14
CHAPTER

FORGING

14.1 INTRODUCTION

Forging is an oldest shaping process used for the producing small articles for which accuracy in size is not so important. The parts are shaped by heating them in an open fire or hearth by the blacksmith and shaping them through applying compressive forces using hammers. Thus forging is defined as the plastic deformation of metals at elevated temperatures into a predetermined size or shape using compressive forces exerted through some means of hand hammers, small power hammers, die, press or upsetting machine. It consists essentially of changing or altering the shape and section of metal by hammering at a temperature of about 980°C, at which the metal is entirely plastic and can be easily deformed or shaped under pressure. The shop in which the various forging operations are carried out is known as the smithy or smith's shop. A metal such as steel can be shaped in a cold state but the application of heat lowers the yield point and makes permanent deformation easier. Forging operation can be accomplished by hand or by a machine hammer. Forging processes may be classified into hot forging and cold forgings and each of them possesses their specific characteristics, merits, demerits and applications.

Hand forging process is also known as black-smithy work which is commonly employed for production of small articles using hammers on heated jobs. It is a manual controlled process even though some machinery such as power hammers can also be sometimes used. Black-smithy is, therefore, a process by which metal may be heated and shaped to its requirements by the use of blacksmith tools either by hand or power hammer. In smithy small parts are shaped by heating them in an open fire or hearth. Shaping is done under hand control using hand tools. This work is done in a smithy shop. In smith forging or hand forging open face dies are used and the hammering on the heated metal is done by hand to get the desired shape by judgment.

Forging by machine involves the use of forging dies and is generally employed for mass-production of accurate articles. In drop forging, closed impression dies are used and there is drastic flow of metal in the dies due to repeated blow or impact which compels the plastic metal to conform to the shape of the dies. The final shape of the product from raw material is achieved in a number of steps. There are some advantages, disadvantages and applications of forging operations which are given as under.

Advantages of forging

Some common advantages of forging are given as under.

1. Forged parts possess high ductility and offers great resistance to impact and fatigue loads.
2. Forging refines the structure of the metal.
3. It results in considerable saving in time, labor and material as compared to the production of similar item by cutting from a solid stock and then shaping it.
4. Forging distorts the previously created unidirectional fiber as created by rolling and increases the strength by setting the direction of grains.
5. Because of intense working, flaws are rarely found, so have good reliability.
6. The reasonable degree of accuracy may be obtained in forging operation.
7. The forged parts can be easily welded.

Disadvantages of forging

Few dis-advantages of forging are given as under.

1. Rapid oxidation in forging of metal surface at high temperature results in scaling which wears the dies.
2. The close tolerances in forging operations are difficult to maintain.
3. Forging is limited to simple shapes and has limitation for parts having undercuts etc.
4. Some materials are not readily worked by forging.
5. The initial cost of forging dies and the cost of their maintenance is high.
6. The metals gets cracked or distorted if worked below a specified temperature limit.
7. The maintenance cost of forging dies is also very high.

Applications of forging

Almost all metals and alloys can be forged. The low and medium carbon steels are readily hot forged without difficulty, but the high-carbon and alloy steels are more difficult to forge and require greater care. Forging is generally carried out on carbon alloy steels, wrought iron, copper-base alloys, alumunium alloys, and magnesium alloys. Stainless steels, nickel-based super-alloys, and titanium are forged especially for aerospace uses.

Producing of crank shaft of alloy steel is a good example which is produced by forging. Forging processes are among the most important manufacturing techniques utilized widely in manufacturing of small tools, rail-road equipments, automobiles and trucks and components of aeroplane industries. These processes are also extensively used in the manufacturing of the parts of tractors, shipbuilding, cycle industries, railroad components, agricultural machinery etc.

14.2 FORGEABILITY

The ease with which forging is done is called forgeability. The forgeability of a material can also be defined as the capacity of a material to undergo deformation under compression without rupture. Forgeability increases with temperature up to a point at which a second phase, e.g., from ferrite to austenite in steel, appears or if grain growth becomes excessive. The basic lattice structure of metals and their alloys seems to be a good index to their relative forgeability. Certain mechanical properties are also influenced by forgeability. Metals which have low ductility have reduced forgeability at higher strain rate whereas highly ductile metals are not so strongly affected by increasing strain rates. The pure metals have good malleability and thus good forging properties. The metals having high ductility at cold working temperature possesses good forgeability.

Cast parts, made up of cast iron are brittle, and weak in tension, though they are strong in compression. Such parts made using cast iron tend to need to be bulky and are used where they will not be subjected to high stresses. Typical examples are machine bases, cylinder blocks, gear-box housings etc. Besides the above factors, cost is another major consideration in deciding whether to cast a component or to forge it. An I.C. engine connecting rod is a very good example of where a forging will save machining time and material, whereas the cylinder block of the same engine would be very expensive if produced by any process other than casting. Another good point associated with casting is that big or small complex shapes can easily be cast. Small parts can directly be machined out from regular section materials economically. A part machined out from the rolled steel stock definitely possesses better mechanical properties than a conventionally cast part. Sometimes the shape and size of a part would mean removing a large amount of material by machining, it is sometimes more economical to forge the part, thereby reducing the machining time and the amount of material required.

The main alloys for cold forging or hot forging are most aluminium and copper alloys, including the relatively pure metals. Carbon steels with 0.25 % carbon or less are readily hot forged or cold-headed. High carbon and high alloy steels are almost always hot forged. Magnesium possessing hexagonal close packed (HCP) structure has little ductility at room temperature but is readily hot forged. Aluminium alloys are forged between 385°C and 455°C or about 400°C below the temperature of solidification. Aluminium alloys do not form scale during hot forging operations, die life is thus excellent. Copper and brasses with 30% or less zinc have excellent forgeability in cold working operations. High zinc brasses can be cold forged to a limited extent but are excellent hot forging alloys. Magnesium alloys are forged on presses at temperature above 400°C. At higher temperatures, magnesium must be protected from oxidation or ignition by an inert atmosphere of sulphur dioxide.

14.3 FORGABLE MATERIALS

Two-phase and multi-phase materials are deformable if they meet certain minimum requirements. The requirement of wrought metals is satisfied by all pure metals with sufficient number of slip planes and also by most of the solid solution alloys of the same metal. Wrought alloys must possess a minimum ductility that the desired shape should possess. To be a forgeable metal, it should possess the required ductility. Ductility refers to the capacity of a material to undergo deformation under tension without rupture. Forging jobs call for materials that should possess a property described as ductility that is, the ability to sustain substantial high plastic deformation without fracture even in the presence of tensile stresses. If failure occurs during forging, it is due to the mechanism of ductile fracture and is induced by tensile stresses. A material of a given ductility may fail very differently in various processes, depending on the deforming conditions imposed on it. Forgeable metals are purchased as hot-rolled bars or billets with round or rectangular cross the sections. Forgeable materials should possess the required ductility and proper strength. Some forgeable metals are given as under in order of increasing forging difficulty.

1. Aluminium alloys
2. Magnesium alloys
3. Copper alloys.
4. Carbon and low alloy steels
5. Martensitic stainless steels
6. Austenitic stainless steels
7. Nickel alloys
8. Titanium alloys
9. Columbium alloys
10. Tantalum alloys
11. Molybdenum alloys
12. Tungsten alloys
13. Beryllium.

14.4 HEATING DEVICES

Forgeable metals are heated either in a hearth or in a furnace. The hearths are widely used for heating the metals for carrying out hand forging operations. Furnaces are also commonly used for heating metals for heavy forging. The forging job is always heated to the correct forging temperature in a hearth (Fig. 14.1) or in a furnace (Fig. 14.2) located near the forging arrangements. Gas, oil or electric-resistance furnaces or induction heating classified as open or closed hearths can be used. Gas and oil are economical, easily controlled and mostly used as fuels. The formation of scale, due to the heating process especially on steel creates problems in forging. A non-oxidizing atmosphere should, therefore, be maintained for surface protection. Special gas-fired furnaces have been developed to reduce scaling to minimum. Electric heating is the most modern answer to tackle scaling and it heats the stock more uniformly also. In some cases, coal and anthracite, charcoal containing no sulphur and practically no ash are the chief solid fuels used in forging furnaces. Forge furnaces are built raise temperatures up to 1350°C in their working chambers. They should be sufficiently large to allow proper combustion of the fuel, and to obtain uniform heating of the forging jobs. Each heating furnace consists of parts including firebox, working chamber, chimney, flues, re-cuperator or regenerator, and various auxiliary arrangements. Various types of furnaces are used for heating the metals and some of them are briefly described as under.

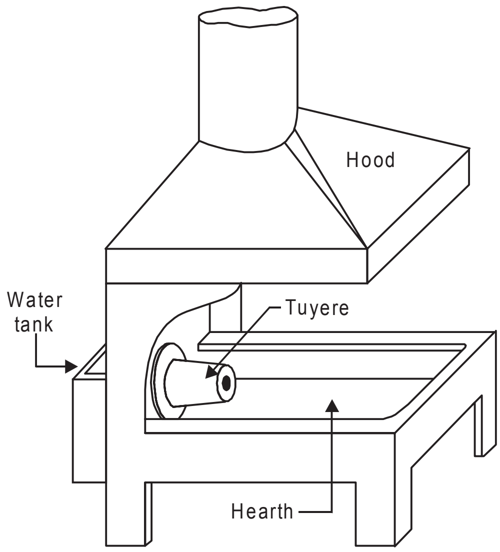

Fig. 14.1 Typical hearth

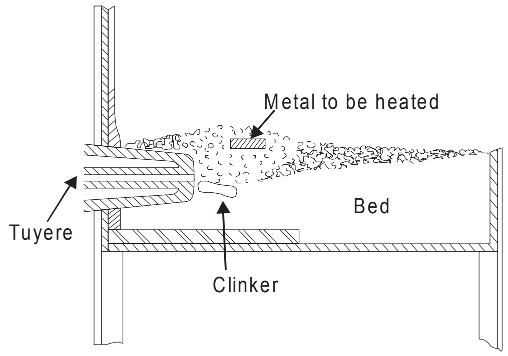

Fig. 14.2 Black smith furnace

14.4.1 Box or batch type furnaces

These furnaces are the least expensive furnaces widely used in forging shops for heating small and medium size stock. There is a great variety of design of box-type furnaces, each differing in their location of their charging doors, firing devices and method, employed for .charging their products. These furnaces are usually constructed of a rectangular steel frame, lined with insulating and refractory bricks. One or more burners for gas or oil can be provided on the sides. The job-pieces are placed side by side in the furnace using a slot through a suitable tong. It is therefore sometimes called slot type furnace.

14.4.2 Rotary-hearth furnaces

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

14.4.3 Continuous or conveyor furnaces

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

14.4.4 Induction furnaces

These furnaces are very popular because induction greatly decreases scale formation and can often be operated by one person. The furnace requires less maintenance than oil or gas-fired furnaces. In induction furnaces the stocks are passed through induction coils in the furnaces. Delivery to forging machine operator can be effected by slides or automatic handling equipment.

14.4.5 Resistance furnaces

These furnaces are faster than induction furnaces, and can be automated easily. In resistance heating furnace, the stock is connected to the circuit of a step-down transformer. Fixtures are also equipped along with furnace for holding different length, shape, and diameter of stock. However, the fixtures are often quite simple and can be adjusted to handle a family of parts.

14.4.6 Open fire and stock fire furnace

The fire itself plays an important part on the efficient heating of stock and it must be kept clean, free from excess dust or clinkers. Work which is laid on top of the fire will get hot underneath and remain colder on the top use it is exposed to the atmosphere, and uneven heating will result. In the same way, work which is red low in the fire but at the same time against the tuyre will become hot on one side, but will have a blast of clod air blowing against it, from the tuyre on the other side. The correct position for heating the job is in the hearth of the fire. The most common methods of firing in forging are namely open fire and stock fire which are discussed as under.

Open fire

Open fire is shown in Fig.14.3. This type of fire is highly convenient for general heating work and is made up in the hollow space in front of tuyre nozzle with coke left from the last fire, covered with green petroleum. As the fire burns away, coke from the top and sides is drawn into the centre, and its place is taken by more green coal taken from the supply maintained on the front place of the forge or taken from the outside. The jobs or work-pieces must be covered with a layer of coal, and to obtain a flame at single spot, the coal should be slightly damped with water and pressed down with a flat shovel. In the spot where the flame is desired, the coal should be loosened with a pocker. To ensure uniform heating of work on all sides, it must be turned round from time to time.

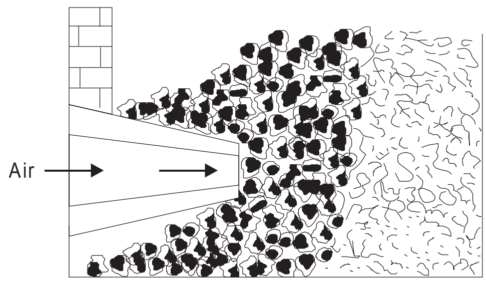

Fig. 14.3 Open fire

Stock fire

A stock fire is depicted through Fig.14.4 which is intended to last for several hours. This type of fire is commonly useful in dealing with large pieces, when a heat may have to be kept for sometime. The job or work has to be turned in all directions to ensure uniform heating of the job. Such fire is made up around a block of the desired size which is placed near the tuyer nozzle and upon which coal damped with water that is closely built into the form of a mound or "stock". Fine coal or pulverized coal is suitable for use in stock fire. The block is then withdrawn from the bed of the hearth with a turning force to prevent the stock from being broken and a tunnel is thus formed with an opening at the top. The fire is then lighted in the hollow space. From the bottom of the tunnel a small amount of coal is removed and a cavity is formed in the place in to which clinker may fall. Here the work is heated, being carefully covered with freshly coke fuel from time to time as the fire burns away.

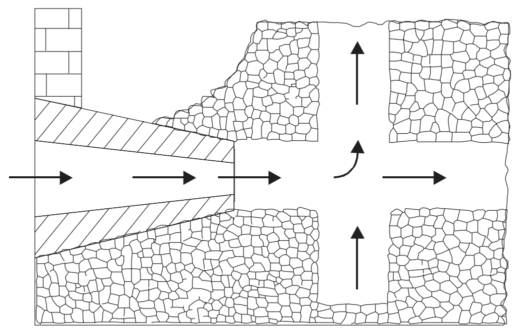

Fig. 14.4 Stock fire

14.4.7 Fuels used in forging shop

The fuels used in forging shop are classified as solid, liquid and gaseous fuels which are discussed as under.

Solid fuels

Wood, coal, anthracite, peat, charcoal, coke, pulverized fuel etc.

Liquid fuels

Crude oil, petroleum, kerosene, tar oil etc.

Gaseous fuels

Natural gas and some artificially produced gases are used generate heat.

A good fuel should have always possesses the following essential characteristic which are given as under.

1. The fuel should be able to generate the required heat.
2. It should have complete combustion.
3. It should be highly efficient.
4. It should not produce excess smoke and flying ash.
5. It should be easy to fire, cheap and easily available.

14.5 CONTROL OF HEATING DEVICES

For good control of heating devices such as hearth or forging furnace, the following points are should always be considered.

1. The nozzle pointing into the centre of the hearth is called the tuyre and is used to direct a stream of air into the burning coke. The air is supplied by centrifugal blower.
2. As the hottest part of the fire is close to the tuyre opening, therefore, the tuyre is provided with a water jacket to prevent it from burning away.
3. The hood provided at the top of hearth collects smoke, fumes etc., and directs them away from the workplace through the chimney in form of exhaust.
4. The fuel for the fire may be either black-smithing coal or coke. To light the fire, either use paper and sticks or preferably a gas poker.
5. Impurities will collect as clinker and must be removed from the bottom of the fire when the fire cools.
6. The blowers are used to control the air supply using forced draught. Regulators control the draught and the temperature of the fire.
7. Blower delivers to forge adequate supply of air at proper pressure which is very necessary for the combustion of fuel.
8. A centrifugal blower driven by an electric motor is an efficient means of air supply in forging hearth.
9. Fire tools such as rake, poker and slice are generally used to control or manage the fire and theses tools are kept nearby the side of the hearth. Rake is used to take heated workpiece out of the fire. Poker is a steel rod which is used to poke (stir) fire in the hearth.

10. The place of the metal to be heated should be placed just above the compact centre of a sufficiently large fire with additional fuel above to reduce the heat loss and atmospheric oxidation.

14.6 FORGING TEMPERATURES

A metal must be heated to a temperature at which it will possess high plastic properties to carry out the forging process. The metal work piece is heated to a proper temperature so that it gains required plastic properties before deformation, which are essential for satisfactory forging. Excessive temperatures may result in the burning of the metal. Insufficient temperatures will not introduce sufficient plasticity in the metal to shape it properly by hammering etc. Moreover, under these conditions, the cold working defects such as hardening and cracking may occur in the product.

The temperature to start the forging for soft, low carbon steels is 1,250 to 1,300°C, the temperature to finish forging is 800 to 840°C. The corresponding temperatures for high carbon and alloy steels which are hard in nature are 1100 to l140°C and 830 to 870°C. Wrought iron is best forged at a temperature little below 1,290°C. Non ferrous alloys like bronze and brass are heated to about 600 to 930°C, the aluminium and magnesium alloys to about 340 to 500°C.

Forging temperature should be proper to get good results. Excessive temperature may result in the burning of the metal, which destroys the cohesion of the metal. Insufficient temperature will not introduce sufficient plasticity in the metal. The forging operation in metal is if finished at a lower temperature, it may lead to cold hardening and cracks may develop in it. However, excessive heating of the forgeable part may result in oxidization and hence material is wasted. The temperature of heating steel for hand forging can be estimated by the color of heat and which color of the light emitted by the heated steel. For accurate determinations of forging temperatures of the heated part, the optical pyrometers are generally used.

14.7 ADVANTAGES OF FORGING IN COMPARASION TO CASTING AND MACHINING

Because of inherent improvement in the grain size and introduction of un-interrupted grain flow in the structure of finished forged component forging has the following advantages in comparison to casting and machining. Some of such advantages are given as under.

(*i*) Greater strength and toughness.

(*ii*) Reduction in weight of the finished part.

(*iii*) Saving in the material.

(*iv*) Elimination of internal defects such as cracks, porosity, blowholes, etc.

(*v*) Ability to withstand unpredictable loads during service.

(*vi*) Minimum of machine finish to be carried out on the component especially when it is forged in dies.

14.8 EFFECT OF FORGING ON METAL CHARACTERISTICS

Generally a forging material is selected based on certain desirable mechanical properties inherent in the composition and/or for those which can be developed by forging. Such properties may be one or several, such as strength, resistance to fatigue, shock or bending, good machining characteristics, durability etc. A continuous and uninterrupted grain flow in a forged component results in higher strength and toughness. In a cast part, there is no grain flow. Cast part is having random orientation of grains so it has weak crystalline structure. In a rolled or machined component, an interrupted grain flow exists. Rolled component is having better ductility in a direction parallel to that of the plastic elongation because of orientation effect of grains. When a component is machined, machining interrupts the continuity of grain flow. In forged parts, the fiber like flow lines of the component are continuous. Forging leads to a re-arrangement of fibers because working is done above recrystallisation temperature.

The original crystals are deformed during forging operation and many of the constituents are precipitated at high temperatures which again become soluble in the solid iron on freezing, thus increasing the local homogeneity of the metal. The properties, like elastic limit, tensile strength of metal are unproved due to the grain flow. If a forged gear blank piece is cut in a plane aligned with the direction and surface is ground smooth and along teeth of the gear blank and immersed in an acid solution, the exposed metal will appear to the naked eye to have a fibre like structure as shown in Fig. 14.5 and Fig.14.6.

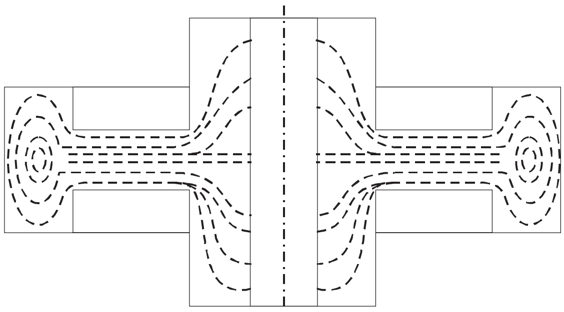

Fig. 14.5 Fibrous forged structure of gear blank

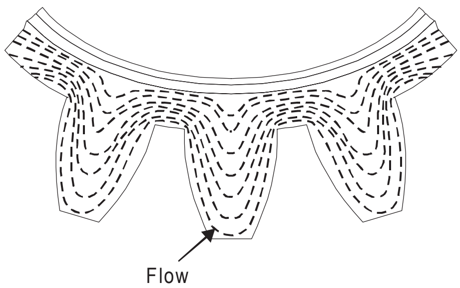

Fig. 14.6

Forging is generally employed for those components which require high strength and resistance to shock or vibrations. It provides fine crystalline structure to the metal, improves physical properties, closes all voids and forms the metal to shapes. It enhances the mechanical properties of metals and improves the grain flow which in turn increases the strength and toughness of the forged component.

But there may be certain defects also, like scale inclusions on the surface, misalignment of the dies, crack, etc. These defects can be controlled. The advantages of forging processes are that, although the metal piece has to be heated to the correct forging temperature before shaping, less metal will be used than if the shape were machined from a solid block of metal. All forgings are covered with scale and hence they require cleaning operation. It is done by pickling in acid, shot peening or tumbling depending upon the size and composition of the forgings. If some distortion has occurred in forging, a sizing or straightening operation may be required. Controlled cooling is usually provided for large forgings. Heat treatment may also be required to provide certain physical properties. However some common characteristics of forged parts are given as under.

(*i*) Forged parts have directional properties and hence have good strength.

(*ii*) Mechanical properties of materials such as percentage elongation, resistance to stock and vibrations are improved.

(*iii*) Forging process confines the structure of metal by closing up the cavities.

(*iv*) Cracks and blow-holes are minimized in forged parts.

14.9 COMMON HAND FORGING TOOLS

For carrying out forging operations manually, certain common hand forging tools are employed. These are also called blacksmith's tools, for a blacksmith is one who works on the forging of metals in their hot state. The main hand forging tools are as under.

1. Tongs
2. Flatter
3. Swage
4. Fuller
5. Punch
6. Rivet header
7. Hot chisel
8. Hammers
9. Anvil
10. Swage block
11. Drift
12. Set-hammer
14. Brass scale
15. Brass
16. Black smith's gauge
17. Heading tool

Some of the hand forging tool are depicted in Fig.14.7- 14.15 and their applications are described as under.

Tongs

The tongs are generally used for holding work while doing a forging operation. Various kinds of tongs are shown in Fig. 14.7.

1. Flat tongs are used for mainly for holding work of rectangular section.
2. Straight-lip fluted tongs are commonly used for holding square, circular and hexagonal bar stock.
3. Rivet or ring tongs are widely used for holding bolts, rivets and other work of circular section.
4. Gad tongs are used for holding general pick-up work, either straight or tapered.

Flatter

Flatter is shown in Fig. 14.7. It is commonly used in forging shop to give smoothness and accuracy to articles which have already been shaped by fullers and swages.

Swage

Swage (Fig. 14.7) is used for forging work which has to be reduced or finished to round, square or hexagonal form. It is made with half grooves of dimensions to suit the work being reduced. It consists of two parts, the top part having a handle and the bottom part having a square shank which fits in the hardie hole on the anvil face.

Fuller

Fuller (Fig. 14.7) is used in forging shop for necking down a forgeable job. It is made in top and bottom tools as in the case of swages. Fuller is made in various shapes and sizes according to needs, the size denoting the width of the fuller edge

Punch

Punch (Fig. 14.7) is used in forging shop for making holes in metal part when it is at forging heat.

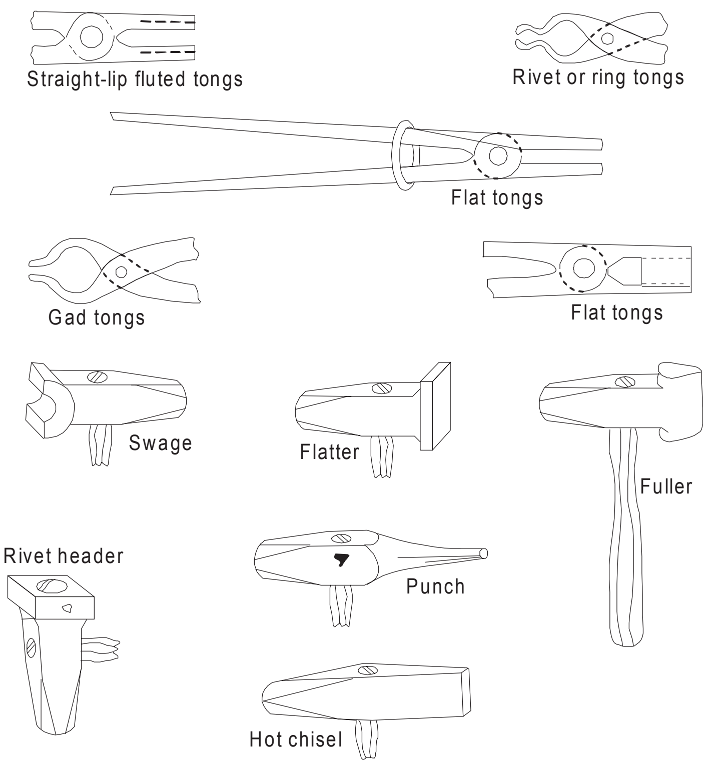

Fig. 14.7 Hand forging tools

Rivet header

Rivet header (Fig. 14.7) is used in forging shop for producing rivets heads on parts.

Chisels

Chisels are used for cutting metals and for nicking prior to breaking. They may be hot or cold depending on whether the metal to be cut is hot or cold. A hot chisel generally used in forging shop is shown in Fig. 14.7. The main difference between the two is in the edge. The edge of a cold chisel is hardened and tempered with an angle of about 60°, whilst the edge of a hot chisel is 30° and the hardening is not necessary. The edge is made slightly rounded for better cutting action.

Hand hammers

There are two major kinds of hammers are used in hand forging: (1) the hand hammer used by the smith himself and (2) the sledge hammer used by the striker. Hand hammers (Fig. 14.8) may further be classified as (*a*) ball peen hammer, (*b*) straight peen hammer, and (*c*) cross peen hammer. Sledge hammers (Fig. 14.8) may further be classified as (*a*) Double face hammer, (*b*) straight peen hammer, and (*c*) cross peen hammer. Hammer heads are made of cast steel and, their ends are hardened and tempered. The striking face is made slightly convex. The weight of a hand hammer varies from about 0.5 to 2 kg where as the weight of a sledge hammer varies from 4 to 10 kg.

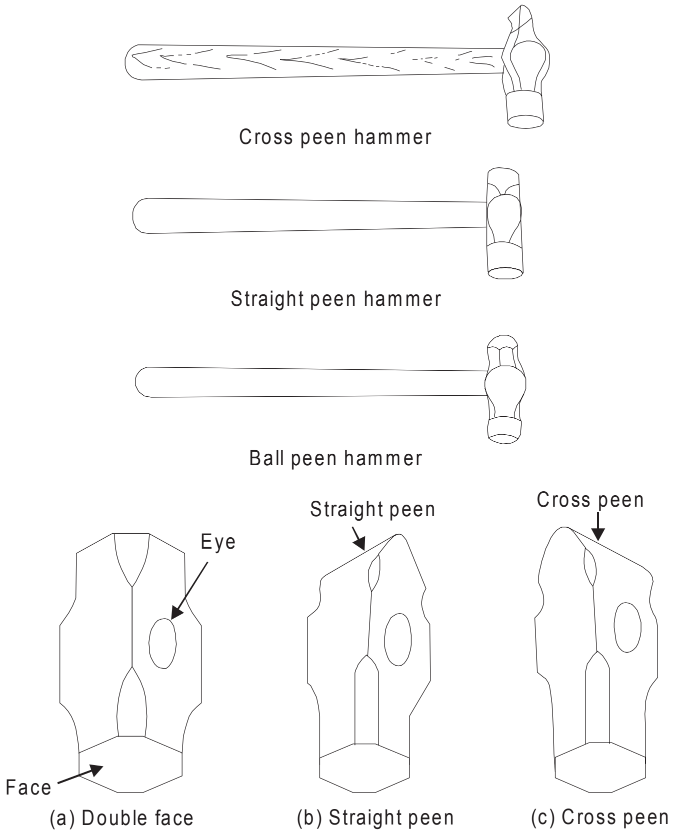

Fig. 14.8 Types of hammers

Set hammer

A set hammer generally used in forging shop is shown in Fig. 14.9. It is used for finishing corners in shouldered work where the flatter would be inconvenient. It is also used for drawing out the gorging job.

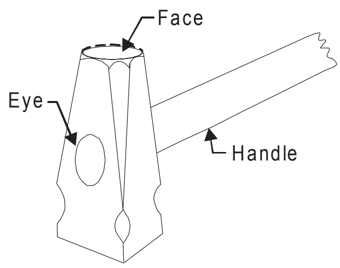

Fig. 14.9 Set hammer

Anvil

An anvil is a most commonly tool used in forging shop which is shown in Fig.14.10. It acts as a support for blacksmith's work during hammering. The body of the anvil is made of mild steel with a tool steel face welded on the body, but the beak or horn used for bending curves is not steel faced. The round hole in the anvil called pritchel hole is generally used for bending rods of small diameter, and as a die for hot punching operations. The square or hardie hole is used for holding square shanks of various fittings. Anvils in forging shop may vary up to about 100 to 150 kg and they should always stand with the top face about 0.75 mt. from the floor. This height may be attained by resting the anvil on a wooden or cast iron base in the forging shop.

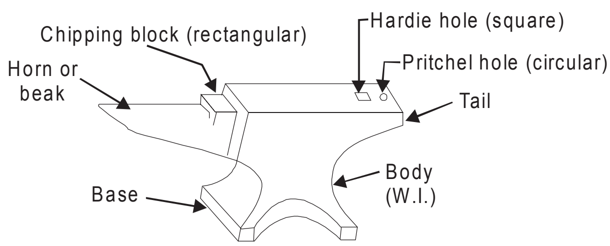

Fig. 14.10 Anvil

Swage block

Swage block generally used in forging shop is shown in Fig. 14.11. It is mainly used for heading, bending, squaring, sizing, and forming operations on forging jobs. It is 0.25 mt. or even more wide. It may be used either flat or edgewise in its stand.

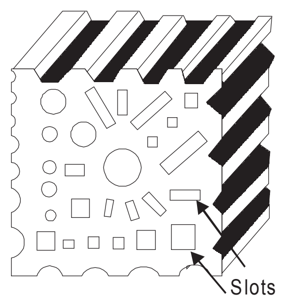

Fig. 14.11 Swage block

Drift

Drift generally used in forging shop is shown in Fig.14.12. It is a tapered rod made of tool steel. Holes are opened out by driving through a larger tapered punch called a drift.

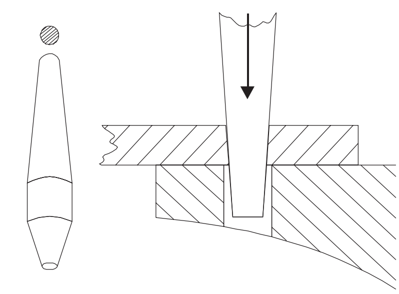

Fig. 14.12 Drift

Hardie

Hardie is a type of chisel used in forging shop. It is shown in Fig. 14.13. Its taper head is fixed into the hardie hole of the anvil, the cutting edge being upward. The part to be cut is kept over the cutting edge of the fixed hardie on anvil and another chisel is placed over the job and the cutting is performed by hammering.

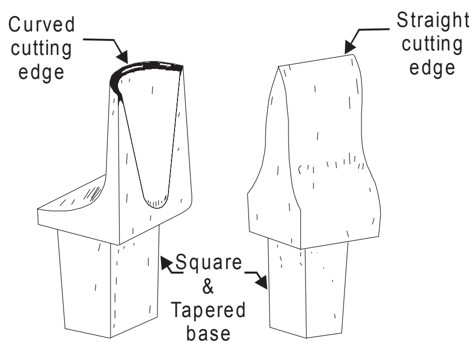

Fig. 14.13 Hardie

Shovel

Shovel generally used in forging shop is shown in Fig. 14.14. It is used to place coal or coke in the furnace. It is also used to set coal pieces in furnace and remove ash from furnace.

Poker

Poker (Fig.14.14) is employed for removing clinker from the furnace and to loose the compact coal pieces in the furnace.

Rake

Rake (Fig. 14.14) is used to put coal pieces on tuyres.

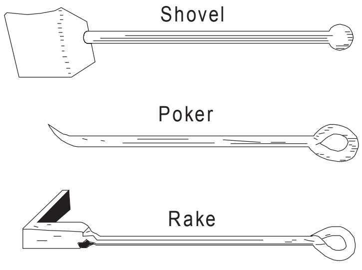

Fig. 14.14 Shovel, Poker and Rake

Beak Iron

Beak iron generally used in forging shop is shown in Fig. 14.15. It is also known as small anvil made of forged steel. Its upper front end consists of horn and upper back end comprises of flat tail. Its taper shank is inserted into the hardie hole of the anvil. It is commonly used as anvil for small forge work.

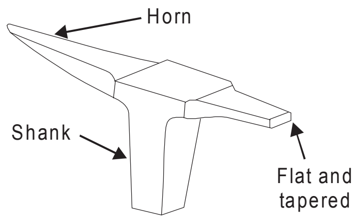

Fig. 14.15 Beak iron

14.10 FORGING METHODS

The forging methods are commonly used for changing the shape of the raw material in to the finished form in the forging shop are generally classified into two categories namely hand forging and power forging. These are being discussed as under

14.10.1 Hand forging

Hand forging is performed in the black smithy shop. The job is heated at the forging temperature in hearth and it is then brought on anvil using tong. It is then forged using hand hammers and other hand forging tools for imparting specific shape.

14.10.1.1 Forging Operations

The hand forging operations (Fig. 14.16) are

1. Upsetting
2. Bending
3. Drawing down
4. Cutting
5. Setting down
6. Punching
7. Flattening
8. Fullering
9. Forge Welding
10. Swaging

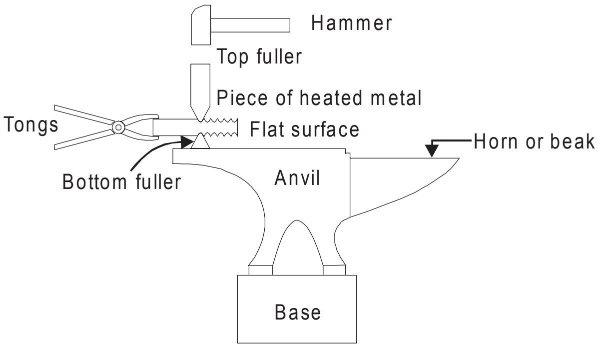

Fig. 14.16 Hand forging

Some important hand forging operations are described as under.

(*i*) Drawing out

Drawing out is used to reduce the thickness of a bar and to increase its length. It may be carried out by working the metal over the horn the anvil as shown in Fig. 14.17, then by hammering it on the anvil face. The rounded horn of the anvil acts as a blunt edge, which forces the metal to flow lengthwise when struck by the hammer. For drawing down very heavy work, fuller may be used for drawing down a bar over the horn (round portion) of anvil.

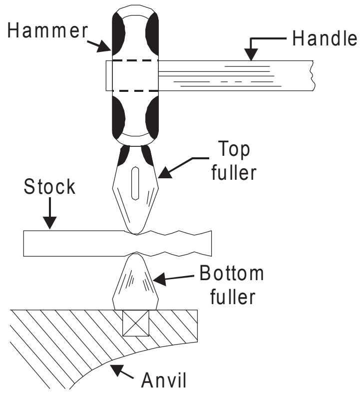

Fig. 14.17 Drawing out

(*ii*) Fullering

Fullering operation generally used in forging shop is shown in Fig. 14.18. It involves heating the stock in the black smith hearth. Then heated stock is placed on the fuller fixed on anvil. A fuller is put over the sock and hammering is done to reduce the cross section of job at required point.

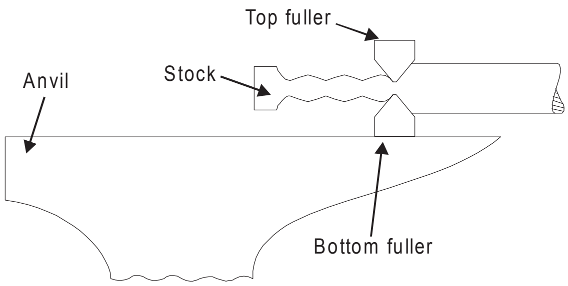

Fig. 14.18 Fullering

(*iii*) Upsetting

Upsetting is also known as jumping operation which is carried out to increase the thickness (or diameter) of a bar and to reduce its length. Generally, the increase in thickness is only local, for example, when forming a bolt head. This operation is an operation just opposite to drawing and involves increasing the cross-sectional area usually by hammering or pressing in a direction parallel to the ingot axis. The length of the ingot decreases and following the path of least resistance it spreads out. The required shape is given the ingot by spreading it between two dies. Only that portion of the bar which is to be upset is heated locally. Or, the whole bar is heated and except for the portion to be upset, the rest is quenched in water so that upset will form only on the hot portion of the bar. In one method of upsetting, the bar is held in the tong and supported vertically on the anvil. The top edge of the bar is then hammered to form the upset on the bottom hot end of the bar. For upsetting, the blow of the hammer must be in line with the bar to prevent bending of the bar.

(iv) Bending

Bending is a very commonly used forging operation in forging shop to give a turn to a metal rod or plate. It is accompanied by spreading of the metal in the inside of the bend and narrowing at outside. The simplest method of bending a piece of metal in hand forging is to support it on the anvil and to strike its free end with a hammer When bent, the metal of the workpiece thins out round bend causing weakness. This can be overcome by upsetting the bar prior to bending.

(*v*) Cutting

Cutting is a main forging operation to cut out a metal rod or plate into two pieces with the help of a chisel and hammer when the metal is in red hot condition. A hot or cold cut (chisel) is used for cutting heated metal bars in a smithy shop. The hot set does not require hardening and tempering. Its cutting edge is keener than that of a cold set. Hot sets are manufactured from a tough variety of steel in order that they may cut through relatively soft red-hot metal with ease. While cutting, it is best to cut half through the workpiece to turn it over and cut through from the other end.

(*vi*) Punching

Punching is a main forging operation used for producing hole in metal plate by using a tool known as punch. The metal plate is placed over the hollow cylindrical die and punch is placed above it at required location where hole is being made. For punching a hole, the metal job must be at near welding heat and the punch is driven part way through the job with hammer blows. The work is then turned over and the hole is completed from the other side. The above said practice is adopted for thicker jobs.

(*vii*) Forge Welding

It is a process of joining two metal pieces to increase the length by pressing or hammering them when they are at forging temperature. It is performed in forging shop and hence sometimes it is called as forge welding.

14.10.2 Power Forging

Hand hammer blows impact will not be always sufficient enough to affect the proper plastic flow in a medium sized or heavy forging. It also causes fatigue to the hammer man. To have heavy impact or blow for more plastic deformation, power hammer are generally employed. These hammers are operated by compressed air, steam, oil pressure, spring and gravity. They are generally classified as spring hammer and drop hammers. The capacity of these hammers is given by the total weight. A 100 kg hammer will be one of which the falling pans weigh 100 kg. The heavier these parts and greater the height from which they fall, the higher will be intensity of blow the hammer will provide. Power hammers are of different types e.g. spring power hammers, pneumatic power hammers etc. These hammers are named due to their construction, according to their way of operation and according to the type of fuel they use for getting the required power for operation. Besides these, a large number of forging presses are also used in forging work. Typical hammers are discussed in following in following paragraphs.

14.10.2.1 Spring Hammer

Spring hammer is commonly used for small forgings. It is light type of power hammer. The typical design of a spring hammer is shown in Fig. 14.19. It consists of a heavy rigid frame carrying a vertical projection at its top. This projection acts as a housing of bearing in which the laminated spring oscillates. The rear end of this spring carries a connecting rod and the other front end a vertical top which carries weight and moves vertically up and down between fixed guides provided for this purpose. The connecting rod at its lower end is attached to an eccentric sheave, which is further connected to the crank wheel. Fox operating the hammer the treadle is pressed downwards which makes the sheave to rotate through the crank wheel and thus the laminated spring starts oscillating in the bearing. This oscillation of the spring is responsible for the up and down movement of the tup thus, the required blows are provided on the job to be forged. A hand lever is also equipped with this mechanical kind of hammer to adjust the stroke of the connecting rod and, hence the intensity of blows. Eccentric type of spring hammer is the one in which a rotating eccentric disc is used for producing vibrations in the spring. It can be operated by means of a foot ring, known as treadle provided at the bottom and is connected to the shaft at the top through a vertical bar having a clutch at its end. The shaft at the top of hammer carries a pulley and a solid disc at the end. The pulley is driven by means of a belt from the line shaft or an electric motor. The solid disc, at the, end of the shaft, carries a crank connected eccentrically to it which has a laminated spring at its lower end. The nip carrying the weight is suspended on a toggle joint connecting the two ends of the laminated spring. When the foot treadle is pressed the clutch engages with the shaft and the disc carrying the crank starts rotating which in turn produces fluctuations in the toggle joint of the machine. It makes the tup to move and down in vertical direction. The speed of blows entirely depends upon the speed of the driving pulley.

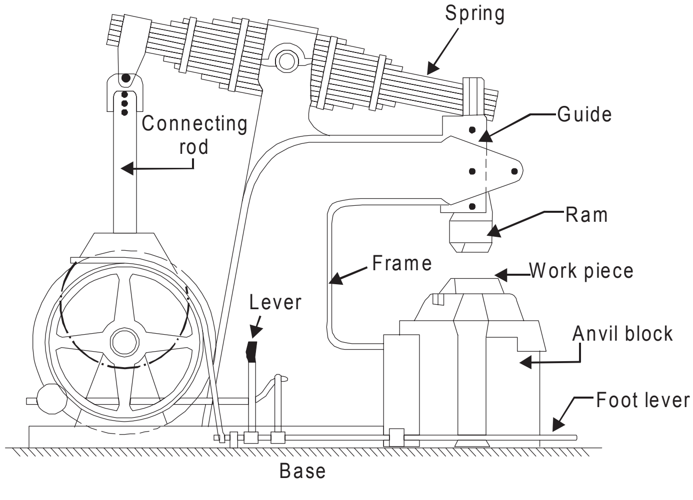

Fig. 14.19 Spring hammer

Spring hammers may be made available in various capacities having the tup weights from 30 to 250 kg. Those having top weights 50 to 100 kg and speed of blows up to 300 per minute are in generally used in forging shop. These hammers have a common drawback in their springs getting broken very frequently due to severe vibrations during forging of the jobs in the forging shop.

14.10.2.2 Drop Hammers

Drop hammers are operated hydraulically and are widely used for shaping parts by drop hammering a heated bar or billet into a die cavity as shown in Fig. 14.20. A drop forging raises a massive weight and allows it to fall under gravity on close dies in which forge component is allowed to be compressed. The die incorporates its shape on to the hot work piece as shown in Fig. 14.21. Drop hammers are commonly used for forging copper alloys and steel.

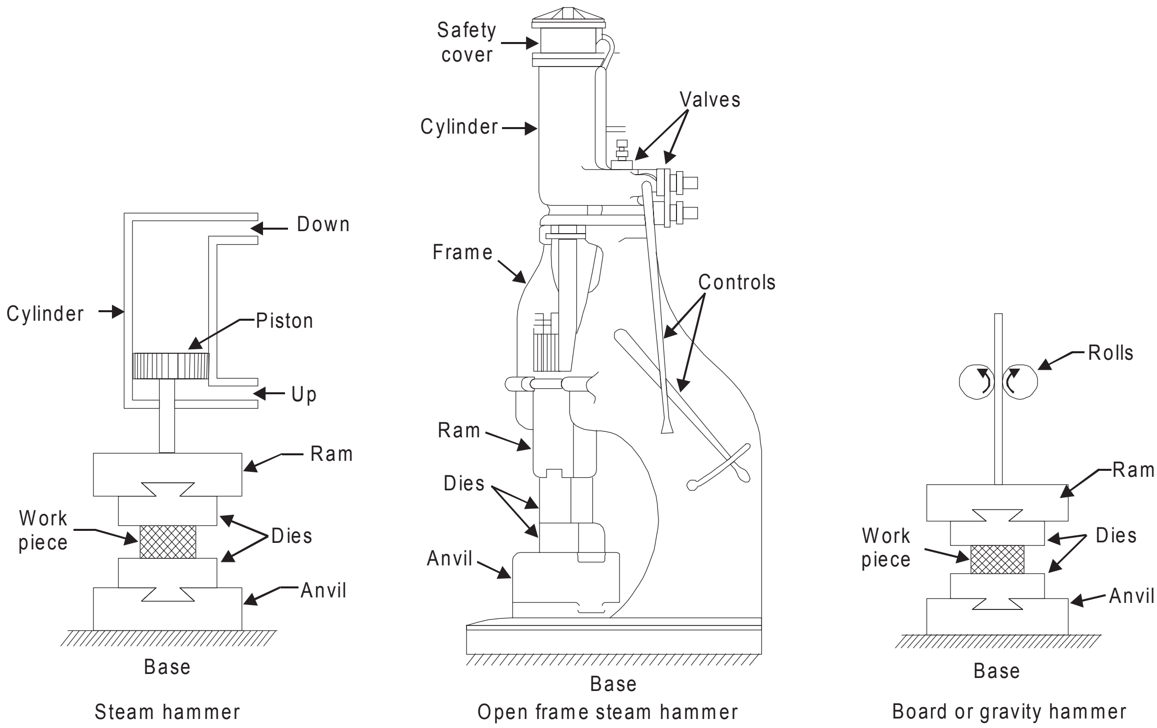

Fig. 14.20 Drop hammers

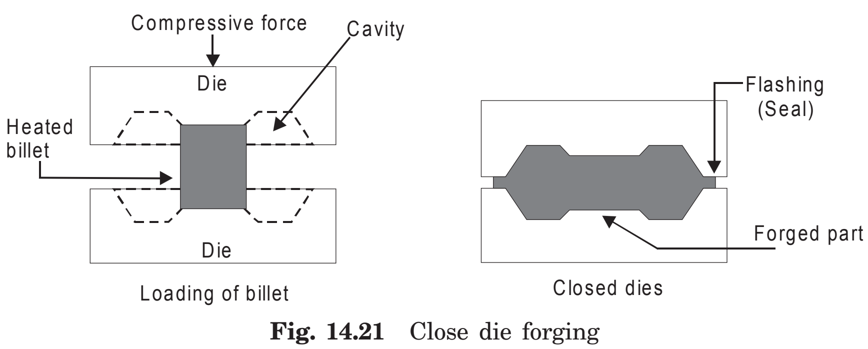

Fig. 14.21 Close die forging

14.10.2.3 Design Principles for drop forging

Certain principles for drop forgings generally followed are given as under:

1. The sections of the forging should be balanced about the parting line. Where this is impossible, design for the simplest irregular parting line which approaches a balanced condition.
2. Generous inside fillets and external radio should be allowed. Minimum radius should be 2 mm for small parts and 4 mm for large parts.
3. Sufficient draft should be allowed for easy removal of: the part, as follows:

14.11 DEFECTS IN FORGED PARTS

Defects commonly found in forged parts that have been subjected to plastic deformation are as follows.

(*i*) Defects resulting from the melting practice such as dirt, slag and blow holes.

(*ii*) Ingot defects such as pikes, cracks scabs, poor surface and segregation.

(*iii*) Defect due to faulty forging design.

(*iv*) Defects of mismatched forging because of improper placement of the metal in the die.

(*v*) Defects due to faulty design drop forging die.

(*vi*) Defects resulting from improper forging such as seams cracks laps. etc.

(*vii*) Defects resulting from improper heating and cooling of the forging part such as burnt metal and decarburized steel.

Some well identified common forging defects along with their reason are given as under.

1. Mismatched forging

Reasons

Due to non alignment of proper die halves.

2. Brunt and overheated metal

Reasons

This is caused by improper heating the metal at high temperature or for a long time.

3. Fibred flow lines discontinued

Reasons

This will occur because of very rapid plastic flow of metal.

4. Scale pits

Reason

These are formed by squeezing of scale into the metal surface during forging.

5. Oversize components

Reasons

Due to worn out dies, incorrect dies, misalignment of die halves.

14.12 REMOVAL OF DEFECTS IN FORGING

Defects in forging can be removed as follows:

(*i*) Surface cracks and decarburized areas are removed from forging parts by grinding on special machines. Care should also be taken to see that the job is not under heated, decarburized, overheated and burnt.

(*ii*) Shallow cracks and cavities can be removed by chipping out of the cold forging with pneumatic chisel or with hot sets.

(*iii*) The parting line of a forging should lie in one plane to avoid mismatching.

(*iv*) Destroyed forgings are straightened in presses, if possible.

(*v*) Die design should be properly made taking into consideration all relevant and important aspects that may impart forging defects and ultimate spoilage

(*vi*) The mechanical properties of the metal can be improved by forging to correct fibre line. The internal stresses developed due to heating and cooling of the job can be removed by annealing or normalizing.

14.13 GENERAL CONSIDERATIONS ADOPTED FOR DESIGNING A FORGING JOB

There are some common considerations adopted while designing a forging job and the same are given below.

1. Sufficient draft on surfaces should be provided to facilitate easy removal of forgings from the dies. It depends mainly on the depth of the die cavity. The greater the depth, the larger draft will be the required. Generally, however, a 1 to 5 degrees draft is provided on press forgings and 3 to 10 degrees on drop forgings.
2. Sharp corners where ever occur should always be avoided as far as possible to prevent concentration of stresses leading to fatigue failures and to facilitate ease in forging. The usual practice is to provide fillets of more than 1.6 mm radius. The exact size of the fillet is however decided according the size of the forging. If a perfectly sharp corner is required, the fillet can be removed at later stage.
3. Forgings which are likely to carry flash, such as in drop and press forgings, should preferably have the parting line in such a position that the same will divide them in two equal halves.
4. As far as possible the parting line of a forging should lie in one plane.
5. The forged component should ultimately be able to achieve a radial flow of grains or fibres.
6. Attention should be given to avoid the presence of pockets and recesses in forgings. If they cannot be avoided, their number should be reduced to a minimum as far as possible.
7. High and thin ribs should not be designed. Also, cavities which are deeper than their diameters should be avoided.
8. Metal shrinkage and forging method should be duly taken into account while deciding the forging and finishing temperatures.
9. Although it is possible to achieve quite close tolerances of the order of 0.4 mm on either side through forging and therefore it is adequate to provide allowances to

compensate for metal shrinkage, machining, die wear, trimming and mis-match of dies.

10. Too thin sections in parts should be avoided to facilitate an easy flow of metal.

14.14 HEAT TREATMENT OF FORGING

Heat treatment is carried out for releasing the internal stresses arising in the metal during forging and cooling of work piece. It is used for equalizing the granular structure of the forged metal and improving the various mechanical properties. Generally forged parts are annealed, normalized and tempered to obtain the desired results.

14.15 SAFETY PRECAUTIONS

Some safety precautions generally followed while working in forging shop are given as under.

1. Always avoid the use of damaged hammers.
2. Never strike a hardened surface with a hardened tool.
3. No person should be allowed to stand in line with the flying objects.
4. Always use the proper tongs according to the type of work.
5. The anvil should always be free from moisture and grease while in use.
6. Always wear proper clothes, foot-wears and goggles.
7. The handle of the hammer should always be tightly fitted in the head of the hammer.
8. Always put out the fire in the forge before leaving the forge shop.
9. Always keep the working space clean.
10. Proper safety guards should be provided on all revolving parts.
11. Head of the chisel should be free from burrs and should never be allowed to spread.
12. During machine forging, always observe the safety rules prescribed for each machine.
13. One must have the thorough knowledge of the working of the forging machine before operating it.

14.16 QUESTIONS

1. What is the difference between smithy and forging?
2. What do you understand by open fire and stock fire? Which of the two is more advantageous and why?
3. Explain the various types of furnaces used in forging work?
4. Write Short notes on:
    1. Drop forging
    2. Press forging
    3. Flattening
    4. Smith's Forge
    5. Pedestal grinder
    6. Power hammers

7. Pneumatic riveting machine
8. Layout of smithy or forging shop.

5 Sketch and describe the following forging tools

(*i*) Anvil. (*ii*) Swage Block, (*iii*) Set hammers
(*iv*) Punches, (*v*) Drift, and (*vi*) Hardie

6 Explain with neat sketches the following forging operations:

(*i*) Upsetting, (*ii*) Drawing down, (*iii*) Bending,
(*iv*) Drifting, (*v*) Punching, (*vi*) Welding
(*vii*) Fullering

7 Describe press forging. How does it differ from drop forging?

8 Describe in brief the various types of forgings?

9 Explain in brief the defects in forging?

10 Why heat treatment is necessary for forging?

11 What are the main considerations in designing a forging?

12 Explain in brief the various safety precautions associated with the forging shop?

15
CHAPTER

HOT WORKING OF METALS

15.1 METAL FORMING

Metal forming is also known as mechanical working of metals. Metal forming operations are frequently desirable either to produce a new shape or to improve the properties of the metal. Shaping in the solid state may be divided into non-cutting shaping such as forging, rolling, pressing, etc., and cutting shaping such as the machining operations performed on various machine tools. Non-cutting or non machining shaping processes are referred to as mechanical working processes. It means an intentional and permanent deformation of metals plastically beyond the elastic range of the material. The main objectives of metal working processes are to provide the desired shape and size, under the action of externally applied forces in metals. Such processes are used to achieve optimum mechanical properties in the metal and reduce any internal voids or cavities present and thus make the metal dense.

Metals are commonly worked by plastic deformation because of the beneficial effect that is imparted to the mechanical properties by it. The necessary deformation in a metal can be achieved by application of mechanical force only or by heating the metal and then applying a small force. The impurities present in the metal are thus get elongated with the grains and in the process get broken and dispersed through out the metal. This also decreases the harmful effect of the impurities and improves the mechanical strength. This plastic deformation of a metal takes place when the stress caused in the metal, due to the applied forces reaches the yield point. The two common phenomena governing this plastic deformation of a metal are (*a*) deformation by slip and (*b*) deformation by twin formation. In the former case it is considered that each grain of a metal is made of a number of unit cells arranged in a number of planes, and the slip or deformation of metal takes place along that slip plane which is subjected to the greatest shearing stress on account of the applied forces. In the latter case, deformation occurs along two parallel planes, which move diagonally across the unit cells. These parallel planes are called twinning planes and the portion of the grains covered between them is known as twinned region. On the macroscopic scale, when plastic deformation occurs, the metal appears to flow in the solid state along specific directions, which are dependent on the processing and the direction of applied forces. The crystals or grains of the metal get elongated in the direction of metal flow. However this flow of metal can be easily be seen under microscope after polishing and suitable etching of the metal surface. The visible lines are called fibre flow lines. The above deformations may be carried out at room temperature or higher temperatures. At higher temperatures the deformation is faster because the bond between atoms of the metal grains is reduced. Plasticity, ductility and malleability are the properties of a material, which retains the deformation produced under applied forces permanently and hence these metal properties are important for metal working processes.

Plasticity is the ability of material to undergo some degree of permanent deformation without rupture or failure. Plastic deformation will take place only after the elastic range has been exceeded. Such property of material is important in forming, shaping, extruding and many other hot and cold working processes. Materials such as clay, lead, etc. are plastic at room temperature and steel is plastic at forging temperature. This property generally increases with increase in temperature.

Ductility is the property of a material enabling it to be drawn into wire with the application of tensile force. A ductile material must be both strong and plastic. The ductility is usually measured by the terms percentage elongation and percent reduction in area often used as empirical measures of ductility. The ductile material commonly used in engineering practice in order of diminishing ductility are mild steel, copper, aluminium, nickel, zinc, tin and lead.

Malleability is the ability of the material to be flattened into thin sheets without cracking by hot or cold working. A malleable material should be plastic but it is not essential to be so strong. The malleable materials commonly used in engineering practice in order of diminishing malleability are lead, soft steel, wrought iron, copper and aluminium. Aluminium, copper, tin, lead, steel, etc. are recognized as highly malleable metals.

15.2 RECRYSTALISATION

During the process of plastic deformation in metal forming, the plastic flow of the metal takes place and the shapes of the grains are changed. If the plastic deformation is carried out at higher temperatures, new grains start growing at the location of internal stresses caused in the metal. If the temperature is sufficiently high, the growth of new grains is accelerated and continuous till the metal comprises fully of only the new grains. This process of formation of new grains is known as recrystallisation and is said to be complete when the metal structure consists of entirely new grains. That temperature at which recrystalisation is completed is known as the recrystallisation temperature of the metal. It is this point, which draws the line of difference between cold working and hot working processes. Mechanical working of a metal below its recrystalisation temperature is called as cold working and that accomplished above this temperature but below the melting or burning point is known as hot working.

15.3 HOT WORKING

Mechanical working processes which are done above recrystallisation temperature of the metal are know as hot working processes. Some metals, such as lead and tin, have a low recrystallisation temperature and can be hot-worked even at room temperature, but most commercial metals require some heating. However, this temperature should not be too high to reach the solidus temperature; otherwise the metal will burn and become unsuitable for use. In hot working, the temperature of completion of metal working is important since any extra heat left after working aid in grain growth. This increase in size of the grains occurs by a process of coalescence of adjoining grains and is a function of time and temperature. Grain growth results in poor mechanical properties. If the hot working is completed just above the recrystallisation temperature then the resultant grain size would be fine. Thus for