1. The *gad tong* used for general pick-up work, either straight or tapered.
2. The *straight-lip fluted tong* used for square, circular and hexagonal bar stock.
3. The *ring tong* used for bolts, rivets and other work of circular section.
4. The *flat tong* used for holding work of rectangular section.

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. 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 (Fig.8.5).

Swages. Swages are used for work which has to be reduced and finished to round, square or hexagonal form. These are made with half grooves of dimensions to suit the work being reduced. Swages consist of two parts --the top part having a handle and the bottom part having a square shank which fits in the hardie hole in the anvil face (Fig. 8.5)

Fullers. Fullers are used for necking down a piece of work. They are made in top and bottom tools as in the case of swages. Fullers are made in various shapes and sizes according to needs, the size denoting the width of the fuller edge (Fig. 8.5)

Flatters. Flatters are used to give smoothness and accuracy to articles which have already been shaped by fullers and swages (Fig.8.5).

The set-hammer. It is really a form of flatter. A set hammer is used for finishing corners in shouldered work where the flatter would be inconvenient. It is also used for drawing out. (Fig. 8.5).

The punch and the drift. A punch is used for making holes in metal part when it is at forging heat, and holes are opened out by driving through a larger tapered punch called a drift (Fig.8.5).

8.6 SMITH FORGING OPERATIONS

A number of operations are used to change the shape of the raw material to the finished form. The typical forging operations are :

1. Upsetting.
2. Drawing down.
3. Setting down.
4. Bending.
5. Welding.
6. Cutting.

7. Punching 8. Fullering

All these operations are carried out with the metal in a heated condition, which must be maintained by taking a 'fresh' heat when the work shows signs of getting cold.

UPSETTING

Upsetting or heading is the process of increasing the thickness of a bar at the expense of its length and is brought about by end pressure. The pressure may be obtained by driving the end of the bar against the anvil, by supporting on the anvil and hitting with the h mer, by placing in swage block hole and hitting with the hammer or by ..amping in a vice and then hammering.

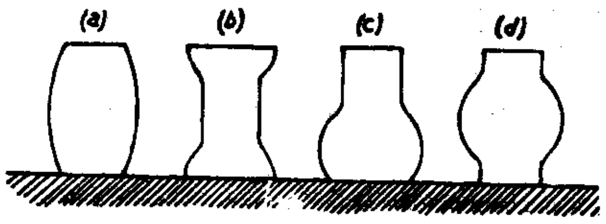

Figure 8.6 Upset forging operations

Fig. 8.6 (a) shows the effect of heavy hammer blows on a uniformly heated bar ; (b) shows the effect of comparatively light hammer blows. Local upsets may be obtained as shown at (c) and at (d) by heating only the end or the middle of the .

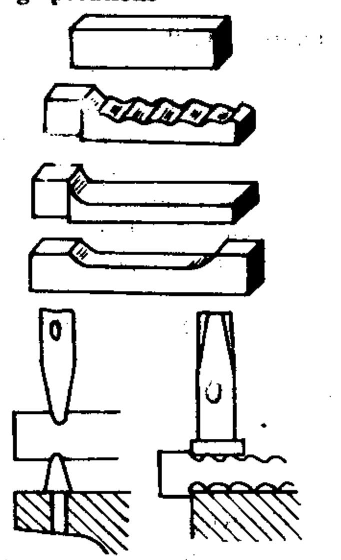

Figure 8.7 Swaging operation

DRAWING DOWN OR SWAGING

It is the process of increasing the length of a bar at the expense of its width or thickness or both. In Fig. 8.7, *A*, *B*, and *C* illustrate this operation. *A* represents the original stock, *B* shows the stock after hammering with a straight peen hammer or with a top fuller and sledge, and *C* shows the finished forging after the flatter has been used.

SETTING DOWN

It is a localized drawing-down or swaging operation as illustrated at *D* in Fig. 8.7. In other words, it may be said as the process of local thinning down effected by the set-hammer or set. Usually, the work is fullered at the place where the setting down commences. In Fig. 8.7, *E* shows the process of setting down both edges of a bar using the top and bottom fuller and *F* illustrates how the flatter may be used close to a shoulder.

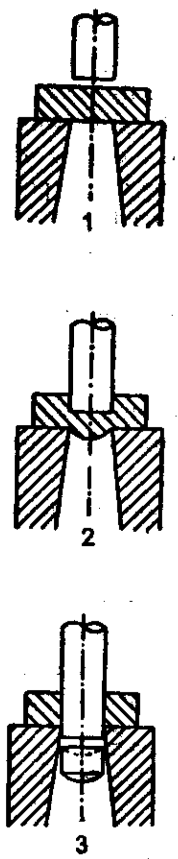

Figure 8.8 Punching operations

PUNCHING

It is the process of producing holes, generally cylindrical, by using a hot punch over the pritchel hole of the anvil, over a cylindrical die, or over a hole of the correct size in the swage block. Fig. 8.8 shows the stages in punching a hole.

BENDING

Bending is an important operation in forging and is one very frequently used. This may be classified as angular or curvilinear. Bending may be done over the edge of the anvil face, over the anvil horn, in special forms such as the swage block edges, or for bar stock, by inserting the end in the pritchel hole and bending the bar with a wrench or tong.

When metal is bent, the layers of metal on the inside are shortened and those on the outside are stretched. This causes a bulging of

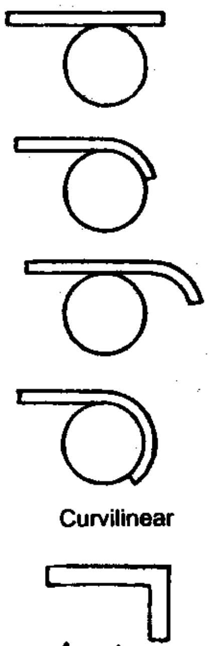

Figure 8.9 Bending operations

the sides at the inside, and a radius on the outside of the bend. If a perfect square bend is required, additional metal must be worked to the place where the bend occurs. When this is bent the additional metal will go to make up the corner. Gradual bends may be made by using the beak of the anvil as a former, or the metal may be bent round a bar of the correct radius held in a vice. Fig. 8.9 shows the stages in bending a bar over the horn of an anvil using a hammer.

WELDING OR SHUTTING

It is perhaps the principal operation performed by the smith. The metal which remains pasty over a wide range of temperature is most easily welded, and in this respect wrought iron and mild steel have some advantage over other metals. The first essential to the production of a sound weld is that the surfaces in contact must be perfectly clean, both mechanically and chemically so that cohesion will take place when the metal is in a plastic state. A protection to the metal is a coating of flux which covers the surfaces of the metal and, by excluding the air prevents oxidation. Fluxes which are commonly used in forge welding consist of clean quartz sand, calcined borax, or a mixture of four parts of borax with one part of sal-ammoniac.

A forge weld is made by hammering together the ends of two bars which have been formed to the correct shape and heated to a welding temperature in a forge fire. The method of preparing the pieces of metal for welding is known as *scarfing*. This involves the shaping of the ends of the pieces to be welded so that they will unite at the centre when they are brought together.

Four forms of welded joint commonly employed are : (1) the lap or scarf weld, in which the ends are prepared so that they may be welded one upon the other, with the joint in an inclined direction ; (2) the butt weld, in which the ends of the pieces to be joined are butted together, the weld being between the ends at right angles to the length of the piece ; (3) the 'T' or jump weld, in which one piece is placed at the centre of another at right angle to each other in the form of an inverted 'T' ; and (4) the split,

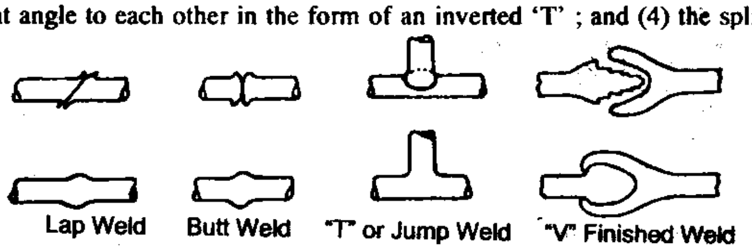

Figure 8.10 Forge welded joints

fork, or 'V' weld or splice, in which the ends are first brought to the shape of fork and tongue respectively. They are illustrated in Fig. 8.10.

In the lap weld, the ends of the pieces to be joined must be upset, and shaped slightly convex, so that when put together the junction takes place first at the centre, extending to the edges, and forcing out the slag in front. Lap weld is easier to make by hand hammering, but butt welding is neither preferable nor easy to make by hand operation. V-weld is regarded as the most secured form of weld and is particularly suitable for thick pieces where the formation of 'V' can be done easily and most conveniently.

CUTTING

Cutting-off is a form of chiseling whereby a long piece of stock is cut into several specified lengths, or a forging is separated (cut-off) from its stock. For hot chiseling, steel must be heated in a blacksmith's hearth or furnace to a light cherry red heat, i.e., from 850 to 950°C. When cutting with chisels, the hammer blows are directed on to the chisel head, which must be slightly rounded.

A notch is first made about one-half the thickness or diameter of the stock. After the spot where the stock is to be cut off has been notched, the work must be turned through an angle of 180° and the chisel is placed exactly opposite the notch. The required length of metal can then be cut-off by giving the chisel a few blows with a sledge hammer. Before striking the last blow, the stock must be placed on an anvil so that its cut-off end is parallel with the edge of the anvil. If the steel is very hard, four notches will be required instead of two and the stock will have to be turned through 90° after each blow, instead of 180°.

FULLERING

Fullering or spreading the metal along the length of the job is done by working separate sections. In this case, the axis of the job is positioned perpendicular to the width of the flat die.

8.7 SMITH FORGING EXAMPLES

It has earlier been discussed of some of the important forging operations. This is because most jobs are produced by a combination of these processes. Some of the cases of smith's everyday work are described hereunder

MAKING A BOLT HEAD

Making a bolt head is illustrated in Fig. 8.11.

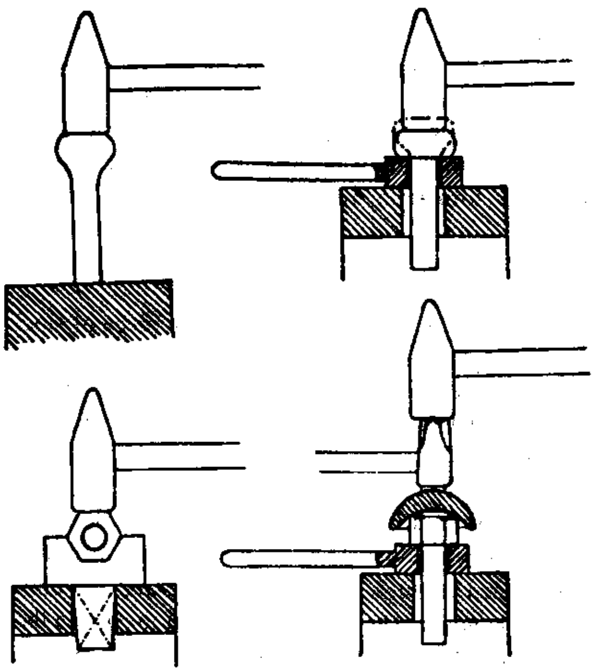

Figure 8.11 Stages in making a bolt head

1. Heat one end of the bar for a sufficient length to make the head.
2. Jump up heated end on an anvil.
3. Flatten head by hammering against the end of a bush, placed directly over the square hole in the anvil, through which the shank will pass.
4. Swage head to size.
5. Forge chamfer on head by a cupping tool, using the bush as support.

Tools used. (1) Anvil, (2) hand hammer, (3) round tong, (4) size plate or bush, (5) flatner, (6) swage, (7) cupping tool, (8) foot-rule, and (9) caliper.

MAKING A COLD CHISEL

How a cold chisel is made in a smith shop is illustrated in Fig. 8.12.

1. Heat one end of the octagon steel bar.
2. Forge chamfer on head.
3. Heat other end, forge to flat taper, and then cut off excess metal.
4. Turn the chisel a quarter turn and, holding the shank horizontally, hammer the narrow sides to make them parallel. Alternate the blows, four or five on the wider surface, then four or five on the narrow surface, and so on until thechisel is in the shape desired.
5. Heat-treat and then grind.

Tools used. (1) Anvil, (2) hammer, (3) flat tong, (4) flatner, and (5) foot-rule.

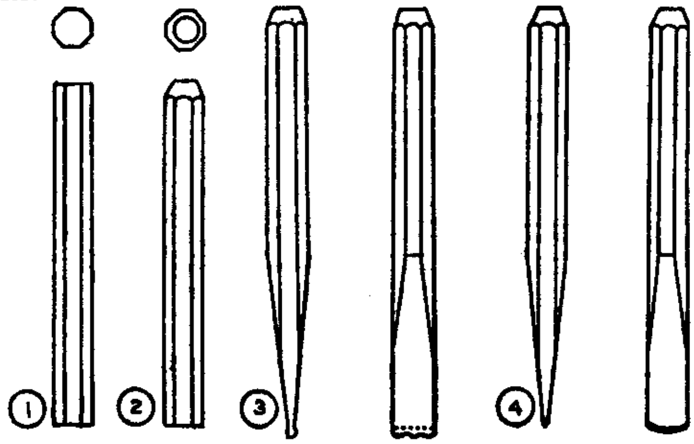

Figure 8.12 Stages in making a cold chisel

Hardening and tempering. After the chisel is forged the next operation is ***annealing***. Heat the chisel to a cherry red (a little hotter than dull red) and cool very slowly ordinarily in air. Annealing serves to relieve, the stress set up by forging and to give the steel an even, close-grained structure.

The next step is ***hardening***. Heat the cutting end to a cherry red about 50 mm back from the cutting edge and quench the steel vertically in cold water to a depth of about 25 mm moving the chisel up and down during this operation. This movement is to avoid having too sharp a line between the hardened and unhardened portions. If this is not done the piece is liable to crack at the water line. Plunge the whole chisel under water and quickly back nearly out, i.e., out to the 25 mm portion that must be left in the water. Remove the chisel from the water and dip into the tempering oil.

Tempering is the next operation. Remove the chisel from the oil bath and polish with a piece of emery cloth. Heat the cutting edge over a flame until the colour of the cutting end becomes purple tinged with blue and then cool very slowly in air.

Finally, *grind* the cutting edge to the shape and angle desired.

MAKING A FLAT DRILL

The process of making a flat drill is as follows (Fig. 8.13) :

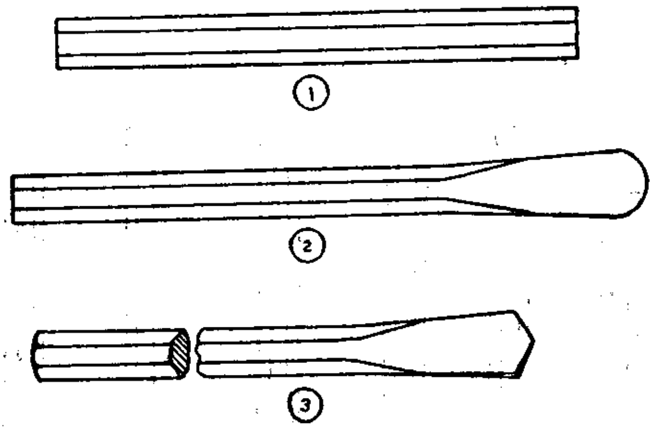

Figure 8.13 Stages in making a flat drill

1. Heat one end of the piece in a forge fire.
2. Forge to flat taper and cut off excess metal.
3. Heat-treat and grind the cutting edge to the shape and angle shown.

Tools used. (1) Anvil, (2) hammer, (3) flat tong, (4) flatner and (5) foot-rule.

MAKING A CHAIN

Stages for making a link for a chain is shown in Fig. 8.14.

1. Cut the rod into four pieces of required size, three of equal lengths for 3 links and the fourth one for the ring.
2. Heat one piece of the rod in a forge fire.
3. Place it with a round tong over the horn of an anvil and bend it by hammering with a hand hammer.

4. Scarf the ends for welding. *Scarfing* is the method of shaping the ends of metal for welding.
5. Heat the whole piece again and bend it into the shape desired and weld the scarfed ends to from the link.
6. Weld the second link in this manner, but the first link already made must be inserted within it an so on until all the links are prepared.

The method of making the ring is same as before. After scarfing the ends, heat the whole piece and bend it to the shape in a set of bending rolls. Finally, place the ring on any end as shown in Fig. 8.15.

To estimate the length of rod required in forging, a little length, in addition to the calculated length, is usually allowed for squaring the ends just before closing. Further, forging involves loss in material due to roasting residue (forging scales) and compression of the material. Therefore, a material allowance of 10 to 20 per cent should be added, depending on the size of the working piece.

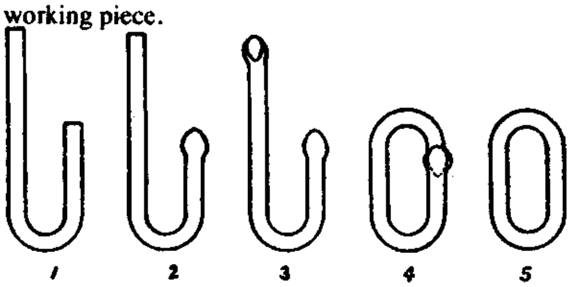

Figure 8.14 Stages in making a link for a chain

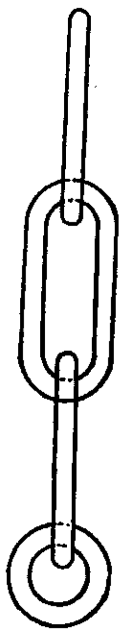

Figure 8.15 A chain

Tools used. (1) Anvil, (2) hammer, (3) tong, (4) chisel, (5) caliper, and (6) footrule.

8.8 FORGING PROCESSES

The processes of reducing a metal billet between *flat-dies* or in a *closed-impression* die to obtain a part of predetermined size and shape are called *smith forging* or *impression-die forging* respectively. Depending on the equipments utilized they are further sub-divided as hand forging, hammer forging, press forging, drop hammer forging, mechanical press forging, upset or machine forging.

In general, the methods of forging may, therefore, be classified as follows :

1. Smith die forging.
   - (a) Hand forging.
   - (b) Power forging.
     - (i) hammer forging.
     - (ii) press forging.
2. Impression-die forging.
   - (a) Drop forging.
   - (b) Press forging.
   - (c) Machine forging.

For production purpose it is important not only that the material can be deformed with feasible pressures and forces, but also that the deformation should be uniform and free from defects.

SMITH DIE FORGING

Smith forging, also called *flat-die* and *open-die forging*, includes the broad field of forging work produced between flatfaced dies and possibly supplemented by stock tooling. The final shape of the forging depends largely on the skill of the smith for size and shape.

Smith forging, done by hand on an anvil, is employed only to shape a small number of light forgings, chiefly in repair shops. Heavy forgings weighing upto 25,000 kg, as well as medium forgings in small batches, are produced exclusively in hammers and presses.

Smith forging or open-die forging processes produce work pieces of lesser accuracy than impression or closed-die forging ; however, tooling is usually simple, relatively inexpensive and allows the production of a large variety of shapes.

8.9 HAND FORGING

The forging is done by hammering the piece of metal, when it is heated to the proper temperature, on an *anvil*. While hammering, the heated metal is generally held with suitable tongs. *Formers* are held on the forging by the smith while the other end is struck with a sledge by a helper. The surfaces of formers have different shapes, and they are used to impart these shapes to the forgings. One type of former, called a *fuller*, having a well-rounded chisel shaped edge is used to draw out the work. Fullers are also made as anvil fittings so that the metal can be drawn out, using both top and bottom fullers. Anvil fittings of various shapes can be placed in the square hole of the anvil. For cutting the metal, hot *chisels* are used. *Punches* and a *block* having proper-sized openings are used for punching out holes. *Welding* can be done by shaping the surfaces to be welded, removing any scale or impurities from between the surfaces with a flux, and hammering the surfaces together.

Hand forging is employed only to shape a small number of light forgings chiefly in repair shops. Hand forging has, recent years, been superseded by power forging.

8.10 POWER FORGING

Large machine parts cannot be forged by hand, since the comparatively light blow of a hand-or sledge-hammer is unable to produce a great degree of deformation in the metal being forged. Moreover, hand forging is a lengthy process and requires repeated heating of the metal. This has led to the use of power hammers and presses in forging. Machines which work on forgings by blow are called ***hammers***, while those working by pressure are called *presses*.

POWER HAMMERS

All power hammers employ the same general principle of operation, a falling weight striking the blow, with the entire energy being absorbed by the work. Where further blows are necessary, the striking weight is raised for the succeeding blow. Some hammers employ only a gravity fall, the energy delivered on the work being the product of the weight of the hammer head and the distance of the fall. Other hammers increase the striking velocity of the hammer head by mechanical means.

The part of the hammer which serves as a rigid support during forging is called the ***anvil block***. The anvil block of a forging hammer is built on a foundation separate from the frame so that the shock of the hammer blows will be cushioned by the foundation and will not be transmitted to the frames. The heavy falling part of the hammer is called the ram. The anvil block and the *ram* each has one die called upper-die and lower-die respectively for squeezing the metal to be forged. In smith forging, the working surfaces of both the upper and lower dies are flat and horizontal.

Hammers are classified as mechanical and air- and steam hammers. In turn, the former is further classified into helve and trip hammer, lever spring hammer, and pneumatic hammer. Air and steam-hammers are sub-classified into single- and double acting hammers. The *capacity* of a hammer is determined by the weight of the falling parts. The weight of the anvil and the reciprocating parts usually have a ratio of 15 to 1 (anvil block).

Helve hammers. Helve hammers are well adapted for general engineering work where the size of the stock is changed frequently. They consist of a horizontal wooden helve, pivoted at one end with a hammer at the other end. An adjustable eccentric between the pivot and the hammer end operates the helve. The eccentric raises the hammer which when falls strikes a blow. They are made in sizes from 5 to 200 kg.

Trip hammers. Trip hammers have a vertically reciprocating ram that is actuated by toggle connection driven by a rotating shaft at the top of the hammer. Trip hammers are also built in sizes from 5 to 200 kg The stroke range of both helve and trip hammers range from about 400 a minute for small sizes to about 175 for large sizes.

Lever-spring hammers. They are mechanical driven hammers with a practically constant lift and an insignificantly variable striking power. It only increases with increasing operating speed and thus has increased number of strokes per minute. The ram is driven from a rocking lever acting on an elastic rod. The rocking lever consists of a leaf spring so that an elastic drive is brought about.

They are suitable for drawing out and flattening small forgings produced in large numbers. Their disadvantage is the frequent breaking of springs due to vibrations when in operations.

Spring hammers are built with rams weighing from 30 to 250 kg. The number of strokes varies from 200 to 40 blows per minute.

Pneumatic hammers. The hammer has two cylinders compressor cylinder and ram cylinder. Piston of the compressor cylinder compresses air, and delivers it to the ram cylinder where it actuates the piston which is integral with ram delivering the blows to the work. The reciprocation of the compression piston is obtained from a crank drive which is powered from a motor through a reducing gear. The air distribution device between the two cylinders consists of rotary valves with ports through which air passes into the ram cylinder, below and above the piston, alternately. This drives the ram up and down respectively. This is illustrated in Fig. 8.16.

The size of a pneumatic hammer may vary in a range from 50 to 1000 kg. Hammers operate at 70 to 190 blows per minute.

Steam – or air – hammers. Steam- or air-hammers can be operated by steam or compressed air. They have no built-in compressor and, therefore, require additional facilities for supplying high pressure steam or compressed air to raise the striking stroke. The principle of a steam forging hammer is illustrated in Fig. 8.17.

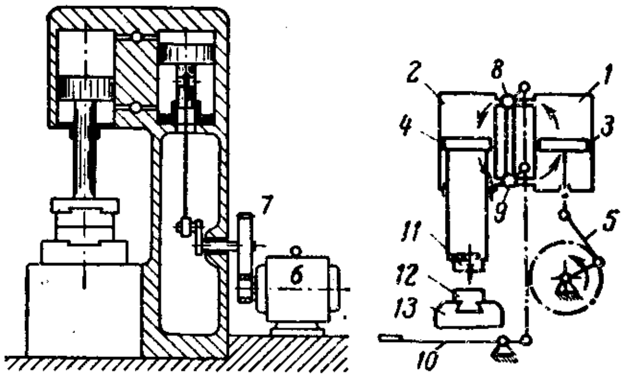

Figure 8.16 A pneumatic hammer
1. Compressor cylinder, 2. Ram cylinder, 3. Piston, 4. Ram, 5. Crank driver, 6. Motor, 7. Reducing gear, 8. & 9. Rotatory valves, 10. Foot treadle, 11. Ram die, 12. Anvil die, 13. Cap

Both single-acting and double acting steam – or air – hammer may be constructed for forging. Single acting is made for comparatively light work, while double-acting is made for heavy work. Steam pressure at the hammer is usually 6 to 8 kgf per cm^2 (590 to 790 kN/m^2) and air pressure is bit smaller than that required for steam. Rated sizes of steam forging hammers range from about 400 to 8,000 kg.

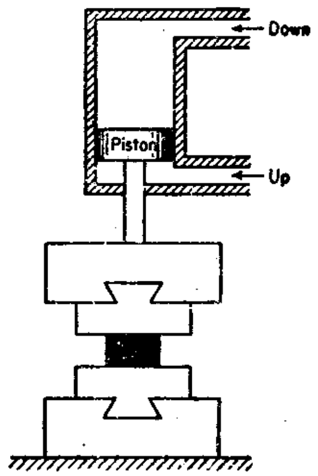

Figure 8.17 Steam hammer

CAPACITY OF FORGING HAMMERS

The ability of a hammer to deform metal depends on the energy it is able to deliver on impact. The energy from falling is used by the work derived from the steam in a double-acting hammer. Steam pressures are commonly from 6 to 2 kgf per cm^2. As an example, a hammer has a falling weight of 1000 kg and a steam cylinder bore d equal to 30 cm. Mean effective steam pressure p is assumed to 8 kgf per cm^2, and the stroke is 75 cm.

The steam force	=	$p \times \pi d^2/4$	=	$8 \times \pi \times 30^2/4$
	=	5656 kgf		
Total downward force	=	5656+1000	=	6656 kgf
Energy in blow	=	6656×0.75	=	4991 kgf m

If the hammer travels 3 mm after striking the metal, the average force exerted is

$$\frac{4991}{0.003} \text{ Kgf} = 1664 \text{ tonne}$$

The amount of energy needed for a particular job is a matter of economics. A starting rule is that a hammer should have at least 4 kgf per cm^2 of cross-sectional area to be worked in the metal.

POWER PRESSES

Forging presses for smithing work are usually of the hydraulic type. The principle of a typical forging press is illustrated in Fig. 8.18. The water passes first from a large capacity tank to a pump and then is delivered on the press with the aid of an accumulator and distributor at 200 to 300 kgf per cm^2 (19,600 to 28,600 kN/m^2). The accumulated water pressure flows into a main cylinder and presses on the top of the large piston. Since the cross-sectional area of the piston in the main material is large, the press ram is forced down upon the material to be forged which lies on the anvil with a high total into its initial position of the action of the working fluid on the piston rods in the pull back cylinder.

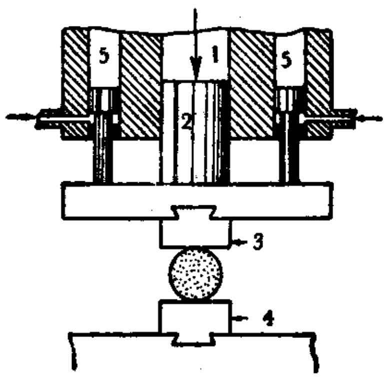

Figure 8.18 Principle of a forging press
1. Main cylinder, 2. Piston, 3. Upper die, 4. Lower die, 5. Pull back cylinder

To perform this motion, a relatively lower water pressure, but a large volume of water per unit of time is required to accelerate the return stroke.

In press forging, pressure or squeeze is applied to the raw material and the intensity of this pressure increases as the plastic metal resists deformation. Due to the great pressure available these presses can be made to have very large capacities ranging from 300×10^3 to 1000×10^3 or $15{,}000\times10^3$ kg.

8.11 IMPRESSION-DIE FORGING

More complex shape of greater accuracy cannot be formed by open-die forging techniques. Commonly known as *die forging* or *drop forging, impression-die forging* makes use of cavities in specially prepared dies to produce forged shapes in large quantities, the finished forging being commercially negatives or duplicates of each other.

Since the die is not fully closed, it should properly be called an *impression die*. The term *closed-die* forging, is nevertheless, often applied, while the term drop forging is sometimes used to denote forging conducted upon a hammer ; but this distinction has no particular merit.

The die cavity, however, must be filled without defects of *material flow*, such as could occur when parts of the workpiece material are punched, folded down or sheared through. A complex shape cannot be filled simply by forging a round or rectangular bar into the die cavity, and some *performing* steps are necessary.

The operations may be so close together that it is unnecessary to heat between them. The number of forging steps necessary to produce the finished forging in the impression die is dependent on the size and shape of the forged part, on production quantities, and on the kind of material being forged.

Generally, when large quantities of identical forgings of greater accuracy are required as is necessary in mass production, impression-die forgings are commonly employed, and where forgings can be made by either of the several methods, the quality is comparable, and the choice is made for economic reasons.

IMPRESSION-DIE FORGING PROCESS

Impression dies generally contains preliminary shaping steps to permit the change from the original forging stock to the finished forging without mechanical defects. Simple symmetrical parts may be forged directly in the finished impression (finishing die cavity) without preliminary shaping. The more difficult or complex shapes may require several different steps to produce a finished forging. The most-used preliminary forging step is the *edger*, which serves to proportion the cross-sectional area along the length of the flowing metal from a section being reduced to a section being enlarged. The *fullering step* or *fuller*, reduces the cross-sectional area between the ends of the forging stock without appreciable change to the end sections. The *bending step* or *bender* forms the length of the forging stock to a shape for the finishing impression. The preform may be further shaped to bring it closer to the final configuration in a so-called *blocker die* which assures proper distribution of material but not the final shape. Excess material is allowed to run out between the flat die surfaces and this *flash* is sometimes removed or *trimmed* prior to forging in the *finishing die*. The excess material is again allowed to escape into a flash, which must now be thin to assure die filling and close tolerances. The flash is reduced to its minimum thickness over only a small width called *flash land*, and the rest is allowed to flow freely into a *flash gutter*.

The production–design engineer must exercise care in determining the amount of material to be inserted in the die. If there is not enough material, the part will not fill up the die. If there is too much material, the flash will be excessive, resulting in wasted material and greater die wear. In general around 10 per cent excess material over calculation is allowed.

Dies must, however, be heated before the first forging is made and often gas or electric heaters are used to keep the dies hot so that the forgings will not cool too fast, shrink, and be difficult to eject. Many mechanical forging presses have lower die ejectors, and upper die strippers can be furnished.

After the forging operation the part must be trimmed to remove the flash. The flash is removed hot or cold. If the carbon content is low and the forging small, it is usually removed cold. Most medium-sized and large forgings are trimmed hot. Subsequent operations to remove the scale or oxide include shot blasting, or pickling.

FORGING DESIGN

The shape of the forging must promote smooth material flow. Therefore, a *parting line*, is chosen with proper consideration of the fibre structure of the finished forging. Fibres, caused by alignment of inclusions, second-phase particles, and micro segregation, should flow the contour of the forging as far as possible, because this ensures greatest toughness and ductility. At the parting line fibres are unavoidably cut through when the flash is trimmed. Therefore, the parting line is best placed where minimum stresses arise in the service of the forging. After the parting line is located, the cavity walls are given sufficient draft to allow removal of the forging from the die cavity. The *internal draft* is greater than the *external draft* because the forging tends to sink on to bosses of dies prior to its removal from the die. Fillets and corners must be given appropriate radii to assure both smooth material flow and reasonable die life.

Die forgings are usually formed hot. The hot materiel cannot stay in contact with the die too long, for the forging then will not be hot enough for the next operation. Also if the hot material is in contact with the die too long, it will overheat the die and so cause excessive wear, softening and breakage. The rapidity with which the part can be formed into uniform shapes and with uniform properties permits the die-forging operation to compete with other processes in high-quality parts.

The use of closed-impression dies improve both the strength and toughness of the metal in all directions. The fibre structure characteristic of metal can be formed so as to improve the mechanical properties in areas where it is most needed to meet specific service conditions. Tools, gear blanks, crankshafts, connecting rods, and a great variety of machine parts are produced by the forgings.

FORGING DIES

Forging dies are constructed from high-grade carbon or alloy steel and must resist heat, abrasion, and pressure. They must withstand severe strains, have a long wear under high production conditions, and minimize checking. The majority of die blocks are heat-treated before impressions are machined to avoid warping or cracking.

Dies are *sunk,* that is the cavities are formed, by milling, electric discharge machining, or sometimes by ceramic casting processes. Machining and shrinkage allowances and draft must be built in just as in patterns for casting. Draft may be form 3° to 10° depending on the part size. Additionally, flash gutters are cut into the die to handle extra metal.

Die life varies widely due to many factors such as metal being forged (steel, aluminium, etc.), the amount of scale on the part, the depth of impressions, and the temperature and uniformity of the slug or preform. The type and proper application of lubrication is also important.

In general, impression-dies last 15,000 to 30,000 *platters* before they need reworking. A platter is the forging with its surrounding flash. Each platter may contain from one to six parts.

The dies are often made in sections, called *inserts,* fitted into the die block. This is economical, as the blocker section may last several times as long as the finish forging section.

Locking surfaces or pins can be provided so that the two dies will match the same way each time they come together.

8.12 DROP HAMMERS

Three types of drop hammers are used in making drop forgings. They are board or gravity hammer, air-lift hammer, and power drop hammer or what is usually called steam hammer. The working principle in each of the two types is almost similar to that of the forging hammers. The anvil block of a forging hammer is built on a foundation separate from the frame, while the anvil of a drop forging hammer is attached to the frames to permit accurate alignment of the upper and lower dies.

BOARD HAMMER

The principle of a board or gravity hammer is illustrates in Fig. 8.19. The ram is fastened to the lower end of a vertical hard-wood board ; the upper part of this board is placed between two counter revolving rolls. When both rolls are pressed against the board between them, they drive upward, lifting the ram. When the tools are released, the ram falls down producing a working stroke. As long as the operator continues to hold down the treadle, the hammer will continue to strike, but when the treadle is depressed, the ram will return to and will remain in its top position. The board hammer is generally driven by electric motor and this requires no steam or high pressure air.

Ratings are given by the weight of the falling parts and range from 250 to 2700 kg ram weigt with heights of 1 m for smaller sizes and 2 m for the larger one. The force of the blow can be varied by changing the distance of the fall, by unclaming and moving the dogs on the front rod. The anvil, which must absorb the blow, is usually 20 times as heavy as the hammer. Wooden beams or special pads under the anvil help absorb the force. A board hammer, which works rapidly, gives over 300 blows a minute. Board hammers can do a wide variety of work and they are less expensive of all types to operate.

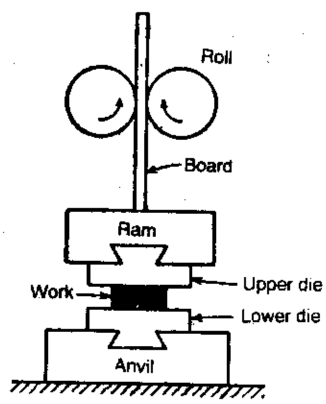

Figure 8.19 Board or gravity hammer

AIR-LIFT HAMMER

Air-lift hammers are modern drop hammers, which also derive their force from a free-falling ram. The hammer uses compressed air to lift the ram.

then lets it fall by gravity similar to the board drop hammer. The ram is lifted by a steel rod connecting it to the piston. A separate air circuit operates a clamp which holds the ram in a raised position between strokes. A series of short and long-stroke blows can be obtained and the operator does not have to regulate the stroke heights. Programme control is present to control the force and the number of blows at each die station. This automation can materially increase the production rate.

These hammers can make upto 50 to 75 strokes per minute depending on their size. Due to lower maintenance costs, and easier operation, air-lift hammers are replacing board hammers.

POWER DROP HAMMERS

Power drop hammer, better known as air or steam hammer, has the same principle as that of a steam forging, but differs from a forging hammer in that the anvil of the former is an integral part of the frame to maintain perfect alignment between the forging die elements used. The steam or air drop hammer has the same essential parts as the board hammer except that a steam or air cylinder, piston, and rod are substituted for the board lifting mechanism. A power hammer using air or steam at a pressure of 7 kgf per cm^2 (690 kN/m^2) will supply two to two and half times as much energy as the same rating of gravity drop hammer.

Steam or air hammers are the largest of the forging hammers and are made from 450 to 25,000 kg (mass) falling weight hammer with as anvil weighing 45,300 kg.

CAPACITY OF DROP HAMMERS

The same factor as explained for forging hammers determines the energy and force delivered by a drop hammer. Direct calculations to determine what capacity is needed is quite complex. An empirical rule of thumb is that a gravity drop hammer's rated size in kilograms should be equal to the product of the area of the final die-impression and the flash times 20 to 37, depending on the shape and type of material. A double-acting steam drop hammer may have a rating of 6 of that of a gravity drop hammer but be suited for the same job.

8.13 PRESS FORGING

Press forging is done in presses rather than with hammers. The action is relatively slow squeezing instead of delivering heavy blows and penetrates deeply because it gives the metal time to flow. Dies may have less draft, and the forgings come nearer to the desired sizes. Pressed forgings are shaped at each impression with a single smooth stroke and they stick to the die impression more rigidly. Unless some provision is, therefore, made, the escape of air and excess die lubricant may be difficult. Thus press forging dies require a mechanical means for ejecting the forgings are venting for the escape of air and lubricant. Press forgings are generally more accurate dimensionally than drop forgings.

Press for closed-die forgings may be of two classes : (1) hydraulic, and (2) mechanical.

A *hydraulic press* for closed-die forging has the same principle as that of a press for smith or flat-die forging except the construction of the dies. In smith forging the press dies have flat surface, while in a closed-die forging the press dies have shaped impressions cut on dies. Moreover, they form an integral part of the frame to maintain accurate alignment of the dies.

Mechanical forging presses of the cranks type have found wide application in forging practice.

The gearing diagram of a crank press is shown in Fig. 8.20. The operative units of the press are powered from motor mounted on the press frame. By means of the V-belt drive, power is transmitted from pulley to flywheel mounted on the auxiliary shaft. The flywheel is equipped with a friction safety device to prevent the overloading of shaft. The flywheel is stopped by the auxiliary brake which is automatically engaged when the motor is switched off. On the other end of the shaft a gear is mounted. It meshes with the gear which drives crankshaft. The latter, through the pitman, reciprocates in slide. The crank mechanism is engaged by a pneumatic clutch which is controlled by a pedal. A band brake stops the

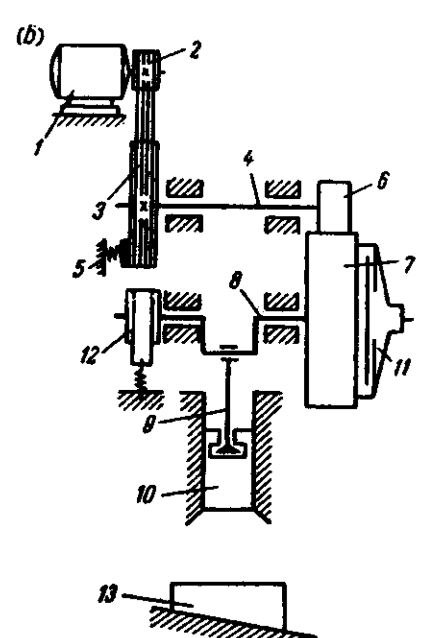

Figure 8.20 The gearing diagram of a crank press

1. Motor, 2. Pulley, 3. Flywheel, 4. Shaft, 5. Brake, 6 & 7. Gears, 8. Crankshaft, 9. Pitman, 10. Slide, 11. Pneumatic clutch, 12. Band brake, 13. Wedge device

crankshaft and slide when the pneumatic clutch is disengaged. The top half of the die is secured to the slide and the bottom half to the bed which is provided with a double-wedge device for adjusting the die space.

They are used for the production of rivets, screws, and nuts where a high operating speed is desired. In capacity, they range from 50,000 to 8,000,000 kg and speeds from 35 to 90 strokes per minute.

8.14 ROLL DIE FORGING

Plain rolling is done on the work of uniform cross-section. Forging by rolling is the production of discrete pieces of lengths of varying cross-section by rollers. Roll forging is considered one of the most modern forging processes.

Roll forging performs an impression-die forging operation, but in this system there are two roll segments on parallel shafts as depicted in Fig. 8.21 have one or more set of grooves. A piece of stock is placed between the rolls which then turn and squeeze the stock in one set of grooves. The stock is passed to a second set of grooves, the rolls turn again, and so on until the workpiece is finished. Each set of grooved segments is made to do a specific job. Roll forging may be used to make reductions in the cross-section and distribution of the metal of a billet, thus saving considerable work in the forging hammer or press. Because it is rapid, roll forging is of advantage in preparing some shapes for forging machines and hammers and also for completely foreign parts like levers, leaf springs, cutlery and scissors, and axles. The most important use of this process is in the preparation of *preformed blanks* for forging.

In a roll forging machine, circular bars, flats and squares can be formed to tolerances grade IT-15. The straightness obtainable in such cases in 1 mm per meters length. Similarly, on ring rolling mills the tolerances of ±0.5 mm can be obtained.

SKEW ROLLING

This is done with two rolls on cross axes as indicated in Fig. 8.21. Each roll has as outside helical pattern that carries the stock along and progressively shapes it as the rolls turn. Such diverse products as steel balls and railway car axles are forged by skew rolling.

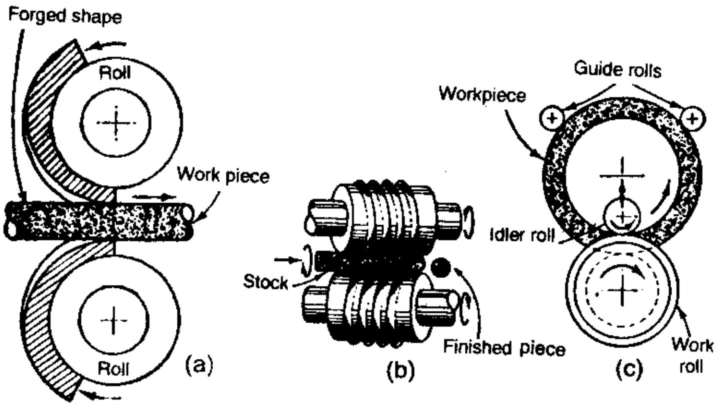

Figure 8.21 The principles of :
(a) roll forging, (b) skew rolling, (c) ring rolling

RING ROLLING

It starts with a small ring blank and deforms it between one or two work rolls and an idler. The ring is increased in diameter and decrease and shaped in cross-section. The blank may be prepared by forging or punching. Pieces finished by this method range from small roller-bearing races to rings 5 m and more in diameter. This is illustrated in Fig. 8.21.

8.15 PRESS VS. HAMMER FORGING

The choice between these two methods is mainly determined by the shape, size and weight of the forging to be made. Hammer-forging depends upon a large number of blows applied in rapid succession. This hammer-blow produces shock and vibration to the structure, its foundations, and surroundings, which impose a practical limit to the size of the hammer. The hammering process tends to give more thorough effect than the pressing which is more in the nature of kneading. Where the thickness of metal is large the effects of hammering may not penetrate right through, and the outer surface of the metal will be better worked than those deeper below. Another important factor is the speed of operation which can be altered according to the size of the forging. In hammering, its position must be altered rapidly between the blows and this can be done up to a limited size and weight.

Press action is slow in comparison to hammer action, but the reduction in the size of heavy parts is comparatively rapid. Press forging provides a method for forming various sized shapes that would not be practicable under a dynamic type of load. Size is not a definite restriction in this process, and therefore, the produces lends itself quite readily to almost any shape. An important effect of press forging is the dispersion of the non-metallic inclusions throughout the metal, which tends to minimize their effects. As a general rule, hammers are employed up to about 10 tonnes capacity, but hydraulic presses, in general use, range from about 20,000 to 15,00,000 kg. Press forging which provides a uniform finished shape is versatile method of forming metals. It may be competitive with drop forging but can often be used where drop forging is not feasible. Shapes formed by press forging are generally dense and homogeneous in structure.

8.16 MACHINE OR UPSET FORGING

Forging of the ring and rod types with all kinds of heads and shoulders, such as bolts, nuts, washers, and collars, pinion-gear blanks, etc. can be conveniently produced in forging machine.

Machine forging consists of applying lengthwise pressure to a hot bar held between grooved dies to enlarge some section or sections, usually the end. Not only bulging, but piercing can also be done by the machine forging method. In this method the metal is displaced from the interior and made to flow around the outside, for the full length of the blank when necessary. Careful gathering of a large volume of metal on the end results in controlled grain structure, with dense fibre for maximum length.

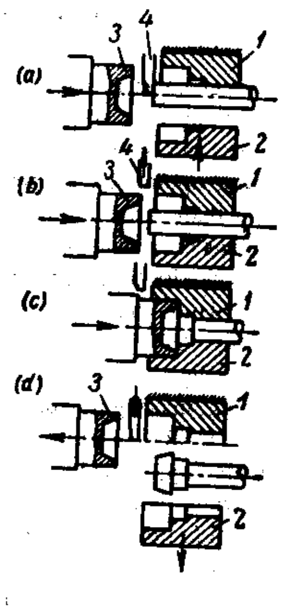

Figure 8.22 Forging sequence for a horizontal machine

1. Stationary die, 2. Movable die, 3. Punch, 4. Stop

Mostly a through-bore is drilled longitudinally through the die for the feeding of bar stock. Further, the die is split up to into halves which form two jaws ; one of them is fixed, whereas the other one can be opened to admit the blank. Mostly, these jaws also serve for clamping the workpiece to be upset.

A forging sequence for a horizontal machine is illustrated in Fig.

8.22. The heated end of the bar stock is inserted into the stationary die upto the stop. At this time, the punch is in its left-hand position (Fig. 8.22a). Next the movable die grips the bar stock and, at the same time, an impression is formed in the closed dies for shaping the projecting stock; the stop is automatically retraced to its idle position (Fig. 8.22b). Then the punch advances to upset the bar and forms the finished forging (Fig. 8.22c) and finally, the movable die and the punch are withdrawn to their initial position (Fig. 8.22d). The rod and forging are shifted to the next pass where the forging is cut off.

Horizontal forging machines operate at a high rate. They have an output of from 400 to 600 forgings per hour and develop a forging force of from 100 to 3000 tonnes.

8.17 HIGH-ENERGY-RATE FORGING (HERF)

Although most presses do not run at high speeds, forging is done at high impact rates on some occasions. This is different from hammer forging because the blows are not repeated. A major contribution to conventional forging operations is their high impact velocity which is 2 to 10 times larger than conventional velocities. In the conventional practice, the mass term has been made ever larger to obtain heavier forging forces, whereas in high-velocity forging the velocity term has been increased.

High-energy-rate forming or forging, sometimes called *high velocity forging (HVF)*, machines are vertical counterflow machines used principally for hot forging, although they can also be used for cold forming, making powdered metal parts, and deep forming sheet metal parts.

HERF machines, except for one which uses exploded gas, are operated by the sudden release of compressed nitrogen. This gas drives the ram which is pressed against a seal ring at the top. Enough high-pressure gas is admitted to the area inside the seal ring to dislodge the piston. The gas in the high-pressure cylinder then acts over the whole piston area and drives the ram down at a high velocity ranging between 9 and 20 m/s. Most parts are formed with a single blow.

At these high velocities, the metal flows plastically since the metal can be worked more at high temperatures. This is because the forging does not give metal time to cool much in contact with die and the heat does not have time to escape. Thus deep, straight-sided parts can be made zero or small draft, which means much less metal to be machines off later. Much thinner walls can be forged. Sections as thin as 3.8 mm have been made in experiments. Tolerances of ±0.25 mm and sometimes less have been achieved. Materials forged successfully by this method include low-alloy steels, aluminium, and nickel steels.

High-energy-rate forming machines are listed with capacities of 2,850 to 3,43,520 kgfm (28,500 to 34,35,200J of energy). This is adjustable over a wide range on each machine. It is important to note that they are actually less expensive, and they do not require as heavy foundations as other forgers. But proper lubrication is very important to achieving good die life.

8.18 FIBROUS STRUCTURE OF FORGINGS : GRAIN-FLOW

In forging, metal flows similar to the flow of sand-cement mortar while being squeezed. Forging causes the grains flow and randomly dispersed small inclusions and segregations found in cast metal to become elongated in the same direction as the metal is caused to flow. If a forged part is cut in a plane aligned with the direction and the surface is ground smooth and then immersed in an acid solution the exposed metal will appear to naked eye to have a fibre-like structure. A section of an upset gear blank after deep etching is shown in Fig. 8.23. These fibres are non-metallic inclusions or segregated phases that are elongated or "flowed" in the direction of working. Grain-flow, fibrestructure, flow lines and forging fibres are terms used to describe this effect. The grain-flow of forged part resembles in many ways the grain of wood. Like wood, the strength and toughness of this metal is greatest in the direction of the fibre. In the directions at right angles to these fibres, the strength is normally no greater than that found in dense, sound casting.

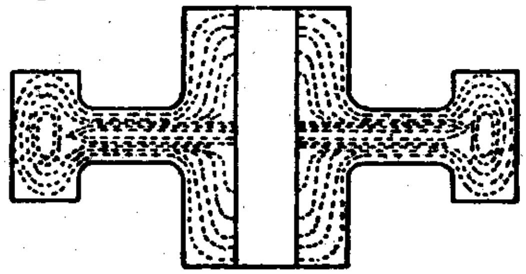

Figure 8.23 An upset gearblank after deep etching

If, on forging, the grain-flow is in a direction parallel to the principal grain-flow it is said to flow in its correct fibre direction, and if otherwise, it is said to flow in its incorrect fibre direction.

The effect of these flow-lines is to produce marked directional properties in steel. For static load, the directions of these flow-lines are not so important, but these are important on parts where shock and fatigue are encountered. The ductility and resistance to impact of the metal are less in a direction at right angles to the flow-lines than parallel with them. Special care is, therefore, taken in the making of forgings for gears, crankshafts or other highly stressed parts to have the metal flow in the most favourable direction in all portions of the forgings. It is common practice for purchasers of forgings to specify the desired directions for the fibre-flow lines to meet the stresses expected under actual service conditions.

Fig. 8.24 also shows the fibre-lines in a forged crankshaft where it can be seen that the directional qualities of the fibre add toughness to the web and where they join the round parts of the shaft.

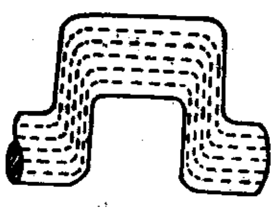

Figure 8.24 Fibre-lines in a forged crankshaft

8.19 EFFECTS OF FORGING : FORGED PARTS VS. CAST PARTS

Forging refines the structure of metal by smashing up large grain formations and closing up any cavities that may be present. In addition to the refinement of grain size other effects also result from suitable forging. Pieces formed by forging exhibit directional properties indicated by the flow lines. The original crystals typical of the cast structure are destroyed, hard films of brittle constituents or impurities are broken up or rolled into fibres and a uniformity is established. In additions to those effects certain mechanical properties, particularly elongation percentage, reduction of area percentage, and resistance to shock and vibration, are improved, and in favourable cases cracks and blow holes are welded up.

A cast iron, on the other hand, is very hard and brittle, and may be easily broken when subjected to shock and vibration. It is very poor in tensile strength. So machine parts which are liable to tension cannot be made of brittle materials. It may also contain during casting, cracks and blow holes and other defects, which make the cast iron very weak ad unsuitable for use in many cases.

8.20 DEFECTS IN FORGING

Defects in metal parts offer a serious factor in the production of the forged parts and thereby it becomes very costly. Defects most commonly found in metals that have been subjected to more or less plastic shaping may be classified as follows :

1. Defects, resulting from the melting practice such as dirt or slag, blow holes, etc.
2. Ingot defects such as seams, piping, cracks, scales or bad surface and segregation.
3. Defects resulting from improper heating and cooling of the forging such as burnt metal, decarburisation, and flakes.
4. Defects resulting from improper forging such as seams, cracks, laps, etc.
5. Faulty forging design.
6. Faulty die design.
7. Improper placement of the metal in the die causing mismatched forging.

Defects in forging can be removed as follows :

1. Shallow cracks and cavities can be removed by chipping out of the cold forging with pneumatic chisel or with hot sets during the forging processes.
2. Surface cracks and decarburized areas are removed from important forgings by grinding on special machines. Care should also be taken to see that the workpiece is not underheated, decarburised, overheated and burnt.
3. Die design should be properly made taking into consideration all relevant and important aspects that may impair forging defects and ultimate spoilage.
4. The parting line of a forging should lie in one plane to avoid mismatching.
5. Destroyed forgings are straightened in presses, if possible.
6. The mechanical properties of the metal can be improved by forging to correct fibre line, and finally internal stresses, developed due to heating and cooling of the workpiece, are removed by annealing and or normalizing.

8.21 HEAT-TREATMENT OF FORGED PARTS

Except for machining operations, steel forgings are sometimes used in the "as forged" condition without additional heat-treatment other than what they receive during the forging operation. However, if maximum service is expected of a steel forging it becomes necessary to give the forging one or more heat-treatment before it goes into service.

Steel forgings are heat-treated for the following purposes :

1. To remove stresses arising in the steel during forging and cooling.
2. To equalize the structure of the metal of the forging.
3. To give the steel that degree of hardness which makes it most easy to machine.
4. To improve some of the mechanical properties of the steel.

Usually, forged parts are annealed and normalizes to obtain desired results.

ANNEALING

Annealing is a form of heat-treatment which is applied to remove stresses, and improve the mechanical properties and machinability of forgings.

The annealing process consists in heating the forgings in a furnace to a temperature of about 750 to 900°C, depending on the carbon content of the steel (to a temperature of about 30 to 50°C above the higher critical point) with subsequent slow cooling. This annealing will result in : (1) refinement of the grain formed in steel on the completion of the forging at high temperature, (2) removal of internal stresses resulting from the hot working of the metal, and (3) comparative softening of the steel.

NORMALIZING

It consists of heating the forged parts in furnaces as in annealing, and subsequent cooling in air. The following results are achieved due to normalizing :

1. A fine-grained structure, the grain being refined to a greater degree than by annealing;
2. Improved mechanical properties-increased tensile strength and ductility ; and
3. Removal of internal stresses.

8.22 DESIGN CONSIDERATIONS

Several factors which call for proper design include draft, angles, fillets, corners, shrinkages, cavities, and dimensional tolerances.

Draft angles. Except for some special types of forging processes where forging is carried out for high tolerance or high precision dimensions, *draft angle* must be provided on the die walls to facilitate removal of the forging from the dies after forging. Conventional draft angles vary with the type, size and shape of forging. Normally, drop forgings have from 3 to 10°, press forgings from 1 to 5° of draft. In general, the deeper the cavity is made the greater the draft is provided.

In the cold dies, ejection mechanisms are used to draw the forged part. Also, a number of deferent protective coatings are used on various materials to permit linear movement in the plastic condition without detracting from the surface finish.

Fillets and corners. These may cause stress concentration in the work causing easy breakage of the part. Their tolerances are relative to the size of the forging. If they are not specifically stated, the die engineers specify them to suit to their production. In general, the maximum fillets and radii must not be less than 1.6 mm, and preferably more.

Shrinkage factor. All metals shrink on cooling, and this factor must therefore be considered. Die engineers must take into consideration the type of material, forging method, and finishing temperatures.

Cavities. In general cavities should not be specified that are deeper than their diameter.

Tolerances. Actually five tolerance areas should be considered. These are :

1. Thickness.
2. Draft angle.
3. Fillets and corners.
4. Width and lengths
5. Quality

Width and length tolerances include shrinkage and die wear, mismatching, and trimmed size. In general, tolerances for economical production are quite large, though tolerances as close as ±0.4 mm can be achieved. This is just an approximation to give an idea of the forging tolerances.

Machining allowance. This is generally a minimum of 0.8 mm per surface. This may be increased if the surface is a large one.

Web thickness. The minimum thickness should be approximately 5 mm with ±0.4 mm tolerance. The approximate *flash thickness* ranges from 1.0 to 2.0 mm.

DESIGN FOR UPSET FORGING

1. Design for smallest diameter or section of stock.
2. Use the minimum of upset material and shape it into confessional styles–round, hexagon, and square.
3. Avoid square corners. Use as large a radius as possible at inside corners.
4. Avoid using head diameter greater than four times the stock diameter. A maximum of 62 mm diameter can be upset at one time.

SUMMARY OF FORGING DESIGN

The following factors will serve to summarize some of the most important forging-design principles :

1. The various sections of the forging should be balanced.
2. Generous fillets and radii should be allowed.
3. Sufficient draft (preferably 7 degree) should be allowed.
4. Deep holes and high projections are not desirable.
5. Holes in two planes will make removal of the forging from the dies impossible.
6. Flash thickness variation should be specified (not less than 0.8 mm).
7. Raised letters or numbers for marking should be used.
8. Keep the parting line on one plane, if possible.

Careful observance of these principles will make better forgings at less expense.

8.23 ADVANTAGES AND LIMITATIONS OF FORGING PARTS

Designing parts for the various processing of forging should result in the following advantages :

1. *Strength*: Forging reduces the risk of part failures. The process yields parts with high strength-to-weight ratios and is particularly appropriate to parts that are subjected to fluctuating stresses caused by sudden shock loading.
2. *Metal conservation*: Practically there is no waste of metal.

3. *Uniformity of qualities for parts.*
4. *Weight saving*: Strong thin-walled parts may be produced without sacrificing important physical requirements.
5. *Machining time*: Forging can be made to close tolerances, which reduces machining time for finishing operations of the products.
6. *Close tolerances.*
7. *Smooth surface.*
8. *Speed of production:* High rate of production is possible.
9. *Incorporation in welded structures*: Parts can be welded easily due to fibrous structure.

Some disadvantages in using the forge processes are :

1. High tool cost.
2. High tool maintenance.
3. No cored holes.
4. Limitation in size and shape.

Heat treatment of the material is incorporated to increase mechanical properties but it increases the cost of the part.

REVIEW QUESTIONS

1. State the difference between 'smithing' and 'forging'. List the advantage and disadvantage of each.
2. Describe in brief of a box type furnace ?
3. Differentiate between induction furnace and resistance furnace. What are the similarities ?
4. Name at least ten numbers of forging tools. Very briefly state their uses.
5. What do you understand by 'open fire' and 'stock fire'? Which one of the two is more advantageous and why ?
6. What are the types of furnace used in forging work? State their special applications.
7. What fuels are generally used in forging furnaces? Which one is best and why ?
8. Name the common materials used for forging. Give the correct forging temperature of some of the common forgivable metals.
9. State which one is forgeable metal and which on is not.
10. Explain with neat sketches the following forging operations : (a) upsetting, (b) drawing down, (c) bending, (d) drifting, (e) punching, (f) welding, and (g) fullering.
11. Describe in detail the process of smithy welding.
12. What are the different types of power hammer you know. Sketch and describe any one.
13. Describe the three types of drop hammer forging machines.
14. Describe press forging. How does it differ from drop forging ?

15. What is the difference between the hammer and press forging ?
16. State the advantages of both mechanical and hydraulic presses for press-forging applications.
17. Describe the steps necessary for a product in impression-die forging. What materiel is used to make forging dies and what physical properties they must possess.
18. Describe roll forging and its principal uses.
19. What is hot-upset forging and how is it dine ? What are the advantages ? Give examples of upset or machine forging.
20. State and describe high-energy-rate forging. For what type of work would you buy a HERF machine.
21. Compare between a forged part and a cast part in relation to mechanical properties.
22. What are the common forging defects, and what are they due to.
23. Why heat treatment is necessary for forging ?
24. What are the main considerations in designing a forging ? State and explain.