LECTURE NOTES

Module-III

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5th Semester

PC 11: Basic Manufacturing Processes

MODULE - I (10 LECTURES)

Foundry: Types of patterns, pattern materials and pattern allowances. Moulding Materials - sand moulding, metal moulding, investment moulding, shell moulding. Composition of molding sand, Silica sand, Zircon sand, binders, additives, Binders - clay, binders for CO2, sand, binder for shell moulding, binders for core sand. Properties of moulding sand and sand testing, Melting furnaces - cupola, resistance furnace, induction and arc furnace, Solidification of castings, design of risers and runners, feeding distance, centre line freezing resistance chills and chaplets. Degasification and inoculation of metals. Casting methods like continuous casting, centrifugal casting, disc casting. Casting defects.

MODULE – II (8 LECTURES)

Welding and cutting: Introduction to gas welding, cutting, Arc welding and equipment's. TIG (GTAW) and MIG (GMAW) welding, resistance welding and thermit welding. Weldablity Modern Welding methods like plasma Arc, Laser Beam, Electron Beam, Ultrasonic, Explosive and friction welding, edge preparation in butt welding. Brazing and soldering, welding defects. Destructive and non-destructive testing of castings and welding.

MODULE – III (08 LECTURES)

Brief introduction to powder metallurgy processes. Plastic deformation of metals: Variables in metal forming and their optimization. Dependence of stress strain diagram on Strain rate and temperature. Hot and cold working of metals, classification of metal forming processes.

Rolling: Pressure and Forces in rolling, types of rolling mills, Rolling defects. Forging: Smith Forging, Drop and Press forging, M/c forging, Forging defects.

MODULE – IV (08 LECTURES)

Extrusions: Direct, Indirect, Impact and Hydrostatic extrusion and their applications, Extrusion of tubes. Wire drawing methods and variables in wire-drawing, Optimum dies shape for extrusion and drawing. Brief introduction to sheet metal working: Bending, Forming and Deep drawing, shearing. Brief introduction to explosive forming, coating and deposition methods.

BOOKS

[1] Manufacturing technology by P.N.Rao, Tata McGraw Hill publication.
[2] Welding Technology by R.A. Little, TMH
[3] Manufacturing Science by A.Ghosh and A K Malick, EWP
[4] Fundamentals of metal casting technology by P.C. Mukherjee, Oxford PIBI.
[5] Mechanical Metallurgy by Dieter, Mc-Graw Hill
[6] Processes and Materials of Manufacture by R.A Lindberg, Prentice hall (India)
[7] A Text Book of Production Engineering by P.C.Sharma, S.Chand.

Digital Learning Resources:

NPTEL MOOCs:

Course Name: Fundamentals of Manufacturing Processes

Course Link: https://nptel.ac.in/courses/108/102/108102047/

Module – III

Powder metallurgy – Basics & Applications

Dr. R. K. Behera, KEC, Bhubaneswar

Powder metallurgy – science of producing metal powders and making finished/semifinished objects from mixed or alloyed powders with or without the addition of Non metallic constituents.

Steps in powder metallurgy:

Powder production, Compaction, Sintering, & Secondary operations Powder production: Raw materials => Powder; Powders can be pure elements, pre-alloyed powders

Methods for making powders –

Atomization: Produces powders of both ferrous and non-ferrous powders like stainless steel, superalloys, Ti alloy powders;

Reduction of compounds: Production of iron, Cu, tungsten, molybdenum; Electrolysis: for making Cu, iron, silver powders Powders along with additives are mixed using mixers Lubricants are added prior to mixing to facilitate easy ejection of compact and to minimize wear of tools; Waxes, metallic stearates, graphite etc.

Compaction: compaction is performed using dies machined to close tolerances. Dies are made of cemented carbide, die/tool steel; pressed using hydraulic or mechanical presses.

The basic purpose of compaction is to obtain a green compact with sufficient strength to withstand further handling operations.

The green compact is then taken for sintering Hot extrusion, hot pressing, hot isostatic pressing => consolidation at high temperatures.

Sintering: Performed at controlled atmosphere to bond atoms metallurgically; Bonding occurs by diffusion of atoms; done at 70% of abs. melting point of materials It serves to consolidate the mechanically bonded powders into a coherent body having desired on service behavior Densification occurs during the process and improvement in physical and mechanical properties are seen Furnaces – mesh belt furnaces (up to 1200C), walking beam, pusher type furnace, batch type furnaces are also used Protective atmosphere: Nitrogen (widely used) Secondary operations: Operations include repressing, grinding, plating can be done; They are used to ensure close dimensional tolerances, good surface finish, increase density, corrosion resistance etc.

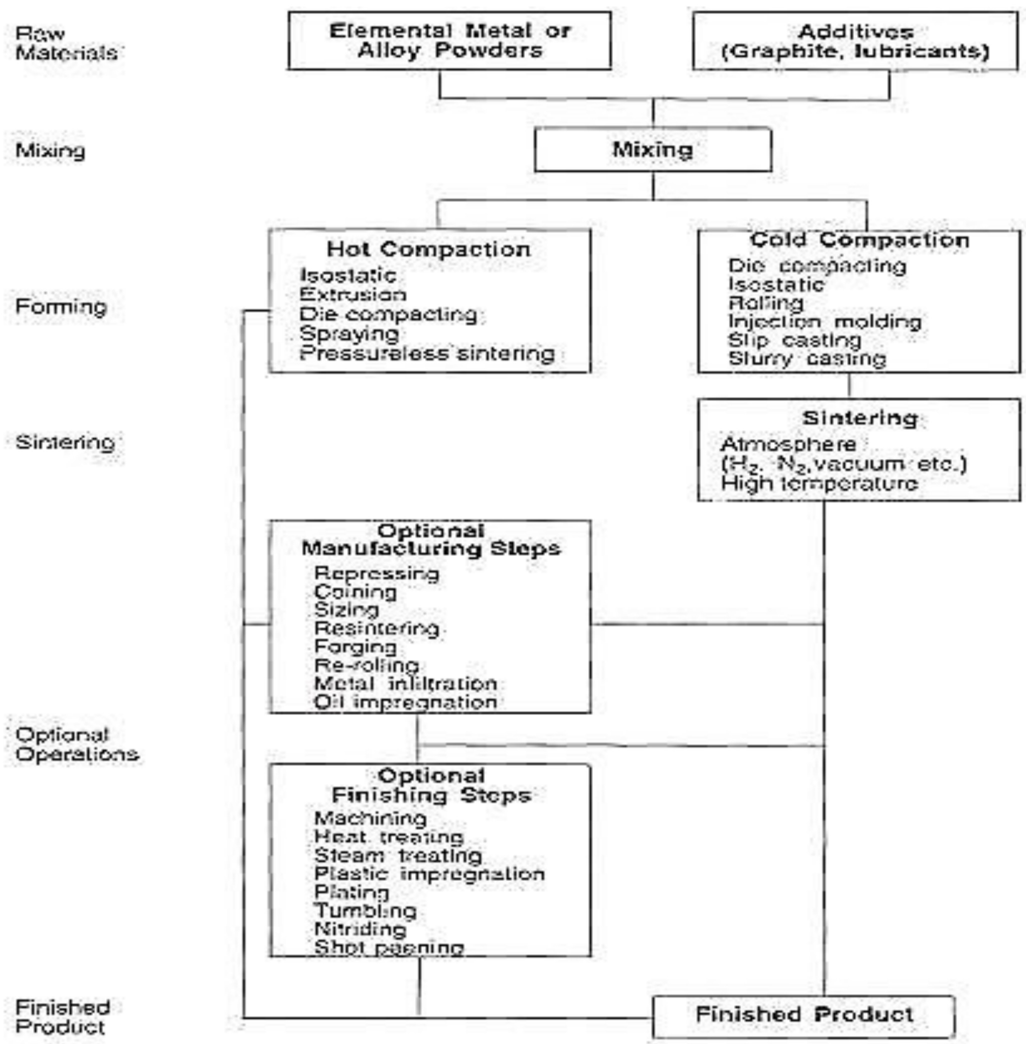


Fig: Flow chart for making P/M components

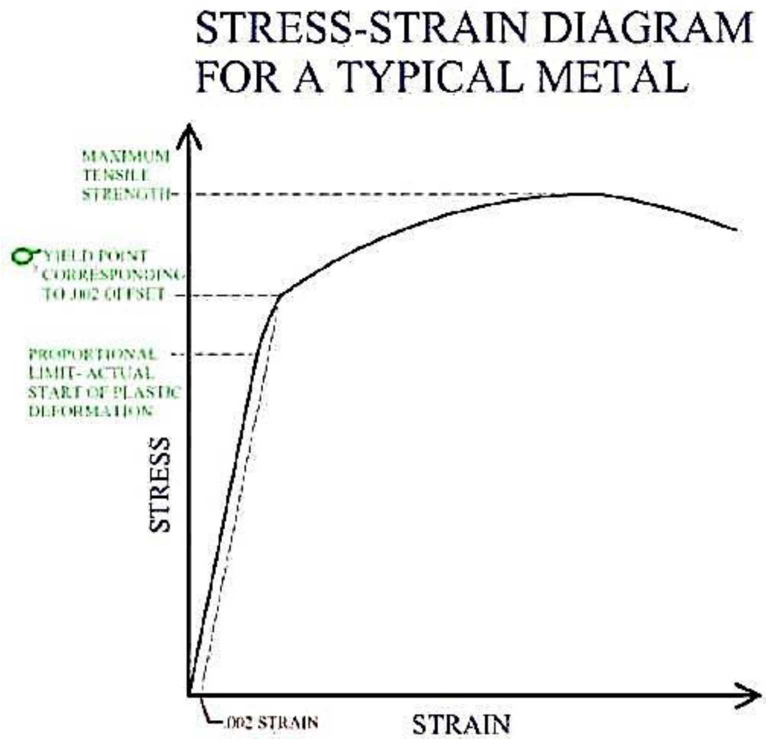
Advantages & limitations

- Efficient material utilization
- Enables close dimensional tolerances – near net shape possible
- Good surface finish

- Manufacture of complex shapes possible
- Hard materials used to make components that are difficult to machine can be readily made – tungsten wires for incandescent lamps
- Environment friendly, energy efficient
- Suited for moderate to high volume component production
- Powders of uniform chemical composition => reflected in the finished part
- wide variety of materials => miscible, immiscible systems; refractory metals
- Parts with controlled porosity can be made
- High cost of powder material & tooling
- Less strong parts than wrought ones
- Less well known process

Plastic deformation of metals

Metal forming is a general term for a large group that includes a wide variety of manufacturing processes. Metal forming processes are characteristic in that the metal being processed is plastically deformed to shape it into a desired geometry. In order to plastically deform a metal, a force must be applied that will exceed the yield strength of the material. When low amounts of stress are applied to a metal it will change its geometry slightly, in correspondence to the force that is exerted. Basically it will compress, stretch, and/or bend a small amount. The magnitude of the amount will be directly proportional to the force applied. Also the material will return to its original geometry once the force is released. Think of stretching a rubber band, then releasing it, and having it go back to its original shape. This is called elastic deformation. Once the stress on a metal increases past a certain point, it no longer deforms elastically, but starts to undergo plastic deformation. In plastic deformation, the geometric change in the material is no longer directly proportional to stress and geometric changes remain after the stress is released; meaning that the material does not recover its shape. The actual level of stress applied to a metal where elastic deformation turns to plastic deformation is called the proportional limit, and is often difficult to determine exactly. The .002 offset convention is usually used to determine the yield point, which is taken for practical purposes as the stress level where plastic deformation, (yielding), begins to occur. For more information on this topic review the mechanical properties of metals section in a material science text book.



It can be seen by the stress-strain graph that once the yield point of a metal is reached and it is deforming plastically, higher levels of stress are needed to continue its deformation. The metal actually gets stronger, the more it is deformed plastically. This is called strain hardening or work hardening. As may be expected, strain hardening is a very important factor in metal forming processes. Strain hardening is often a problem that must be overcome, but many times strain hardening, when used correctly, is a vital part of the manufacturing process in the production of stronger parts.

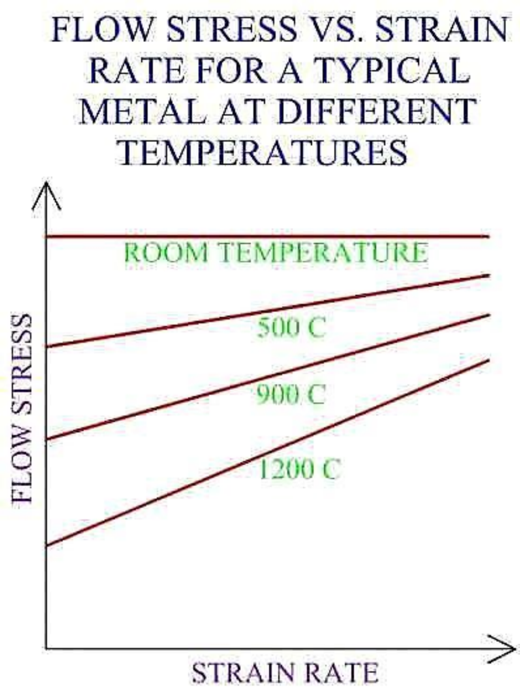
Flow Stress

During a metal forming operation, it is important to know the force and power that will be needed to accomplish the necessary deformation. The stress-strain graph shows us that the more a work piece is deformed plastically, the more stress is needed. The flow stress is the instantaneous value of the force necessary to continue the yielding and flow of the work material at any point during the process. Flow stress can be considered as a function of strain. The flow stress value can be used to analyze what is going on at any particular point in the metal forming process. The maximum flow stress may be a critical measurement in some metal forming operations, since it will specify the force and power requirements for the machinery to perform the process. The force needed at the maximum strain of the material would have to be calculated in order to determine maximum flow stress.

For different types of metal forming processes, the flow stress analysis may be different. For a process like forging, the maximum flow stress value would be very important. However, for a process like extrusion, where the metal is continuously being deformed and the different stages of the metal's deformation are occurring simultaneously, it is of interest to analyze the mean flow stress value.

Strain Rate

The strain rate for any particular manufacturing metal forming process is directly related to the speed at which deformation is occurring. A greater rate of deformation of the work piece will mean a higher strain rate. The specific process and the physical action of the equipment being used has a lot to do with strain rate. Strain rate will affect the amount of flow stress. The effect strain rate has on flow stress is dependent upon the metal and the temperature at which the metal is formed. The strain rate with relation to flow stress of a typical metal at different temperatures is shown in figure.



Effect of Temperature In Metal Forming

Properties of a metal change with an increase in temperature. Therefore, the metal will react differently to the same manufacturing operation if it is performed under different temperatures and the manufactured part may posses different properties. For these reasons, it is very important to understand the materials that we use in our manufacturing process. This involves knowing their behavior at various temperature ranges. In industrial metal forming manufacture, there are three basic temperature ranges at which the metal can be formed, cold working, warm working, and hot working.

Cold Working

Cold working, (or cold forming), is a metal forming process that is carried out at room temperature or a little above it. In cold working, plastic deformation of the work causes strain hardening as discussed earlier. The yield point of a metal is also higher at the lower temperature range of cold forming. Hence, the force required to shape a part is greater in cold working than for warm working or hot working. At cold working temperatures, the ductility of a metal is limited, and only a certain amount of shape change may be produced. Surface preparation is important in cold forming. Fracture of the material can be a problem, limiting the amount of deformation possible. In fact, some metals will fracture from a small amount of cold forming and must be hot formed. One main disadvantage of this type of process is a decrease in the ductility of the part's material, but there are many advantages. The part will be stronger and harder due to strain hardening. Cold forming causes directional grain orientation, which can be controlled to produce desired directional strength properties. Also, work manufactured by cold forming can be created with more accurate geometric tolerances and a better surface finish. Since low temperature metal forming processes do not require the heating of the material, a large amount of energy can be saved and faster production is possible. Despite the higher force requirements, the total amount of energy expended ismuch lower in cold working than in hot working.

Warm Working

Warm working, (or warm forming), is a metal forming process carried out above the temperature range of cold working, but below the recrystallization temperature of the metal. Warm working may be preferred over cold forming because it will reduce the force required to perform the operation. Also, the amount of annealing of the material that may have been necessary for the cold formed part may be less for warm working.

Hot Working

Hot working, (or hot forming), is a metal forming process that is carried out at a temperature range that is higher than the recrystallization temperature of the metal being formed. The behavior of the metal is significantly altered, due to the fact that it is above its recrystallization temperature. Utilization of different qualities of the metal at this temperature is the characteristic of hot working.

Although many of these qualities continue to increase with increasing temperature, there are limiting factors that make overly high temperatures undesirable. During most metal forming processes the die is often cold or slightly heated. However, the metal stock for hot working will usually be at a higher temperature relative to the die. In the design of metal forming process, it is critical to consider the flow of metal during the forming of the work. Specific metal flow, for different forming processes, is discussed in latter sections under each specific process. For metal forming manufacturing, in general, the temperature gradient between the die and the work has a large effect on metal flow during the process. The metal nearer to the die surfaces will be cooler than the metal closer to the inside of the part, and cooler metal does not flow as easily. High temperature gradients, within the work, will cause greater differences in flow characteristics of different sections of the metal, these could be problematic. For example, metal flowing significantly faster at the center of the work compared to cooler metal near the die surfaces that is flowing slower, can cause part defects. Higher temperatures are harder to maintain throughout the metal forming process. Work cooling during the process can also result in more metal flow variations. Another consideration with hot forming manufacture, with regard to the temperature at which to form the part, is that the higher the temperature the more reactive the metal is likely to be. Also if a part for a hot working process is too hot then friction, caused during the process, may further increase heat to certain areas causing melting, (not good), in localized sections of the work. In an industrial hot metal working operation, the optimum temperature should be determined according to the material and the specific manufacturing process.

When above its recrystallization temperature a metal has a reduced yield strength, also no strain hardening will occur as the material is plastically deformed. Shaping a metal at the hot working temperature range requires much less force and power than in cold working. Above its recrystallization temperature, a metal also possesses far greater ductility than at its cold worked temperature. The much greater ductility allows for massive shape changes that would not be possible in cold worked parts. The ability to perform these massive shape changes is a very important characteristic of these high temperature metal forming processes.

The work metal will recrystallize, after the process, as the part cools. In general, hot metal forming will close up vacancies and porosity in the metal, break up inclusions and eliminate them by distributing their material throughout the work piece, destroy old weaker cast grain structures and produce a wrought isotropic grain structure in the part. These high temperature forming processes do not strain harden or reduce the ductility of the formed material. Strain hardening of a part may or may not be wanted, depending upon the application. Qualities of hot forming that are considered disadvantageous are poorer surface finish, increased scale and oxides, decarburization, (steels), lower dimensional accuracy, and the need to heat parts. The heating of parts reduces tool life, results in a lower productivity, and a higher energy requirement than in cold working.

Selection of Temperature Range for a Metal Forming Operation

Production at each of these temperature ranges has a different set of advantages and disadvantages. Sometimes, qualities that may be undesirable to one process may be desirable to another. Also, many times work will go through several processes. The goal is to design the manufacture of a part in such a way as to best utilize the different qualities to meet or enhance the specifications of the part. To produce a strong part with excellent surface finish, then a cold forming process could be a good choice.

However, to produce a part with a high ductility a hot forming process may be best. Sometimes the advantages of both hot forming and cold forming are utilized when a part is manufactured by a series of processes. For example, hot working operations may first be performed on a work piece to achieve large amounts of shape change that would not be possible with cold forming due to strain hardening and limited ductility. Then the last process that completes the manufacture of the part is a cold working operation. This process does not require a significant shape change, since most of the deformation was accomplished by the hot forming process. Having a cold forming process last will finish the shape change, while strengthening the part, giving a good surface finish and highly accurate tolerances.

Friction and Lubrication in Metal Forming

Metal forming processes are characteristic of high pressures between two contacting surfaces. In hot forming operations, these high pressures are accompanied by extreme temperatures. Friction and die wear are a serious consideration in metal forming manufacturing. A certain amount of friction will be necessary for some metal forming processes, but excessive friction is always undesirable. Friction increases the amount of force required to perform an operation, causes wear on tooling, and can affect metal flow, creating defects in the work.

Where friction is involved, lubricants can usually help. For some metal forming processes and materials no lubrication is used, but for many lubrication is applied to contacting surfaces to reduce friction forces. Lubricants used in industry are different depending upon the type of metal forming process, the temperature at which the operation occurs, and the type of material formed. Lubricants should be effective and not produce any toxic fumes. Lubricants used in manufacturing industry for metal forming processes include, vegetable and mineral oils, soaps, graphite dispensed in grease, water based solutions, solid polymers, wax, and molten glass.

Different Types of Metal Forming Processes

Metal forming processes can be classified under two major groups. Bulk deformation processes and sheet metal working processes.Bulk deformation is characteristic in that the work formed has a low surface area to volume ratio. In sheet metal working, the metal being processed will have a high surface area to volume ratio. The following is a brief overview of the major metal forming processes that will be covered in detail later.

Bulk Deformation:

Rolling: Rolling is a metal forming process that deforms the work by the use of rolls. Rolling processes include flat rolling, shape rolling, ring rolling, thread rolling, gear rolling, and the production of seamless tube and pipe by rotary tube piercing or roll piercing.

Forging: Forging is characteristic in the use of dies to compress and shape a work piece. The die may be flat or may contain an impression of a certain geometry.

Extrusion: Extrusion involves forming by forcing metal through a die opening, producing work of variable length and constant cross section.

Drawing: Drawing is similar to extrusion, in that a length of metal is madeto flow through a die opening and forming is done over its cross section.

The difference between drawing and extrusion is the application of force to the work piece. In extrusion the work is pushed through the die opening, in drawing the work is pulled through the die opening.

Sheet Metal Working:

Shearing: Shearing is the cutting of the work piece, this would include punching holes. Technically shearing does not involve shaping by plastic deformation, but it is a critical process in sheet metal working operations and should be understood along with metal forming processes.

Bending: Bending involves the deformation of the work by way of bending about a certain axis.

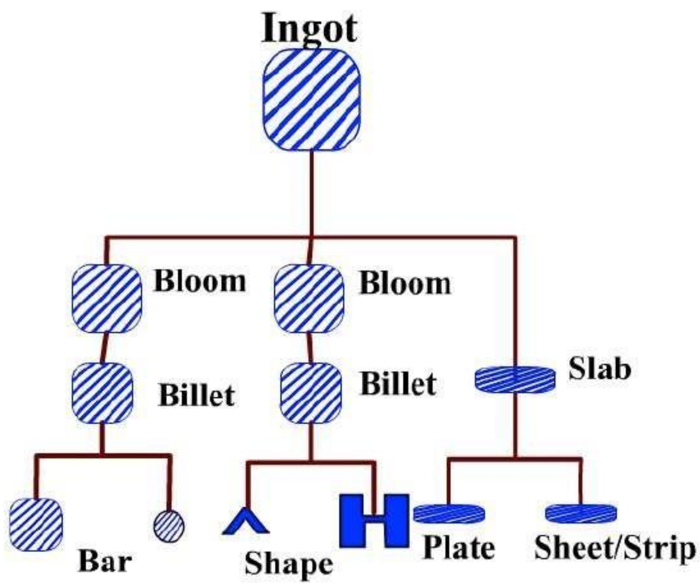
Deep Drawing: Deep drawing is a metal forming process in which a flat piece of plate or sheet is forced into a die cavity to take a shape, such as acup.

Optimization Strategies for Metal Forming Processes:

Cost saving and product improvement have always been important goals in the metal forming industry. To achieve these goals, metal forming processes need to be optimised. During the last decades, simulation software based on the Finite Element Method (FEM) has significantly contributed to designing feasible processes more easily. More recently, the possibility of coupling FEM to mathematical optimisation techniques is offering a very promising opportunity to design optimal metal forming processes instead of just feasible ones. The developed structured methodology for modelling optimisation problems in metal forming is based on the generally applicable Product Development Cycle. This Product Development Cycle has been related to metal parts and their forming processes and subsequently to the modelling of optimisation problems, i.e. defining objective function, constraints and design variables. In the modelling methodology yields a mathematically formulated optimisation model for a variety of optimisation problems, products and metal forming processes. Solving the modelled optimisation problem is done in two stages: screening and optimising using an algorithm. The number of design variables may also be large, which makes solving the optimisation problem prohibitively time consuming. Screening techniques based on Mixed Array Design of Experiment (DOE) plans and Mean response plots have been developed to remove discrete design variables by selecting the best level of the discrete variable. Resolution III fractional factorial DOE plans, ANalysis Of VAriance, and Pareto and Effect plots assist in reducing the number of continuous design variables. The implemented screening techniques reduce the size of the optimisation problem in order to solve it efficiently in a second solving stage: optimisation. For optimisation, a Sequential Approximate Optimisation (SAO) algorithm has been developed. Running the corresponding FEM simulations yields response measurements through which metamodels can be fitted using Response Surface Methodology (RSM) and Kriging metamodelling techniques. These metamodels are subsequently optimised very quickly using a global multistart SQP algorithm. Several sequential improvement strategies have been implemented to efficiently improve the accuracy of the obtained optimum. Process robustness and reliability play an important role for industrial metal forming processes. To this end, the deterministic optimisation strategy described above has been extended to a robust optimisation strategy. In addition to deterministic control variables, noise variables are included as normally distributed inputs. Also, objective function and constraints are consequently stochastic quantities having a certain distribution. The screening techniques developed for deterministic optimisation can be applied to robust optimisation problems without any adaptations. The SAO algorithm has been adapted to efficiently optimise response distributions rather than response values. The deterministic and robust optimisation strategies have been applied to several industrial metal forming processes. These applications comprise different products and processes (a forged spindle and gear, a deep drawn automotive part, a hydro-formed automotive part, and a deep drawn small cup). It can be concluded from these applications that both the deterministic and robust optimisation strategies are generally applicable to a wide variety of metal forming problems, products and processes. Comparisons between the deterministic and robust optimisation strategies demonstrated that taking into account process robustness and reliability during optimisation is an important issue for optimising industrial metal forming processes. Next to general applicability, efficiency is a second requirement for the optimisation strategy. Screening plays an important role in reducing the problem size at the expense of a limited number of FEM simulations only. The efficiency of the SAO algorithm has been compared to that of other optimisation algorithms by application to two forging processes: the SAO algorithm yielded better results using less FEM simulations. Additionally, the optimisation strategy solved the three complicated industrial optimisation problems in less than 100 FEM simulations each. The screening techniques, the SAO algorithm and robust extension allow for running FEM simulations in parallel, which reduces the calculation time.

Rolling

Rolling is one of the most important industrial metal forming operations. Hot Rolling is employed for breaking the ingots down into wrought products such as into blooms and billets, which are subsequently rolled to other products like plates, sheets etc. Rolling is the plastic deformation of materials caused by compressive force applied through a set of rolls. The cross section of the work piece is reduced by the process. The material gets squeezed between a pair of rolls, as a result of which the thickness gets reduced and the length gets increased. Mostly, rolling is done at high temperature, called hot rolling because of requirement of large deformations. Hot rolling results in residual stress-free product. However, scaling is a major problem, due to which dimensional accuracy is not maintained. Cold rolling of sheets, foils etc is gaining importance, due to high accuracy and lack of oxide scaling. Cold rolling also strengthens the product due to work hardening. Steel ingot is the cast metal with porosity and blowholes. The ingot is soaked at the hot rolling temperature of 1200o C and then rolled into blooms or billets or slabs. Bloom is has a square cross section, with area more than 230 cm2 . A slab, also from ingot, has rectangular cross-section, with area of at least 100 cm2 and width at least three times the thickness. A billet is rolled out of bloom, has at least 40 mm X 40 mm cross-section. Blooms are used for rolling structural products such as I-sections, channels, rails etc. Billets are rolled into bars, rods. Bars and rods are raw materials for extrusion, drawing, forging, machining etc. Slabs are meant for rolling sheets, strips, plates etc.



Rolling sequence for fabrication of bars,shapes and flat products from blooms,billets and slabs

Flow diagram showing Rolling of different products

Plates have thickness greater than 6 mm whereas strips and sheets haveless than 6 mm thickness.

Sheets have greater width and strip has lower width – less than 600 mm.

Rolling mills:

Rolling mill consists of rolls, bearings to support the rolls, gear box, motor, speed control devices, hydraulic systems etc.

The basic type of rolling mill is two high rolling mill. In this mill, two opposing rolls are used.

The direction of rotation of the rolls can be changed in case of reversing mills, so that the work can be fed into the rolls from either direction. Such mills increase the productivity.

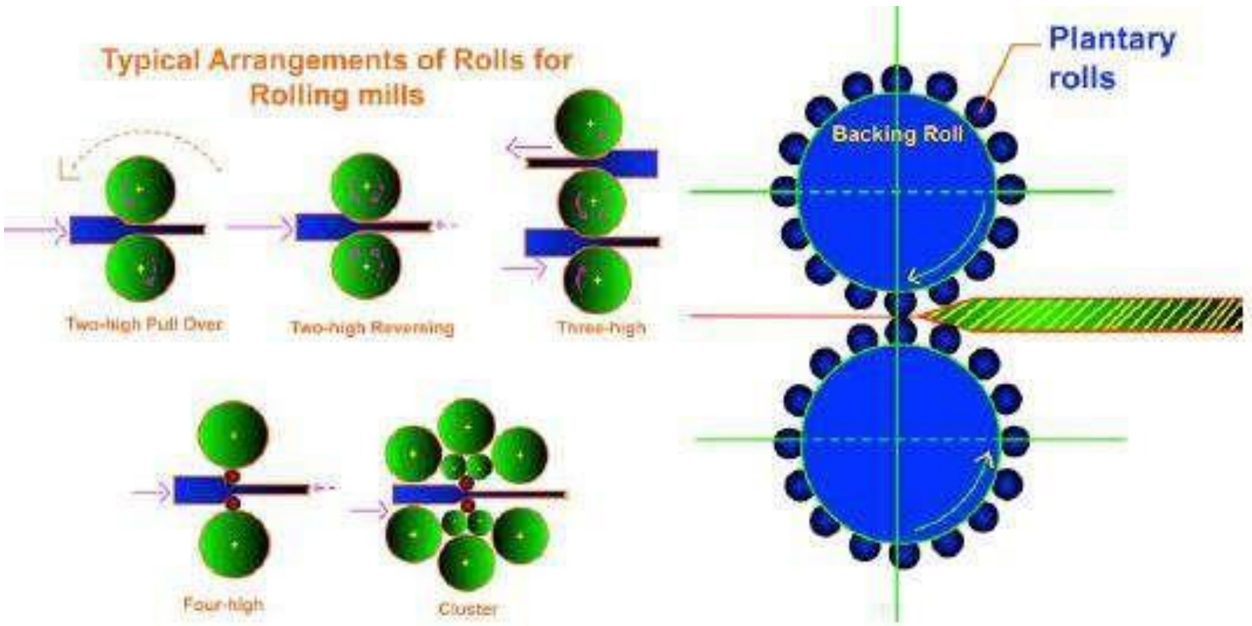
Non reversing mills have rolls rotating in same direction. Therefore, the work piece cannot be fed from the other side. Typical roll diameters may be 1.4 m.

A three high rolling mill has three rolls. First rolling in one direction takes place along one direction. Next the work is reversed in direction and fed through the next pair of roll. This improves the productivity.

Rolling power is directly proportional to roll diameter. Smaller dia rolls can therefore reduce power input. Strength of small diameter rolls are poor. Therefore, rolls may bend. As a result, largerdia backup rolls are used for supporting the smaller rolls. Four high rolling mill is one such mill.

Thin sections can be rolled using smaller diameter rolls. Cluster mill and Sendzimir mill are used for rolling thin strips of high strength materials and foils [0.0025 mm thick].
The work roll in these mills may be as small as 6 mm diameter — made of tungsten carbide. Several rolling mills arranged in succession so as to increase productivity is called rolling stand.

In such arrangement, anuncoiler and windup reels are used. They help in exerting back tension and front tension.



Planetary mill has a pair of large heavy rolls, surrounded by a number of smaller rolls around their circumference. In this mill, a slab can be reduced to strip directly in one pass. Feeder rolls may be needed in order to feedthe work piece into the rolls.
Merchant mill is specifically used for rolling bars.

Hot rolling is usually done with two high reversing mill in order to breakdown ingots into blooms and billets. For increased productivity, universal mill has two vertical rolls which can control the width of the work simultaneously. Non ferrous materials are cold rolled into sheets from hot rolled strips. Four high tandem mills are generally used for aluminium and copper alloys. In order to achieve upto 90% reduction in thickness in cold rolling, a series of rolling mills may be used to share the total reduction.

One important application of cold rolling is the removal of yield point from mild steel sheets using skin pass rolling [temper rolling]. In this the steel sheet is given a light reduction of 0.5 to 1.5% . Such a process eliminates yield point elongation. If yield elongation of steel occurs during sheet metal operation, such as deep drawing, the surface of the sheet metal becomes rough due to formation of Luder bands, also called stretcher strains. Flatness of rolled sheets can be increased by roller leveling. In this process, the sheet is passed between a pair of rolls which are driven by individual motors and are slightly offset.

Rolls should have high stiffness, hardness and strength. Cast iron, cast steel and forged steel are also used as rolls.

Grain structure in rolling:

When the wrought or cast product gets hot rolled, the grain structure, which is coarse grained, becomes finer in size, but elongated along the directionof rolling. This type of textured grain structure results in directional property [anisotropy] for the rolled product. In order to refine the grains, heat treatment is performed immediately after rolling, which results in recrystallization after rolling.

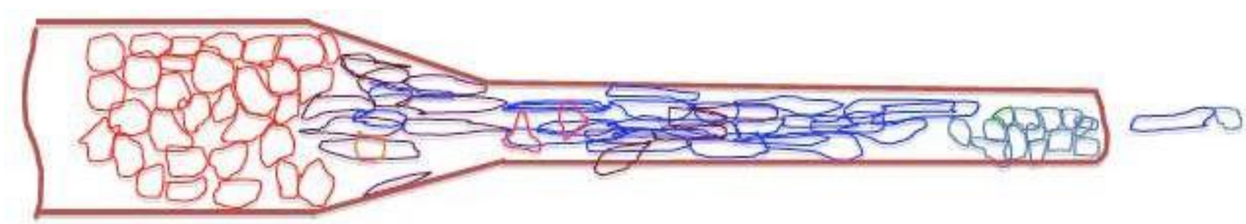


Fig: Variation of grain structure, size during longitudinal rolling

Special rolling processes:

Bulk deformation processes such as shape rolling, thread rolling, roll piercing, ring rolling also use pair of rolls. Some of such important processes are discussed briefly below: Thread and gear rolling:

Threads on cylindrical work pieces can be cold formed using a pair of flat dies or cylindrical rolls under reciprocating or rotary motion. Screws, bolts and other externally threaded fasteners are produced by thread rolling. Thread rolling is a high productivity process involving no loss of material.

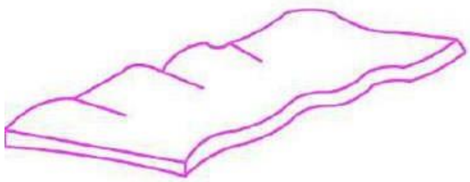
Due to grain flow in thread rolling strength is increased. Surface finish of rolled threads is very good. Gears can also be produced by the thread rolling process. Compressive stresses introduced during the process isfavourable for fatigue applications. Auto power transmission gears are made by thread rolling. Shape rolling: Structural sections such as I- sections, rails, channels can be rolled using set of shaped rolls. Blooms are usually taken as raw materials for shape rolling. Multiple steps are required in shape rolling. Ring rolling: Smaller diameter, thicker ring can be enlarged to larger diameter, thinner section by ring rolling. In this process, two circular rolls, one of which is idler roll and the other is driven roll are used. A pair of edging rollers are used for maintaining the height constant. The ring is rotated and the rings are moved closer to each other, thereby reducing the thickness of ring and increasing its diameter. Rings of different cross-sections can be produced. The major merits of this process are high productivity, material saving, dimensional accuracy and grain flow which is advantageous. Large rings for turbines, roller bearing races, flanges and rings for pipes are some of the applications of this process.

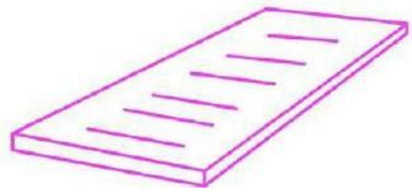
Rolling defects: Mill spring is a defect in which the rolled sheet is thicker than the required thickness because, the rolls get deflected by high rolling forces. Elastic deformation of the mill takes place. If we use stiffer rolls, namely roll material of high stiffness or elastic constant, we could avoid mill spring. Normally elastic constant for mills may range from 1 to 4 GNm-1.

Roll elastic deformation may result in uneven sheet thickness across. Roll material should have high elastic modulus for reducing the roll deformation. For producing very thin gage sheets like foils, small diameter rolls are used. They are supported with larger rolls. We can say the minimum thickness of rolled sheets achieved is directly proportional to roll radius, friction, flow stress.

Flatness of rolled sheets depends on the roll deflection. Sheets become wavy as roll deflection occurs.

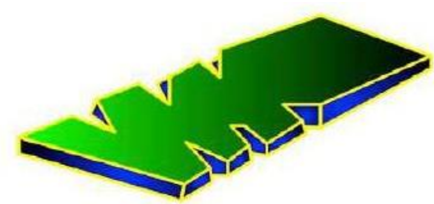
If rolls are elastically deflected, the rolled sheets become thin along the edge, whereas at centre, the thickness is higher. Similarly, deflected rolls result in longer edges than the centre. Edges of the sheet elongate more than the centre. Due to continuity of the sheet, we could say hf1 hf2 ho Strip thickness that the centre is subjected to tension, while edges are subjected to compression. This leads to waviness along edges. Along the centre zipper cracks occur due to high tensile stress there. Cambering of rolls can prevent such defects. However, one camber works out only for a particular roll force.





Wavy edge Zipper cracks

In order to correct roll deflection for a range of rolling conditions, hydraulic jacks are used, which control the elastic deformation of rolls according to requirement.



Centre crack Edge cracks

If rolls have excess convexity then the center of the sheet metal will have more elongation than the edges. This leads to a defect called centre buckle. Edge defect due to heavy reduction Small thickness sheets are more sensitive to roll gap defects leading to greater defects. Thin strips are more likely to undergo waviness or buckling. These defects are corrected by doing roller leveling or stretch leveling under tension. Stretch leveling is carried out between roller leveler rolls. During rolling the sheet will have a tendency to deform in lateral direction. Friction is high at the centre. Therefore, spread is the least at the centre. This leads to rounding of ends of the sheet. The edges of the sheet are subjected to tensile deformation.

This leads to edge cracks. If the center of the sheet is severely restrained and subjected to excess tensile stress, center split may happen. Non-homogeneous material deformation across the thickness leads to high secondary tensile stress along edge. This leads to edge cracks. Secondary tensile stresses are due to bulging of free surface. Edge cracks can be avoided by using edge rolls. Due to non homogeneous flow of material across the thickness of the sheet, another defect called allegatoring occurs. This is due to the fact that the surface is subjected to tensile deformation and centre to compressive deformation. This is because greater spread of material occurs atcenter.

Rolling force in hot rolling:

Material flow in hot rolling is less homogeneous. Strain rate also affects the flow stress of the material. Further, friction conditions are rather unpredictable. Friction coefficient in hot rolling may be high — ranges from
0.2 to 0.7. Strain rate in hot rolling can be found out from the expression:

$\dot{\varepsilon} = \ln(\frac{h_0}{h_f})$ / time -------------- 5.3

Time can be writtenas : L/V, where V is velocity of roll, L is projected arc length.

Therefore, $\dot{\varepsilon} = (V/L)\ln(\frac{h_0}{h_f}) = (V/\sqrt{R\Delta h})\ln(\frac{h_0}{h_f})$ ------------------ 5.4

From flow curve we can determine the flow stress for the corresponding strain rate.

Total roll force:

Roll force is equal to roll pressure multiplied by area of contact between roll and work.

Roll torque and power:

$F = \int_0^{\theta_n} pwRd\theta + \int_{\theta_n}^{\alpha} pwRd\theta$ ------------------------5.5

If friction is ignored, we can write an approximate expression for roll force as:

$F = Lw\overline{Y'}$ ---------------5.6

With friction:

$F = Lw\overline{Y'}(1+\frac{\mu L}{2h_{av}})$ ------5.7

Where, h_{av} is given by: $(h_o+h_f)/2$

Roll torque can be estimated from the rolling force. Torque is equal to force multiplied by the radius at which the force acts.

We can assume that the roll force is acting perpendicular to the strip at a radius equal to one half of the projected arc length of contact.

For each roll, the torque is: T = FL/2

Roll power is given by:

Power = 2πNT ------------5.8

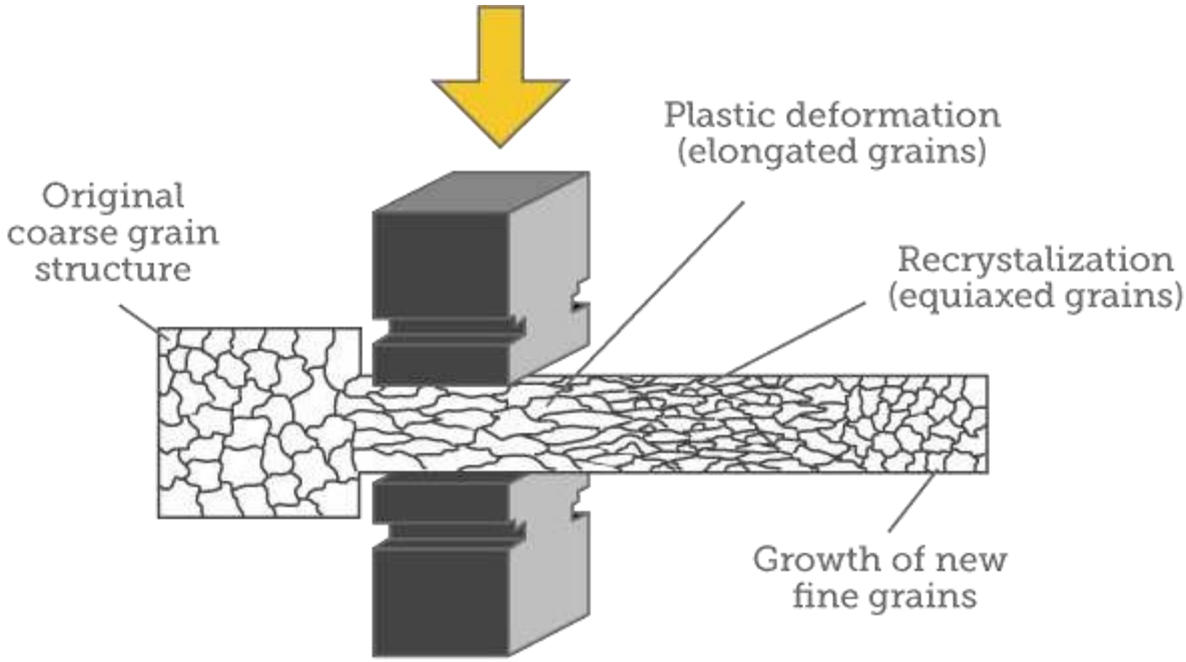
Torque can be more accurately determined from:

$$T = \int_0^{\theta_n} pwR^2 d\theta - \int_{\theta_n}^{\alpha} pwR^2 d\theta \quad \text{--------------5.9}$$

Here the minus sign is due to the fact that the friction force acts against the rolling direction beyond the neutral section. Total roll torque consists of the rolling torque plus the torque required to overcome friction in roll bearings plus torque at motor shaft plus torque for overcoming friction in transmission system.

Roll power is applied in order to deform the work material, to overcome friction in rotating parts etc.

Forging is the process of forming and shaping metals through the use of hammering, pressing or rolling. The process begins with starting stock, usually a cast ingot (or a "cogged" billet which has already been forged from a cast ingot), which is heated to its plastic deformation temperature, then upset or "kneaded" between dies to the desired shape and size.



How the open die forging process affects the crystal structure.

Type of forging

1. smith forging
2. drop forging
3. press forging
4. machine forging

1: Smith forging

This is the traditional forging operation done openly or in-openly dies by thevillage black smith or modern shop floor by manual hammering or by the power hammer. The process involves heating the stock in the black smith hearth and then beating it over the anvil. To get the desire shape the operator has to manipulate the component in between the blows.

The types of operation available are fullering, flattering, bending , upsetting and swaging.

2: Drop forging

This is the operation done in closed impression dies by means drop hammer here the force for shaping the component is applied in a series of blows.

Drop forging utilizes a closed impression die to obtain the desire shape of the component , the shaping is done by the repeated hammering given to the material in the die cavity. The equipment use for delivering for blows are called drop hammers. The drop forging die consists of two halves. The lower halve of the die is fixed to the anvil of the machine , while the upper halve is fixed to ram. The heated stock is kept in the lower die, while the ram delivers 4-5 blows on the metal spreads and completely fills in the die cavity. When the two die of halves closed the complete is formed. The typical products obtained in drop forging are cranks, crank shaft, connecting rods, wrench, crane hooks etc. The types of operations are fullering, edging, bending, blocking , finishing and trimming etc.

3: *Press forging*

Similar to the drop forging , the press forging is also done in closed impression dies with the expectation that the force is continuous squeezing type applied by the hydraulic press. Press forging dies are similar to drop forging dies as also the process in press forging, the metal is shaped not bymeans of a series of blows as in drop forging , but by means of a single continuous squeezing action. This squeezing is obtained by means of hydraulic presses. Because of the continuous action of by hydraulic presses, the material gets uniformly deform through out its entire depth ,the press forging dies with the various impression , such as fuller, bender and finisher impression properly arranged.

4: *Machine forging:*

Unlike the press or drop forging where the material is drawn out , in machine forging the material is only upset to get the desire shape. As it involves the upsetting operation some time it is simply called as upset forging. Originally this was develop for making bolts head in a continuous fashion, but now there are fairly large number of diverse.

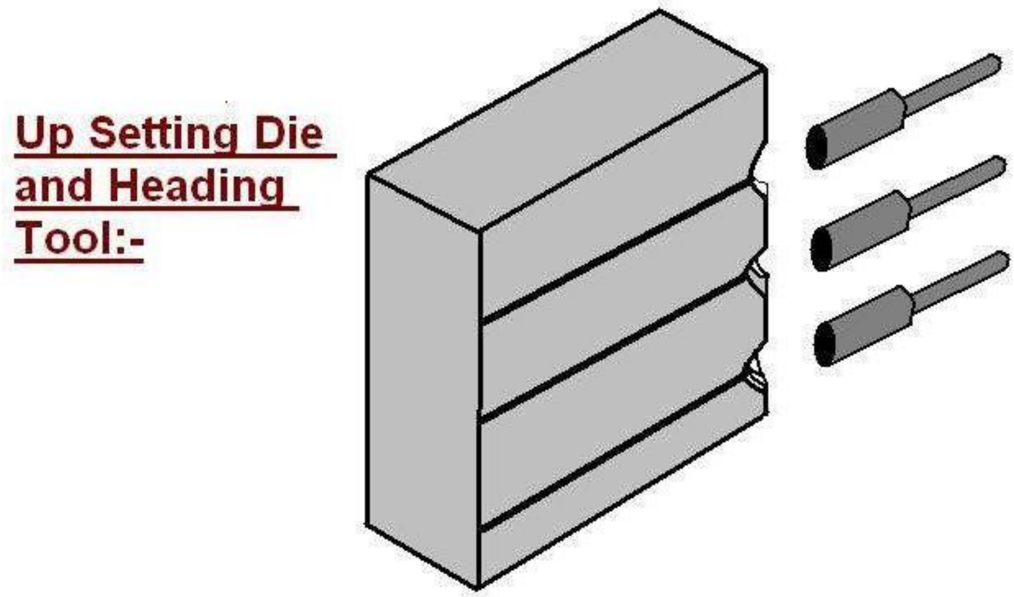
Uses of this process:

Because of the beneficial grain flow obtain from upsetting. It is used for making gears, blanks, shafts, excels, and similar parts. Upsetting machine called up setter are generally horizontal acting. The die set consists of die and corresponding punch or a heading tool. The die consists of two parts, one called the stationary gripper die which is fixed to the machine frame and the other movable gripper die which moves along with the die slide of the up setter. The stock is held then between these two gripper dies.

The upset forging cycle start with the, movable die sliding against thestationary die to grip the stock. The two dies when in closed position from the necessary die cavity then the heading tool advance against the stock and upset it to completely filled to the die cavity.

Having completed the upsetting the heading tool moves back to its back position. Then the movable gripper die releases the stock by sliding backward. Similar to drop forging it is not possible to get the final shape ina single pass in machine forging also. Therefore the operation is carried out in number of stages. The die cavities is required for the various operations are all arrange vertically on the gripper dies. The stock is the move from stage one to another in proper sequence till the final forging is ready. A heading tool each for every upsetting stage is arranged on the heading slide of the upsetting machine.

A typical upsetting die and heading tool is shown:



Forging defects:

Though forging process give generally prior quality product compared other manufacturing processes. There are some defects that are lightly to comea proper care is not taken in forging process design.

A brief description of such defects and their remedial method is givenbelow.

(A): **Unfilled Section:**

In this some section of the die cavity are not completely filled by the flowing metal. The causes of this defects are improper design of the forging die or using forging techniques.

(B): **Cold Shut:**

This appears as a small cracks at the corners of the forging. This is caused manely by the improper design of die. Where in the corner and the fillet radie are small as a result of which metal does not flow properly into the corner and the ends up as a cold shut.

(C): **Scale Pits:**

This is seen as irregular depurations on the surface of the forging. This is primarily caused because of improper cleaning of the stock used for forging. The oxide and scale gets embedded into the finish forging surface. When the forging is cleaned by pickling, these are seen as depurations on the forging surface.

(D): **Die Shift:**

This is caused by the miss alignment of the die halve, making the two halve of the forging to be improper shape.

(E): **Flakes:**

These are basically internal ruptures caused by the improper cooling of the large forging. Rapid cooling causes the exterior to cool quickly causing internal fractures. This can be remedied by following proper cooling practices.

(F): **Improper Grain Flow:**

This is caused by the improper design of the die, which makes the flow of the metal not flowing the final interred direction.