-1
(D) P-2, Q-4, R-1, S-3

**20.** The major difficulty during welding of aluminium is due to its **[2014]**

(A) High tendency of oxidation
(B) High thermal conductivity
(C) Low melting point
(D) Low density

**21.** In solid-state welding, the contamination layers between the surfaces to be welded are removed by **[2014]**

(A) Alcohol
(B) Plastic deformation
(C) Water jet
(D) Sand blasting

**22.** A rectangular hole of size 100 mm × 50 mm is to be made on a 5 mm thick sheet of steel having ultimate tensile strength and shear strength of 500 MPa and 300 MPa, respectively. The hole is made by punching process. Neglecting the effect of clearance, the punching force (in kN) is **[2014]**

(A) 300 (B) 450
(C) 600 (D) 750

**23.** For spot welding of two steel sheets (base metal) each of 3 mm thickness, welding current of 10000 A is applied for 0.2 s. The heat dissipated to the base metal is 1000 J. Assuming that the heat required for melting 1 $mm^3$ volume of steel is 20 J and interfacial contact resistance between sheets is 0.0002 W, the volume (in $mm^3$) of weld nugget is ____ **[2014]**

**24.** Within the heat affected zone (HAZ) in a fusion welding process, the work material undergoes **[2014]**
(A) Microstructural changes but does not melt
(B) Neither melting nor microstructural changes
(C) Both melting and microstructural changes after solidification
(D) Melting and retains the original microstructure after solidification

**25.** A butt weld joint is developed on steel plates having yield and ultimate tensile strength of 500 MPa and 700 MPa, respectively. The thickness of the plates is 8 mm and width is 20 mm. Improper selection of welding parameters caused an undercut of 3 mm depth along the weld. The maximum transverse tensile load (in kN) carrying of the developed weld joint is ____ **[2014]**

**26.** A DC welding power source has a linear voltage-current (V-I) characteristic with open circuit voltage of 80 V and a short circuit current of 300 A. For maximum arc power, the current (in Amperes) should be set as ______. **[2015]**

**27.** During a TIG welding process, the arc current and arc voltage were 50 A and 60 V, respectively, when the welding speed was 150 mm/min. In another process, the TIG welding is carried out at a welding speed of 120 mm/min at the same arc voltage and heat input to the material so that weld quality remains the same. The welding current (in A) for this process is: **[2015]**
(A) 40.00 (B) 44.72
(C) 55.90 (D) 62.25

**28.** Which two of the following joining processes are autogeneous? **[2015]**
(i) Diffusion welding
(ii) Electroslag welding
(iii) Tungsten inert gas welding
(iv) Friction welding
(A) (i) and (iv) (B) (ii) and (iii)
(C) (ii) and (iv) (D) (i) and (iii)

**29.** Under optimal conditions of the process the temperatures experienced by a copper work piece in fusion welding, brazing and soldering are such that **[2016]**
(A) $T_{\text{welding}} > T_{\text{soldering}} > T_{\text{brazing}}$
(B) $T_{\text{soldering}} > T_{\text{welding}} > T_{\text{brazing}}$
(C) $T_{\text{brazing}} > T_{\text{welding}} > T_{\text{soldering}}$
(D) $T_{\text{welding}} > T_{\text{brazing}} > T_{\text{soldering}}$

**30.** The welding process which uses a blanket of fusible granular flux is: **[2016]**
(A) Tungsten inert gas welding
(B) Submerged arc welding
(C) Electroslag welding
(D) Thermit welding

**31.** The voltage-length characteristic of a direct current arc in an arc welding process is $V = (100 + 40l)$, where $l$ is the length of the arc in mm and $V$ is arc voltage in volts. During a welding operation, the arc length varies between 1 and 2 mm and the welding current is in the range 200–250 A. Assuming a linear power source, the short circuit current is ________ $A$. **[2016]**

**32.** Spot welding of two steel sheets each 2 mm thick is carried out successfully by passing 4 kA of current for 0.2 seconds through the electrodes. The resulting weld nugget formed between the sheets is 5 mm in diameter. Assuming cylindrical shape for the nugget, the thickness of the nugget is _______ mm. **[2016]**

| | |
|---|---|
| Latent heat of fusion for steel | 1400 kJ/kg |
| Effective resistance of the weld joint | 200μΩ |
| Density of steel | 8000 kg/m$^3$ |

**33.** In a sheet metal of 2 mm thickness a hole of 10 mm diameter needs to be punched. The yield strength in tension of the sheet material is 100 MPa and its ultimate shear strength is 80 MPa. The force required to punch the hole (in kN) is _________. **[2016]**

## ANSWER KEYS

## EXERCISES

### Practice Problems 1

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** C | **2.** B | **3.** A | **4.** B | **5.** D | **6.** C | **7.** D | **8.** C | **9.** C | **10.** A |
| **11.** C | **12.** A | **13.** D | **14.** B | **15.** A | **16.** C | **17.** D | **18.** A | **19.** C | **20.** B |

### Practice Problems 2

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** D | **2.** B | **3.** B | **4.** A | **5.** B | **6.** C | **7.** C | **8.** D | **9.** C | **10.** C |
| **11.** A | **12.** B | **13.** B | **14.** A | **15.** D | **16.** A | **17.** B | **18.** C | **19.** C | **20.** A |
| **21.** C | **22.** C | **23.** C | **24.** B | **25.** C | **26.** D | **27.** D | **28.** A | **29.** C | 30. B |

### Previous Years' Questions

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **1.** D | **2.** None | **3.** C | **4.** D | **5.** B | **6.** C | **7.** A | **8.** C | **9.** D | **10.** A |
| **11.** B | **12.** A | **13.** C | **14.** C | **15.** C | **16.** A | **17.** A | **18.** C | **19.** A | **20.** A |
| **21.** B | **22.** B | **23.** 140 to 160 | | | **24.** A | **25.** 68 to 72 | | **26.** 149 to 151 | |
| **27.** A | **28.** A | **29.** D | **30.** B | **31.** 423 to 428 | | **32.** 2.85 to 2.95 | | **33.** 4.9–5.1 | |