# PRINCIPLES OF METAL WORKING PROCESSES

P. Poddar
National Metallurgical Laboratory, Jamshedpur 831007
e-mail : palash@nmlindia.org

## INTRODUCTION

Forging, dates back to ancient times, was associated with the village blacksmith. Virtually all-ductile metals may be forged by first preheating the work piece to a forging temperature. The work piece can be a billet, a wrought bar, a cast or sintered ingot etc. The forging process can then be completed, by hammering the work piece to the desired shape. The design and control of metal working processes depend on the characteristic of the material, conditions of metal and tools interface, operating deformation mechanism and equipment used for working. 'Damascene technique' meant the forge welding of steel and iron or two types of steel. 'Damascus sword' was prepared by this technique. Forging has a marked beneficial effect on the metals being shaped. Their toughness and strength are improved because the process results in a beneficial orientation of the metal grain structure. The repeated hot working causes the metal to become more dense and the grain flow lines to follow the contour of the final component. The as cast structure is detrimental to the mechanical properties and therefore, it requires modification to improve the mechanical properties by refinement of microstructure and homogenous distribution of phases. The generic bulk forming processes are forging, rolling, extrusion and drawing. All these processes give a very high plastic deformation to the materials as the strain rate involved in these processes are considerable high. Forging is a high strain rate process where material is shaped under the effect of impact load or pressure.

The rolling is a process where slab or stock is dragged through the gap between two rolls rotating in opposite direction. Rolling is the most important metal working process and can be performed on either hot or cold metal. The work is subjected to high compressive stresses from the squeezing action of the rolls and to surface shear stresses as a result of the friction between the rolls and the metal. The frictional force is the responsible for drawing the metal into the rolls. Cold rolling of metal has reached to a position of major importance in industries. Sheets, foils, strips with good surface finish are produced by cold rolling.

## FUNDAMENTALS OF METAL WORKING

The importance of metals in modern technology is due to the ease to form into useful shapes. Enormous processes have been developed for specific metal working applications. These processes may be classified into a few categories, based on the nature of force applied to the work piece as it is formed into shape. The categories are as follow:

- Direct compression
- Indirect compression
- Tension
- Bending
- Shearing

In direct compression process the force is applied to the surface of the work piece and the metal flows at right angle to the direction of the compression. Forging and rolling come under this category of compressive force.

Indirect compressive processes include wire and tube drawing, extrusion and deep drawing of a cup. The primary applied forces are frequently tensile, but indirect compressive forces developed by the reaction of the work piece with the die reach high values. Therefore, the metal flows under the action of combined stresses, which include high compressive forces in at least one of the principle directions. The best example of a tensile type forming process is stress forming, where a metals sheet is wrapped to the contour of a die under the application of tensile forces. Bending involved the bending moment to the sheet while shearing involved the application of shearing forces of sufficient magnitude to rupture the metal in the plane of shear.

Plastic forming operations are performed for at least two purposes. One purpose is to produce a desired shape. The second purpose is to improve the properties of the materials through the alteration of the distribution of micro-constituents, the refinement of grain size, and the introduction of strain hardening. An important purpose of plastic deformation is to break down and refine the columnar or dendritic structure present in the cast metals and alloys. Forging and rolling are frequently used for breaking down the cast structure.

Plastic deformation processes, which are designed to reduce an ingot or billet to a standard mill product of simple shape, such as sheet, plate, and bar, are called primary mechanical working processes. Forming methods, which produce a part of a final finished shape are called secondary working processes, such as wire drawing, tube drawing etc.

## HOT WORKING

Forming processes are commonly hot working and cold working operations. Metals are generally deformed at specific temperature and strain rate so that recovery takes place simultaneously with the deformation. This is known as hot working. When recovery processes are not effective at the time of deformation, the processes are called cold working processes. Very large amount of deformation can be given by hot working because strain hardening and distorted grain structures are simultaneously eliminated with the formation of new grains. But this does not occur in the case of cold working, and total rate of deformation is less.

Hot working is the initial step of metal working. It decreases the energy required for deformation. Hot working increases the ability of metal to flow with out cracking, but rapid diffusion at hot working temperatures aids in decreasing the chemical inhomogeneity of the cast ingot structure. Blow holes and porosity are eliminated by welding together. Cavities and course columnar grains of the castings are broken down and refined into small equiaxed recrystallised grains. Thus, ductility and toughness of the metals are increased over the cast state. Hot working at high temperature has the risk of metal loss due to oxidation. Reactive metals like Mo become brittle due to oxidation. Therefore, they must be hot worked in an inert atmosphere. Surface de-carburization of steel during hot working is also a serious problem. Rolled in oxide makes it difficult to produce good surface finishes on hot rolled products. Because allowances must be made for expansion and contraction, the dimensional tolerance must be made greater than for cold worked products. Hot worked product has finer re-crystallised grain size at the surface while interior of the product has courser grains.

Most hot working operations are carried out in number of multiple steps. Generally working temperature for the intermediate steps is kept well above the minimum working temperature in order to take advantage of economy offered by lower flow stress. It is likely that some grain growth will occur subsequent to recrystallisation at these temperatures. The finish temperature is generally maintained just above the minimum recrystallisation temperature to obtain fine-grained structure. In order to ensure a fine re-crystallised grain size, the amount of deformation in the last pass should be relatively large.

## COLD WORKING

Cold working on metal increases the strength and decreases the ductility of the products. To avoid failure or cracking damage of the metal, cold working operations are usually carried out in several steps with intermediate annealing. To produce the desired strength of the products, the final cold working step should be of proper degree of deformation. Followed by a stress relieving operation to remove the residual stresses.

## FORGING PROCESSES

Forging is the working of metal into a useful shape by hammering or pressing. It is the oldest of the metal working arts, having its origin to primitive blacksmiths of ancient times. During the indŭstrial revolutions, inventor gave a good thought to develop the machinery to relieve the hands of the artisans. There are wide varieties of forging equipment to make parts of different ranges. Generally, forging operation is done in hot condition of the metals. Forging hammer or drop hammer and forging press are the two major classes of equipment. Forging hammer/drop hammer is used to apply rapid impact force on the metal while press is used to slow squeeze the metals in between dies or platens. Forging has a marked beneficial effect on the metals being shaped. Their toughness and strength are improved because the process results in a beneficial orientation of the metal grain structure.

### Open die forging

Using hammers or presses in conjunction with blacksmith tools or flat type dies makes open die (or smith forging). There is little lateral confinement of the work piece. The desired shape is obtained by manipulating the workpiece between blows. A schematic representation of open-die forging process is shown in Fig. 1.

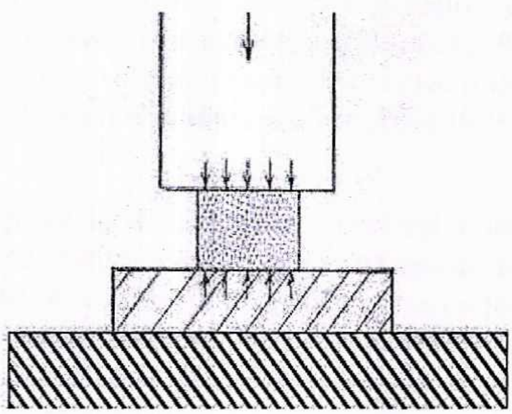

*Fig. 1 : Schematic diagram of open-die forging*

This process employs low cost tooling, is relatively simple, but has less control in determining grain flow, mechanical properties and dimensions than other forging methods. This process can only be performed by skilled operators.

### Closed die forging

This process is based on hammering the work pieces into the desired shape by means of closing dies. The hammering or pressing is performed respectively, by a mechanical or hydraulic press.

A schematic of closed-die forging process is shown in Fig. 2. Small and medium sized forgings are generally made in presses ranging in capacity from 500 to 10000 tons. Closed die forgings have good dimensional accuracy, with improved mechanical properties compared to open die forgings. The process has good reproducibility and rapid production rates are possible. The initial cost of tooling is very high in this method. Close die forgings made on a forging hammer is usually called drop forging.

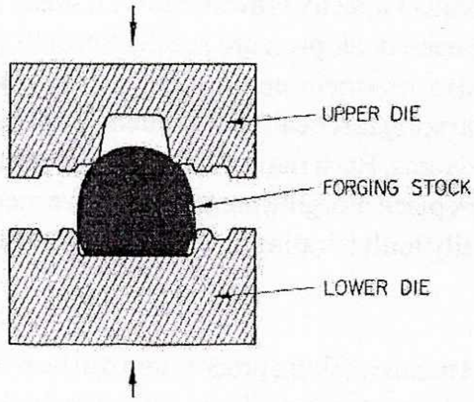


*Fig. 2 : Schematic representation of closed-die forging*

**Upset forging**

This process uses bar stock, which is heated at the end to be forged. The bar is gripped in the fixed half of a die so that the length of material being forged projects. The forging blow is delivered by a moving die. Simple shapes are produced in a single stage but more complicated shapes require multiple stages (Fig. 3).

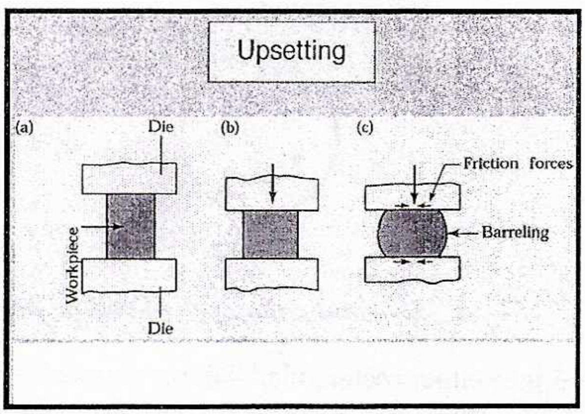


*Fig. 3 : (a) Solid cylindrical billet upset between two flat dies. (b) Uniform deformation of the billet without friction. (c) Deformation with friction. Note barrelling of the billet caused by friction forces at the billet-die interfaces.*

**Forging equipment**

In forging hammer, the force is applied by falling weight. Ram board hammer and steam hammer is the two basic types of hammers. In board hammer, upper die and ram are raised by rolls with gripping the board. When ram is released it falls under gravitational force. The energy applied is equal to the potential energy and the machine is capable to produce product, weighing up to 50 kg. Forging hammer of greater capacity is available with steam /compressed air hammer. In this type of the hammer, the steam or air pressure accelerates falling weight of the ram. Energy supplied to the blow is related to the kinetic energy of the falling mass. The important feature of the steam hammer is that the striking force can be regulated. A unique type of pneumatic hammer has two horizontally opposed rams. Each ram strikes the work piece at high velocity and all the energy is absorbed by the work piece. Forging presses may have mechanical or hydraulic design. Hydraulic presses are generally built to ratings of 500 to 18,000 tons.

## ROLLING

Rolling is the most important metal working process and can be performed on either hot or cold metal. Material is passed between cast or forged steel rolls, which compress it and drag it forward. Rolling is an economical method of deformation if metal is required in long lengths of uniform cross section. Normal rolling achieves thickness reduction of about 2:1. A schematic of rolling process is shown in Fig. 4.

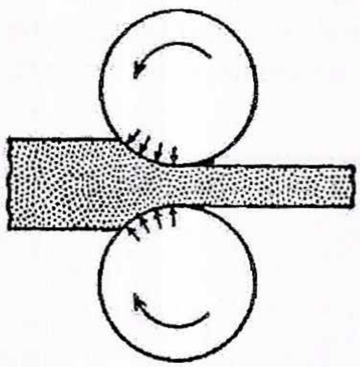


*Fig. 4 : Schematic diagram of rolling process*

Ingots are first rolled into either rectangular slabs or square blooms, which are produced as intermediate stages. In the rolling process the ingots are passed through the plain rolls repeatedly in one direction and then in the reverse direction. At each stage, the rolls are brought closer to each other. If square blooms are required the material is rotated through $90^0$ between rolling operations.

The rolling process can be used to produce plates, strips and rolled sections including channels, universal column, angle, sections etc. The plates and strips are generally formed using plain rolls. The rolls can bow which results in the plate being thicker at the middle. The rolls can be backed up in four high roll arrangements with additional rolls to reduce this tendency.

Small diameter planetary rolling mills are more effective than large ones in conveying rolling forces to deforming metal. Planetary mills take advantage of this principle. This process can achieve thickness reductions of up to 25:1.

A rolling mill consists of minimum a pair of rolls, bearings, a housing for accommodating these parts, and driving and controlling mechanism. The forces involved or required in rolling can easily reach many tons.

Rolling mill can be conveniently classified with respect to the number and arrangement of rolls. The common type of rolling mill is two high mill. Rolls of equal sizes are rotated in one direction. Stocks are returned to the entry end manually. A large decrease in power required for rolling can be achieved by the use of smaller diameter rolls supported by bigger diameter back up rolls.

In the 'cluster mill' each of the rolls is supported by two backup rolls. The Sendzimir mill is a modification of cluster mill and used to roll thin sheet or foil from high strength alloy. For high rate of production, a series of rolling mills one after another in tandem is kept. Each set of rolls is called stand and different reduction is taken at each stand thus a continuous length of strips of desired thickness is produced. The speed of each set of rolls is synchronised in such a fashion that each successive stand takes the strip at a speed equal to the delivery speed of the preceding stand.

The first hot working operation for steel products is done in the blooming mill. The mill consists of two high reversing mills with 24 to 54 inch diameter rolls. Blooming represent initial break down of ingot structure, it is done in small steps with repeated heating. Desired size of the billet is, produced by repeated reheating and rerolling in blooming mill. The billet may then be rolled into different shapes and sizes. High speed four high tandem mills with three to four stands are used for cold rolling of steel sheets, aluminium and copper alloys. The elimination of yield point from annealed steel sheets is an important practical problem since yield point elongation results inhomogeneous deformation during deep drawing or forming. The usual practice is to give the annealed sheet a final, small reduction by cold rolling, temper rolling or skin passes which eliminate yield point elongation. Temper rolling also results in better surface and improved flatness.

## EXTRUSION

The extrusion process can be described as follows. A metal slug or billet is placed in an enclosed chamber. The metal is then caused to move through a die opening at one end of the chamber by applying pressure with a mechanically or hydraulically operated ram. The metal passing through the die retains the cross sectional shape of the die aperture.

Soft metal can be readily deformed at room temperatures. Metals with higher resistance to deformation have to be heated to a temperature at which they are plastic, as in conventional hot working processes. Alternatively, high velocity methods of deformation can be utilised.

**Methods of Extrusion**

Direct extrusion: In this process, the flow of metal through the die aperture is in the same direction as in the movement of the ram. The ram is the same diameter as the bore of the container. (Fig. 5(a))

Indirect extrusion: In this, the ram is the same diameter as the bore of the container but the ram is hollow. A die is mounted over the bore of the ram and the metal flows on extrusion in the opposite direction to the ram movement and through the bore of the ram. (Fig. 5(b))

Backward extrusion: The ram is smaller in diameter than the container and the material is moved up the annulus formed by the ram and container. Normally a heated billet is used. (Fig. 5(c))

Impact extrusion: This is similar in principle to backward extrusion but is carried out at higher velocity and much lower temperatures. The extruded product will not usually require supporting after extrusion, therefore the container is made as short as possible. (Fig. 5(d))

Hydrostatic extrusion: In this, the metal is surrounded by a working fluid, which is pressured to give the extrusion force. (Fig. 5(e))

**Extrusion equipment**

The design of an extrusion press is determined by the end product, throughput required and the material being required. Presses can be constructed vertically or horizontally and are operated

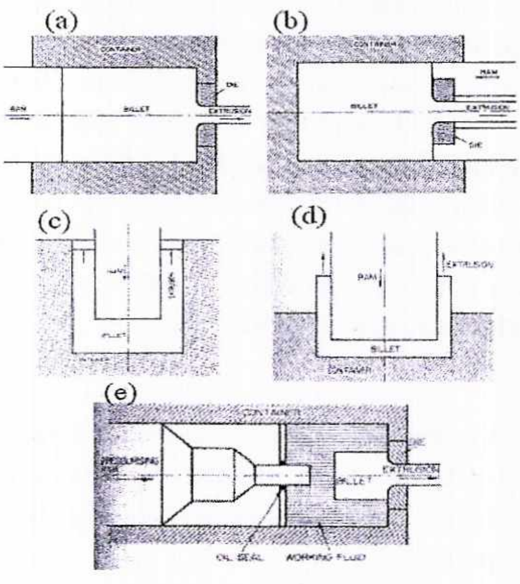


*Fig. 5 : Schematic representation of various methods of extrusion processes; (a) Direct extrusion. (b) Indirect extrusion. (c) Backward extrusion. (d) Impact extrusion. (e) Hydraulic extrusion*

either mechanically or hydraulically. Vertical presses are ideally suited to carbon and low alloy steel production. Vertical presses are extremely reliable but there are limitations in weight and head-room which restrict capacity to the range 600-1000 tons. Vertical presses can be more accurately aligned than horizontal presses and are, therefore, suited to high rates of production for accurate components. They are normally mechanically operated. Horizontal presses, which overcome the limitations of headroom, can be rated much higher. Presses upto 12500 tons rated pressure in operation and pressure upto 20000 tons are being considered. However, except for large presses for tonnage production of large diameter tubing, most horizontal presses operating today for the production of tubing and sections in ferrous and non-ferrous alloys are in the range of 1000-5000 tons. They are normally hydraulically operated.

**The Extrusion Process**

*Preparation of billet material*

Preparation of the billet is important as surface defects may be retained on the extruded product. Low carbon steels can be extruded in the rolled condition after desiccating, particularly if the methods used permit upsetting of the billet to the container size without internal or surface rupture of the metal. Rolled bar is not normally sufficiently round to fit the press container uniformly. All steels need a good degree of surface finish-a smooth turned finish of the order of 120/140 min. In those materials, which are more difficult to hot work due to a short range of hot working temperatures, surface defects will cause rupture of the surface, particularly when non-uniform sections are being extruded.

Heating of the billet prior to extrusion :

Heating of the billet can be accomplished by a variety of methods:

- Gas fired rotary or fixed hearth furnace.
- Salt bath.
- Induction heating.

Lubrication :

The lubricant has two specific applications in the process, i.e.

- Die
- Container lubrication

The extrusion process contains some more ingredient parts and those are namely :

a) Press tooling

b) Container

c) Press stem

d) Pressure disc

e) Dies

f) Mandrels

Factors affecting the dimensions of extruded products:

- **Extrusion temperature**
- **Extrusion speed :** The extrusion speed should be as high as possible to ensure consistency of section. If the section is at the limit of pressure available and speed is low, then there can be a large variation in dimensions, the back end being thicker than the leading end.
- **Extrusion ratio :** The extrusion ratio controls the specific pressure required. High ratios, with higher specific pressures, give greater die wear than low ratios.
- **Die temperature :** Over heating of the die permits 'wash' and loss of section, particularly on re-entrant angles.

**Economics of extrusion**

A direct comparison of the economics of extrusion with those of other metal forming processes is difficult because of the many variables involved. Generally speaking, however, the extruded products compete with other hot working processes in the following fields,

1) Production of low carbon alloy and stainless steel tubing in certain size ranges where high output horizontal extrusion presses, combined with stretch reducing mills, can produce tubing involving fewer operations from the melting furnace to the finished tube than was previously possible by conventional tube making processes.

2) Primary shaping of metals, i.e. exotic nickel base alloys which are difficult, if not possible, to produce by conventional forging and rolling techniques.

3) Extrusion of solid or hollow complex sections that cannot be produced by other methods.

The extrusion process is capable of producing competitive engineering components where:

a) Non-standard sections are required, particularly in relatively small quantities.

b) Substantial weight saving can be achieved, e.g., hollow sections where, in addition to reducing the initial cost per foot by direct weight saving, the subsequent machining operations will also be minimised.

c) Sections that cannot in any case be rolled, i.e. externally and internally finned tubing and sections with re-entrant angles.

d) Materials, which are difficult or impossible to roll, e.g., certain nickel base alloys.

## WIRE DRAWING

The technique of wire drawing can be divided into two main groups - the drawing of ferrous metals and the drawing of non-ferrous metals. The second group can then be sub-divided again into two categories namely, the drawing of heavy non-ferrous metals, such as copper and the drawing of light non-ferrous metals such as aluminium. Wire drawing has been defined as pulling a wire economically through a die under predetermined conditions and to satisfy these requirements, one must pull through the die in one operation, the longest length of wire possible at the highest speed, and with the lowest scrap figures. These demand high quality raw material and efficient machines and dies. Bad quality of metal can lead to wire breakage and rejects, giving increased scrap figures and, thus, in advertently affecting the manufacturing cost. The wire manufacturer must be extremely critical of the acquired raw material. The processes of melting, casting and rolling produce material for the rod mill, which can be totally unsatisfactory in quality. Surface imperfections such as slivers, seams, cracks, scabs and tears, may be present, as may also internal defects, such as pipe and segregation, originating from the original ingot or wire bar.

The hot rolled metallurgical structure of the rod is an extremely important factor to the wire drawer. In the cases of copper and aluminium one is mainly concerned with the purity of metal and its softness, but in the case of steel, the metallurgical structure can be a dominant influence. The structure of the steel rod, leaving the finishing mill, consists of a solid solution of carbon in iron. The rate of cooling from this temperature (1000$^{o}$C) controls the structure and subsequent wire drawing properties of the rod. Cooled too rapidly, the structure is brittle, impossible to draw; cooled too slowly, the rod shows excessive scale. In cooling the rods, the critical temperature is 720$^{o}$C. At this temperature, the carbon is precipitated in platelets; the structure is referred to as pearlite. Slow cooling gives these plates a coarse structure. Rapid cooling gives fine pearlite, much more suitable for drawing and permitting much higher reduction in area. Normal steel rod mill cooling consists of water quenching in pipes to 750/850$^{o}$C, between the finishing mill and the coilers, and then cooling the forming rod coil with air. This provides a satisfactory low carbon rod for drawing, but the lack of uniformity and slow cooling of the rod in coil does not give a suitable high carbon steel rod.

### Wire drawing machinery

Modern wire drawing machines fall into two main classes :

1) Single block machines.
2) Continuous machines.

The single block machine is mainly used on ferrous materials. It consists of a vertical spindle directly connected to an electric motor. Typical products are chain wires, pipe winding wire, reinforcing wire, cold heading wire. Tensile strengths are low, as maximum reduction in area is about 35%.

**Continuous machines consists of—**

a) Non slip-These machines are, again, principally used for ferrous metal but are also used for aluminium. The most common type in use is the overhead take-off accumulator machine. These are widely used in low and high carbon steel wire production and are designed for moderate wire speeds. This machine has a variation in the composite overhead take-off and double block accumulative machine. In this machine, there is a next construction of overhead take-off and double block types. This permits the use of larger inlet sizes than the double block will accept and also retains, at the finishing end.

b) Non-accumulating machine: This consists basically of a series of vertical spindle D.C. single blocks linked by tension arm from which the speed of the preceding motor is regulated by means of a 'dancer' rheostat. There is no slip between wire block and no twist from block to block. Each spindle is driven by an individual motor and the machine is synchronised to draw the same weight of wire on each block. The pre-set speed of the finishing block controls the speed of the other blocks. The amount of cooling on the wire is governed by the turns on each block. Higher speeds are possible than on accumulating machines.

c) Double block accumulator machine: This machine combines the excellent cooling of accumulator type equipment with the operating advantages of 'dancer' type machines. The wire is always under tension and no slip or twist occurs, allowing high-speed operation. The second block is mounted on the same spindle, and above the drawing block. The drawing block is keyed to the spindle and the second block revolves freely. Wire is accumulated equally on both blocks and is transferred from one to the other by a transfer pulley, which operates in a similar way to the spinner ring on an accumulating machine.

d) Slip type machine: This type of machine is used with wet lubricants for fine steel wire and exclusively for copper wire. An intermediate machine for copper or aluminium. The most common type is the cone machine, which has a series of capstans mounted on the same shaft, with each succeeding capstan bigger than the one before to compensate for elongation of the wire; thus forming a cone. The machines are line shafts driven with the reduction in area between dies being fixed. The peripheral speed of the drawing capstan is greater than the cone speed and slipping occurs.

**Preparation for drawing**

Cleaning: Much of the work in wire drawing is expended upon deformation, but friction in wire drawing is also an important factor. The rod mill scale is brittle, hard and abrasive, with a high coefficient of friction to other metal surfaces. It must therefore, be removed before attempting to draw wire. In the case of steel, the scale can be removed by mechanical methods, e.g. reverse bending descalers, which flex the material around pulleys to fracture and displace the scale from the rod surface, or by shot blasting where the steel shot bombard the scale breaking it away from the rod surface. However, the most common method of scale removal is acid cleaning. Hydrochloric acid is extensively used in Britain, because it can be used at ambient temperature and the spent acid can generally be sold. Sulphuric acid could be used equally well, but has to be heated and is more difficult to dispose of. Cleaning of non-ferrous rods may be relatively simple, as in case of copper where diluted sulphuric acid readily removes the scale or be very difficult as in case of nickel and chromium alloys. In this latter case a pre treatment in a sodium hydride bath, which reduces the scale, permits easy final cleaning in a suitable acid bath.

Coating: An obvious essential in wire drawing, is the wire drawing lubricant, but when one intends drawing ferrous rods or tough non ferrous rods, e.g., the nickel alloys, it is necessary to pre coat the rods, after rod cleaning with a lubricant carrier peaks and depressions are pronounced on a cleaned rod and it is essential to cover the peaks and fill out the depressions with a coating which will act as a separator and pick up drawing lubricant in the die box carrying it into the die.

**Wire drawing process requires; wire drawing dies, lubricants**

The wortle plates of steel and cast iron, which required great skill in preparation and maintenance, are quite unsuitable for continuous drawing or multi-hole drawing and the only alternative is the diamond die which is already a well-known tool, even in steel wire drawing. Hardness is the property, which is closest, related to abrasive wear resistance and it is some times necessary to sacrifice hardness for toughness. This can be accommodated by change in the cobalt content, The lower the cobalt, the lower the hardness unlike steel, tungsten carbide retains great hardness at high temperatures and is not affected by repeated heating and cooling. The co efficient of thermal expansion is only half that of the steel. The high wear resistance is due to the combination of properties; 1) retention of high hardness at low and high temperatures, 2) low coefficient of friction giving greater resistance to metal pick up and seizure, 3) ability to take and maintain a high surface finish, 4) high resistance to deformation.

Lubrication during the wire drawing process is a vital and complex part of the operation. The complexity is greatest in ferrous drawing .The harder, ferrous materials are predominantly drawn with dry, powdered soaps of sodium and calcium but greases, pastes, aqueous soap solutions and emulsions may also be used nonferrous materials, apart from the exotic metals are drawn with soap solutions. In the case of ferrous metals, the rod is coated with lime, borax or phosphate. When the rod passes through the lubricant, a small amount adheres to the surface and travels through the die. The heat and pressure transforms the powder to a plastic film, which reduces friction and prevents the metal to die wall contact. Soaps, fats and fatty oils are thinned by heat and thickened by pressure. Heavy lubricants, particularly soaps of fatty acids exhibit polarity, an electrostatic property, which bonds the lubricant to the metal atoms. This type of lubricant is difficult to squeeze out of the die.

**Heat treatment for wire drawing**

This is an extremely important aspect of wire manufacture.

1) **Lead and air patenting :** This is a heat treatment carried out on 0.4-0.8% carbon steel to facilitate wire drawing and give optimum physical properties. The rod structure consists of coarse plates of iron carbide in soft iron. The structure does not draw easily. Heat treatment at 1000°C and cooling in liquid lead at 530°C gives a very fine lamellar structure, which draws satisfactorily giving high tensile values. Cooling in air gives an intermediate structure and properties.

2) **Annealing :** The most common reason for annealing wire is to induce softness, this is true for ferrous and non-ferrous material. Many copper wires, for instance, are required in the soft condition. For example, wire for power cables are supplied in the range 1 - 2.7 mm, plain for plastics covering, tinned for rubber covering. The softening of steel, copper and aluminium, is due to recrystallisation or formation of new grains. The temperature at which this occurs is lowered with increasing amounts of cold work. Variations of the annealing process can be adopted in the case of steel to give structures with special advantages. For instance, prolonged annealing below the critical temperature gives a spheroidised structure, where the carbide plates coalesce and become spheroidal. This gives very soft, malleable characteristics and is used extensively for cold heading wire. Specialist heat treatments are available for high carbon steels. For example, stress relieving is a low temperature (200-300°C) process, which results in a higher tensile strength and limit of proportionality and lower relaxation figures. It is used for spring wire and pre stressed concrete wire. Further improvement of these properties particularly relaxation, are achieved by applying plastic strain while the wire is at the stress relieving temperature. This heat treatment is used for pre stressed concrete wire and strand.