

HIGH ENERGY RATE FORMING PROCESSES

- In these forming processes large amount of energy is applied for a very short interval of time.
- Many metals tend to deform more readily under extra - fast application of load which make these processes useful to form large size parts out of most metals including those which are otherwise difficult - to - form.

- ✓ Parts are formed at a rapid rate, and thus these processes are also called high - velocity forming processes.

- ✓ There are several advantages of using these forming processes,
 - like die costs are low,
 - easy maintenance of tolerances,
 - possibility of forming most metals,
 - and material does not show spring-back effect.

- ✓ Production cost of components by such processes is low.

- ✓ Limitation of these processes is the need for skilled personnel.

There are three main high energy rate forming processes:

1. Explosive forming
2. Magnetic forming
3. Electro hydraulic forming

Explosive Forming

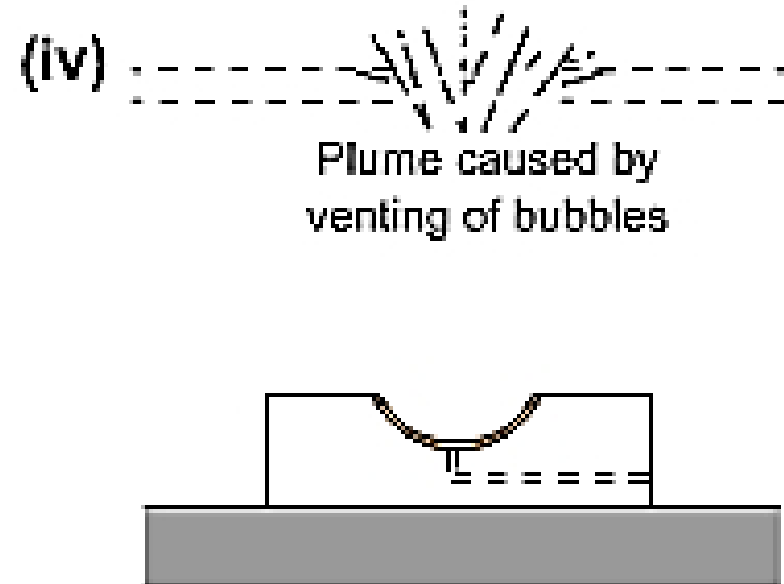
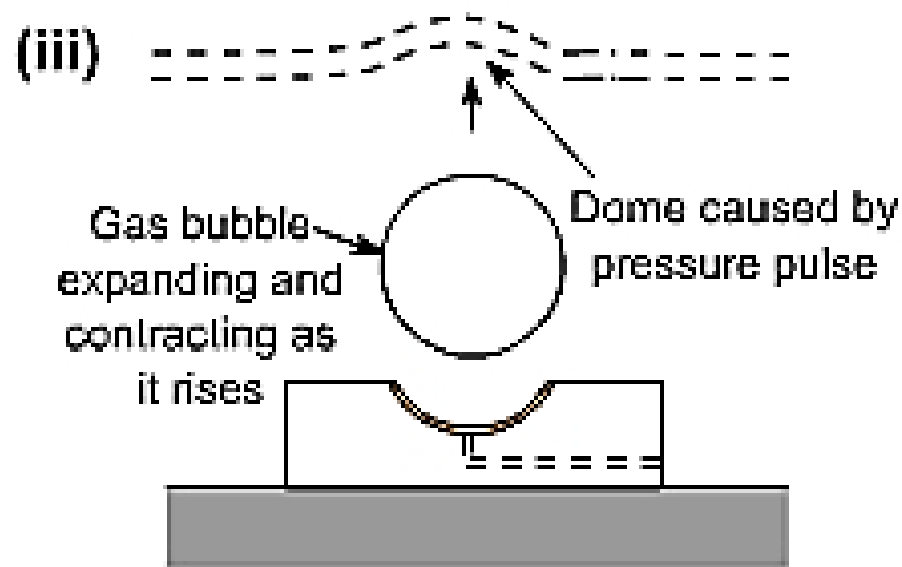
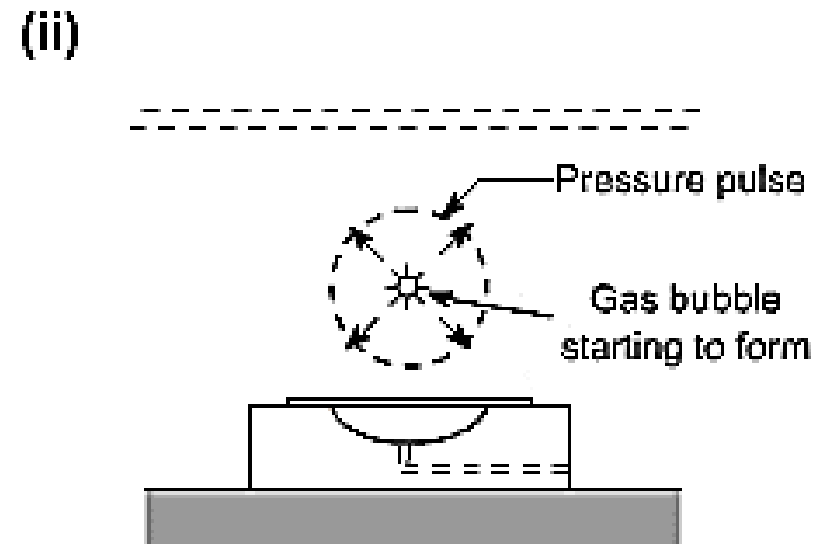
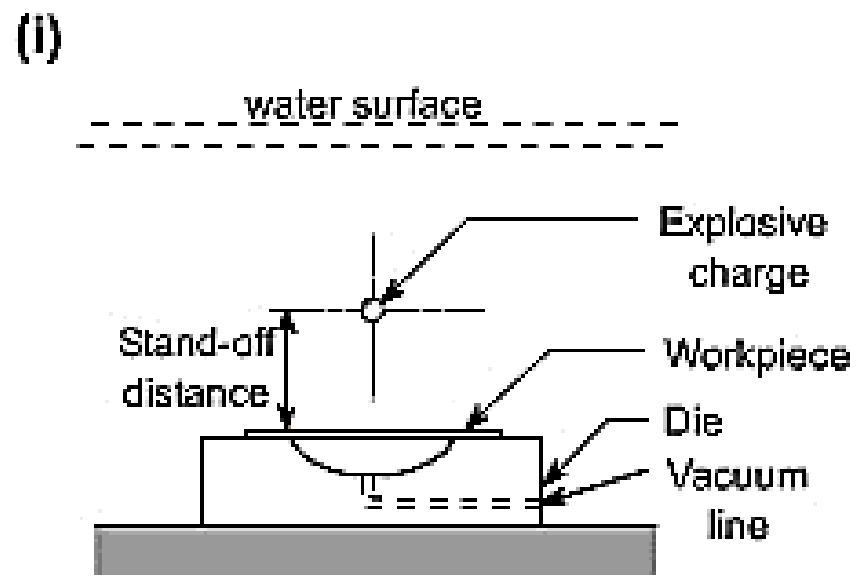
- ✓ Explosive forming, is distinguished from conventional forming in that the punch or diaphragm is replaced by an explosive charge.
- ✓ Explosives used are generally high - explosive chemicals, gaseous mixtures, or propellants.

There are two techniques of high - explosive forming:

- Stand - off technique
- Contact technique

Standoff Technique

- Sheet metal work piece blank is clamped over a die and the assembly is lowered into a tank filled with water.
- Air in the die is pumped out.
- Explosive charge is placed at some predetermined distance from the work piece.
- On detonation of the explosive, a pressure pulse of very high intensity is produced.
- Gas bubble is also produced which expands spherically and then collapses.
- When the pressure pulse impinges against the work piece, the metal is deformed into the die with as high velocity as 120 m/s.



Sequeuce of underwater explosive forming operations. (i) explosive charge is set in position (ii) pressure pulse and gas bubble are formed as the detonation of charge occurs, (iii) workpiece is deformed, and (iv) gas bubbles vent at the surface of water.

Use of water as the energy transfer medium ensures a uniform transmission of energy and muffles the sound of the explosive blast.

Process is versatile - a large variety of shapes can be formed, there is virtually no limit to the size of the work piece, and it is suitable for low - quantity production as well.

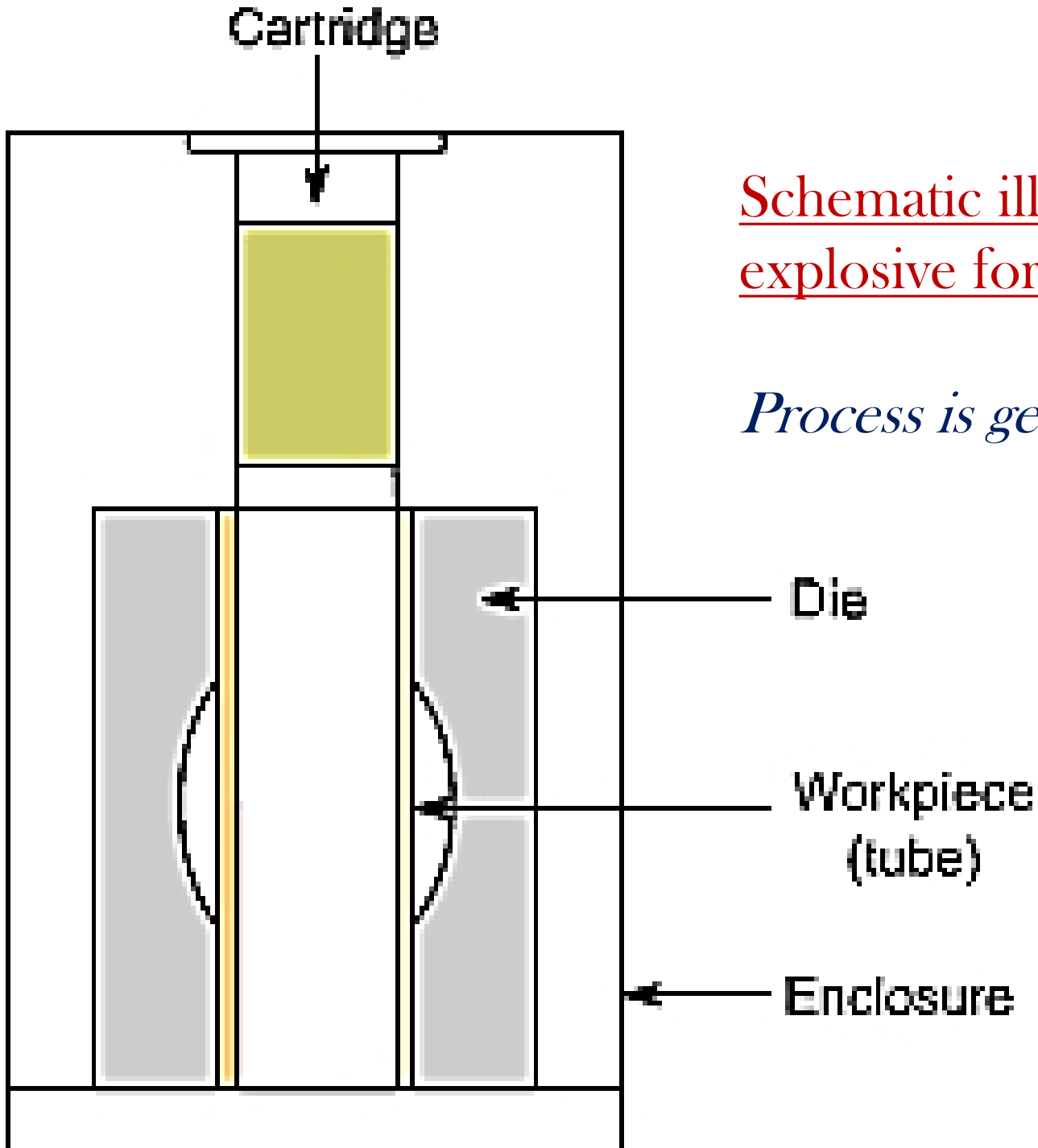
Process has been successfully used to form steel plates 25 mm thick x 4 m diameter and to bulge steel tubes as thick as 25 mm.

Contact Technique

- ✓ Explosive charge in the form of cartridge is held in direct contact with the work piece while the detonation is initiated.
- ✓ Detonation builds up extremely high pressures (upto 30,000MPa) on the surface of the work piece resulting in metal deformation, and possible fracture.
- ✓ Process is used often for bulging tubes

Schematic illustration of contact technique of explosive forming.

Process is generally used for bulging of tubes



Applications

- Explosive forming is mainly used in the aerospace industries but has also found successful applications in the production of automotive related components.
- Process has the greatest potential in limited - production prototype forming and for forming large size components for which conventional tooling costs are prohibitively high.

Explosives used can be:

- High energy chemicals like TNT, RDX, and Dynamite.
- Gaseous mixtures
- Propellants.

Factors to be considered while selecting an HERF process:

- Size of work piece
- Geometry of deformation
- Behavior of work material under high strain rates
- Energy requirements/ source
- Cost of tooling / die
- Cycle time
- Overall capital investment
- Safety considerations.

Role of water:

- Acts as energy transfer medium
- Ensures uniform transmission of energy
- Muffles the sound of explosion
- Cushioning/ smooth application of energy on the work without direct contact.

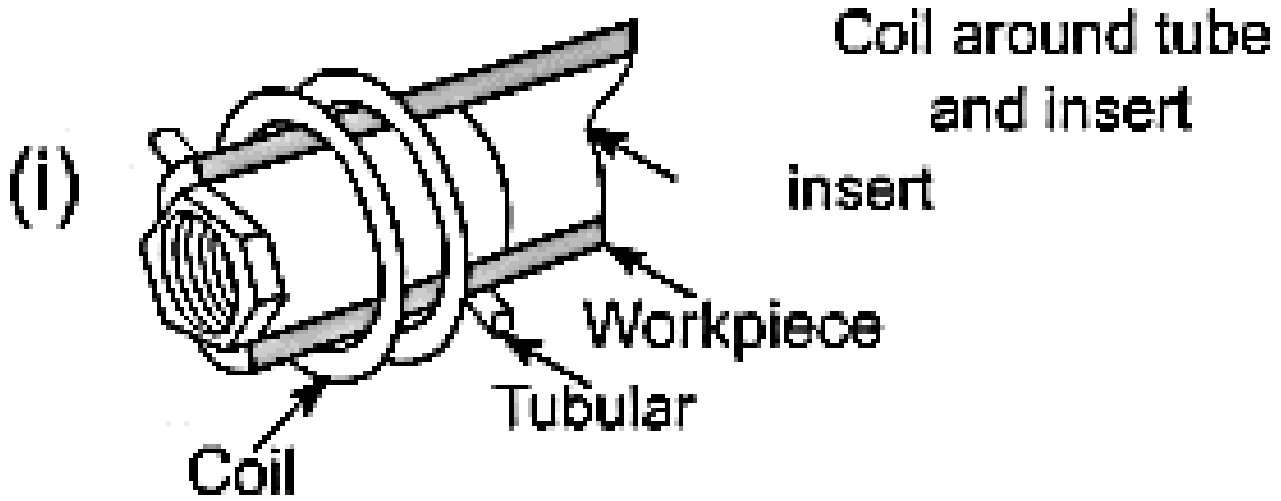
Process Variables

- ❑ Type and amount of explosive: wide range of explosive is available.
- ❑ Stand off distance - SOD- (Distance between work piece and explosive): Optimum SOD must be maintained.
- ❑ The medium used to transmit energy: water is most widely used.
- ❑ Work size
- ❑ Work material properties
- ❑ Vacuum in the die

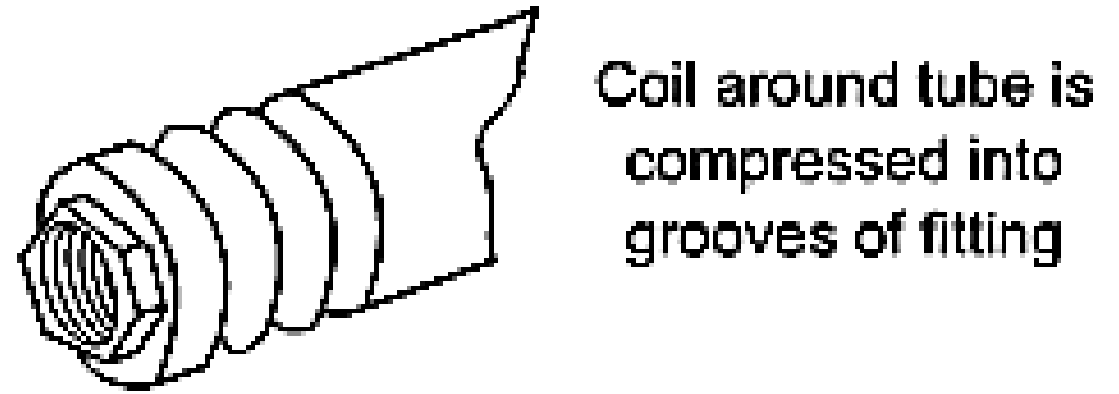
Electro Magnetic Forming

- ✓ Process is also called *magnetic pulse forming* and is mainly used for swaging type operations, such as fastening fittings on the ends of tubes and crimping terminal ends of cables.
- ✓ Other applications are blanking, forming, embossing, and drawing.

Before forming



After forming

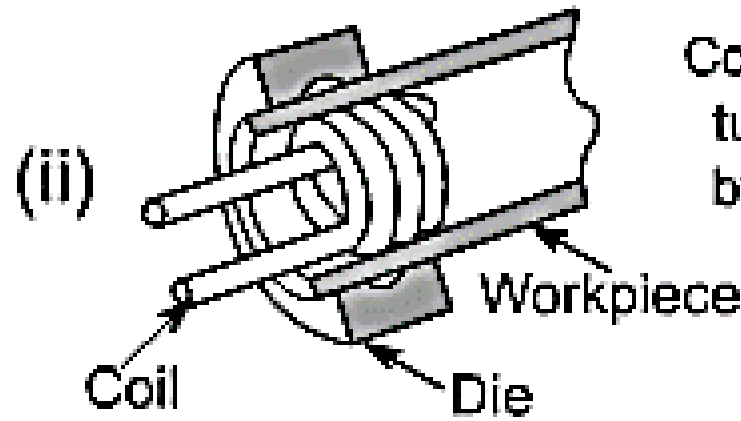


Various applications of magnetic forming process. (i) Swaging

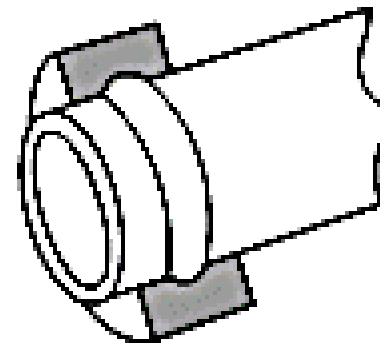
Process details/ Steps:

- The electrical energy is stored in the capacitor bank
- The tubular work piece is mounted on a mandrel having the die cavity to produce shape on the tube.
- A primary coil is placed around the tube and mandrel assembly.
- When the switch is closed, the energy is discharged through the coil
- The coil produces a varying magnetic field around it.
- In the tube a secondary current is induced, which creates its own magnetic field in the opposite direction.
- The directions of these two magnetic fields oppose one another and hence the rigidly held coil repels the work into the die cavity.
- The work tube collapses into the die, assuming its shape.

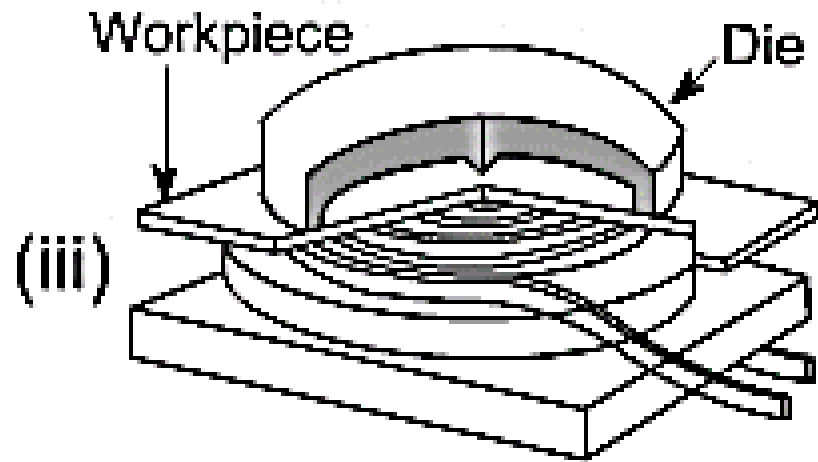
- ✓ A high charging voltage is supplied for a short time to a bank of capacitors connected in parallel. (The amount of electrical energy stored in the bank can be increased either by adding capacitors to the bank or by increasing the voltage).
- ✓ When the charging is complete, which takes very little time, a high voltage switch triggers the stored electrical energy through the coil.
- ✓ A high - intensity magnetic field is established which induces eddy currents into the conductive work piece, resulting in the establishment of another magnetic field.
- ✓ The forces produced by the two magnetic fields oppose each other with the consequence that there is a repelling force between the coil and the tubular work piece that causes permanent deformation of the work piece.



Coil inserted inside
tube surrounded
by die and insert



Tube is expanded
into die to form beading



Coil placed
under flat sheet
with die on top



Flat sheet is
formed to contours
of die

Various applications of magnetic forming process. (ii) Expanding, and (iii) Embossing or blanking.

Magnetic forming can be accomplished in any of the following three ways, depending upon the requirements.

- ❑ Coil surrounding work piece:- When a tube - like part x is to fit over another part y, coil is designed to surround x so that when energized, would force the material of x tightly around y to obtain necessary fit.
- ❑ Coil inside work piece:- Consider fixing of a collar on a tube - like part. The magnetic coil is placed inside the tube - like part, so that when energized would expand the material of the part into the collar.
- ❑ Coil on flat surface:- Flat coil having spiral shaped winding can also be designed to be placed either above or below a flat work piece. These coils are used in conjunction with a die to form, emboss, blank, or dimple the work piece.

- ❑ Either permanent or expandable coils may be used. Since the repelling force acts on the coil as well the work, the coil itself and the insulation on it must be capable of withstanding the force, or else they will be destroyed.
- ❑ Expandable coils are less costly and are also preferred when high energy level is needed.

In electromagnetic forming, the initial gap between the work piece and the die surface, called the *fly distance*, must be sufficient to permit the material to deform plastically.

- From energy considerations, the ideal pressure pulse should be of just enough magnitude that accelerates the part material to some maximum velocity and then let the part come to zero velocity by the time it covers the full fly distance.

Process parameters:

- Work piece size
- Electrical conductivity of the work material.
- Size of the capacitor bank
- The strength of the current, which decides the strength of the magnetic field and the force applied.
- Insulation on the coil.
- Rigidity of the coil.

Advantages:

- i) Suitable for small tubes
- ii) Operations like collapsing, bending and crimping can be easily done.
- iii) Electrical energy applied can be precisely controlled and hence the process is accurately controlled.
- iv) The process is safer compared to explosive forming.
- v) Wide range of applications.

Limitations:

- i) Applicable only for electrically conducting materials.
- ii) Not suitable for large work pieces.
- iii) Rigid clamping of primary coil is critical.
- iv) Shorter life of the coil due to large forces acting on it.

Applications

- It has found extensive applications in the fabrication of hollow, non - circular, or asymmetrical shapes from tubular stock.
- Compression applications involve swaging to produce compression, tensile, and torque joints or sealed pressure joints, and swaging to apply compression bands or shrink rings for fastening components together.
- Flat coils have been used on flat sheets to produce stretch (internal) and shrink (external) flanges on ring and disc - shaped work pieces.
- Electromagnetic forming has also been used to perform shearing, piercing, and rivetting.

Electro Hydraulic Forming

- ❑ Electro hydraulic forming (EHF), also known as electro spark forming, is a process in which electrical energy is converted into mechanical energy for the forming of metallic parts.
- ❑ A bank of capacitors is first charged to a high voltage and then discharged across a gap between two electrodes, causing explosions inside the hollow work piece, which is filled with some suitable medium, generally water.

- ❖ These explosions produce shock waves that travel radially in all directions at high velocity until they meet some obstruction.
- ❖ If the discharge energy is sufficiently high, the hollow work piece is deformed.
- ❖ The deformation can be controlled by applying external restraints in the form of die or by varying the amount of energy released.

ELECTRO HYDRAULIC FORMING

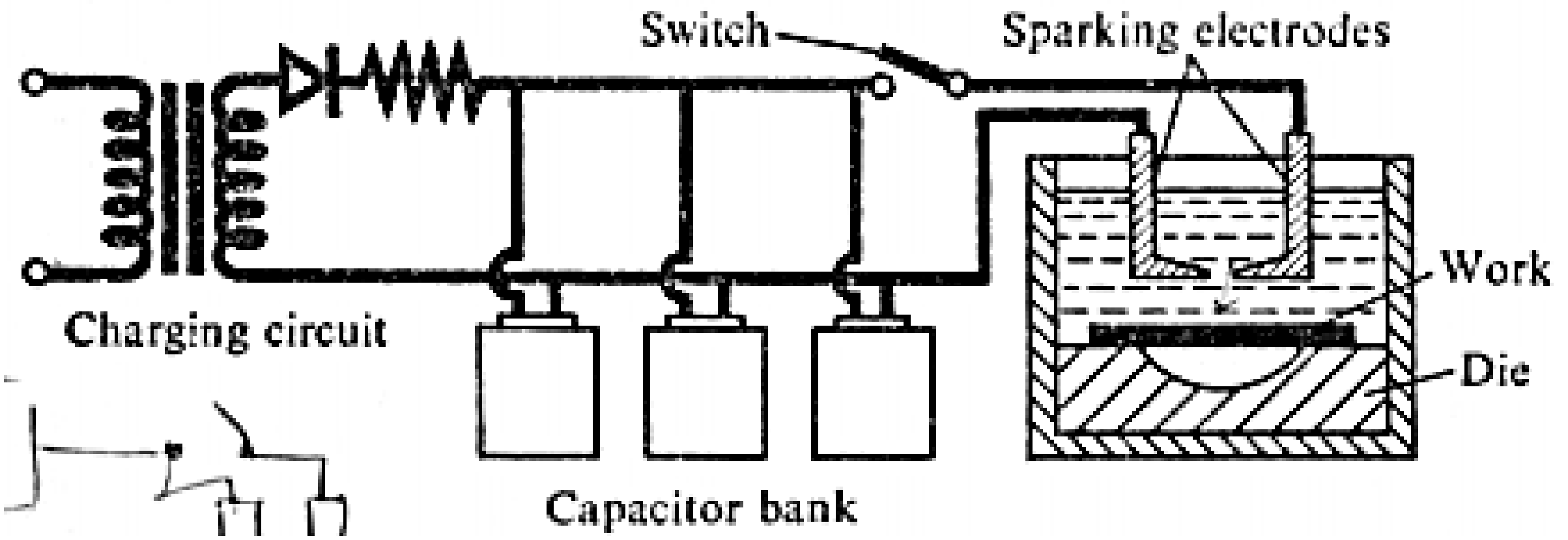
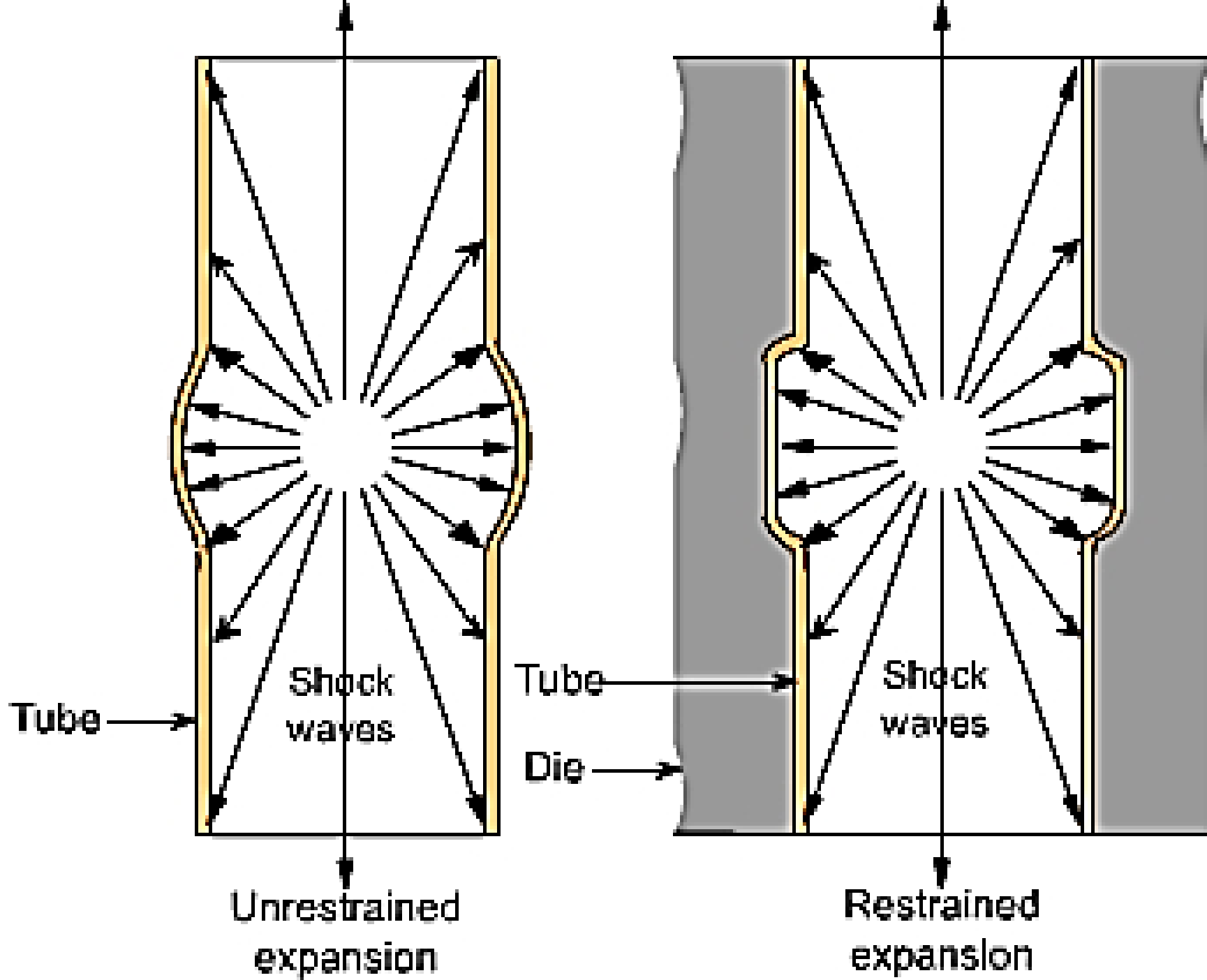


Fig. Electro Hydraulic Forming



Unrestrained and restrained electrohydraulic forming process.

Principle

A sudden electrical discharge in the form of sparks is produced between electrodes and this discharge produces a shock wave in the water medium.

This shock wave deforms the work plate and collapses it into the die.

Characteristics of this process are similar to those of explosive forming.

Major difference, however, is that a chemical explosive is replaced by a capacitor bank, which stores the electrical energy.

Capacitor is charged through a charging circuit.

When the switch is closed, a spark is produced between electrodes and a shock wave or pressure pulse is created.

Energy released is much lesser than that released in explosive forming.

Process Characteristics:

- Stand off distance: It must be optimum.
- Capacitor used: The energy of the pressure pulse depends on the size of capacitor.
- Transfer medium: Usually water is used.
- Vacuum: the die cavity must be evacuated to prevent adiabatic heating of the work due to a sudden compression of air.
- Material properties with regard to the application of high rates of strain.

Advantages

- ✓ EHF can form hollow shapes with much ease and at less cost compared to other forming techniques.
- ✓ EHF is more adaptable to automatic production compared to other high energy rate forming techniques.
- ✓ EHF can produce small - to intermediate sized parts that don't have excessive energy requirements.

- ✓ Better control of the pressure pulse as source of energy is electrical- which can be easily controlled.
- ✓ Safer in handling than the explosive materials.
- ✓ More suitable if the work size is small to medium.
- ✓ Thin plates can be formed with smaller amounts of energy.
- ✓ The process does not depend on the electrical properties of the work material.

Limitations:

- Suitable only for smaller works
- Need for vacuum makes the equipment more complicated.
- Proper SOD is necessary for effective process.

Applications:

- They include smaller radar dish, cone and other shapes in thinner and small works.

Accuracy of parts produced

- ❑ Accuracy of electro hydraulically formed parts depends on the control of both the magnitude and location of energy discharges and on the dimensional accuracy of the dies used.
- ❑ External dimensions on tubular parts are possible to achieve within ± 0.05 mm with the current state of technology.

Materials formed

- ❖ Materials having low ductility or having critical impact velocity less than 30 m/s are generally not considered to be good candidate for EHF.
- ❖ All materials that can be formed by conventional forming processes can be formed by EHF also.
These materials are aluminum alloys, nickel alloys, stainless steels, titanium, and Inconel 718.

ADVANTAGES OF HRF

- ❑ Production rates are higher, as parts are made at a rapid rate.
- ❑ Die costs are relatively lower.
- ❑ Tolerances can be easily maintained.
- ❑ Versatility of the process – it is possible to form most metals including difficult to form metals.
- ❑ No or minimum spring back effect on the material after the process.

- ❑ Production cost is low as power hammer (or press) is eliminated in the process. Hence it is economically justifiable.
- ❑ Complex shapes / profiles can be made much easily, as compared to conventional forming.
- ❑ The required final shape/ dimensions are obtained in one stroke (or step), thus eliminating intermediate forming steps and pre forming dies.
- ❑ Suitable for a range of production volume such as small numbers, batches or mass production

The forming processes are affected by the rates of strain used.

Effects of strain rates during forming:

1. The flow stress increases with strain rates
2. The temperature of work is increases due to adiabatic heating.
3. Improved lubrication if lubricating film is maintained.
4. Many difficult to form materials like Titanium and Tungsten alloys, can be deformed under high strain rates.

Principle / important features of HERF processes:

- The energy of deformation is delivered at a much higher rate than in conventional practice.
- Larger energy is applied for a very short interval of time.
- High particle velocities are produced in contrast with conventional forming process.
- The velocity of deformation is also very large and hence these are also called High Velocity Forming (HVF) processes.
- Many metals tend to deform more readily under extra fast application of force.
- Large parts can be easily formed by this technique.

- For many metals, the elongation to fracture increases with strain rate beyond the usual metal working range, until a critical strain rate is achieved, where the ductility drops sharply.
- The strain rate dependence of strength increases with increasing temperature.
- The yield stress and flow stress at lower plastic strains are more dependent on strain rate than the tensile strength.
- High rates of strain cause the yield point to appear in tests on low carbon steel that do not show a yield point under ordinary rates of strain.

LIMITATIONS OF HERF

- Highly skilled personnel are required from design to execution.
- Transient stresses of high magnitude are applied on the work.
- Not suitable to highly brittle materials
- Source of energy (chemical explosive or electrical) must be handled carefully.
- Governmental regulations/ procedures / safety norms must be followed.

- Dies need to be much bigger to withstand high energy rates and shocks and to prevent cracking.
- Controlling the application of energy is critical as it may crack the die or work.
- It is very essential to know the behaviour or established performance of the work metal initially

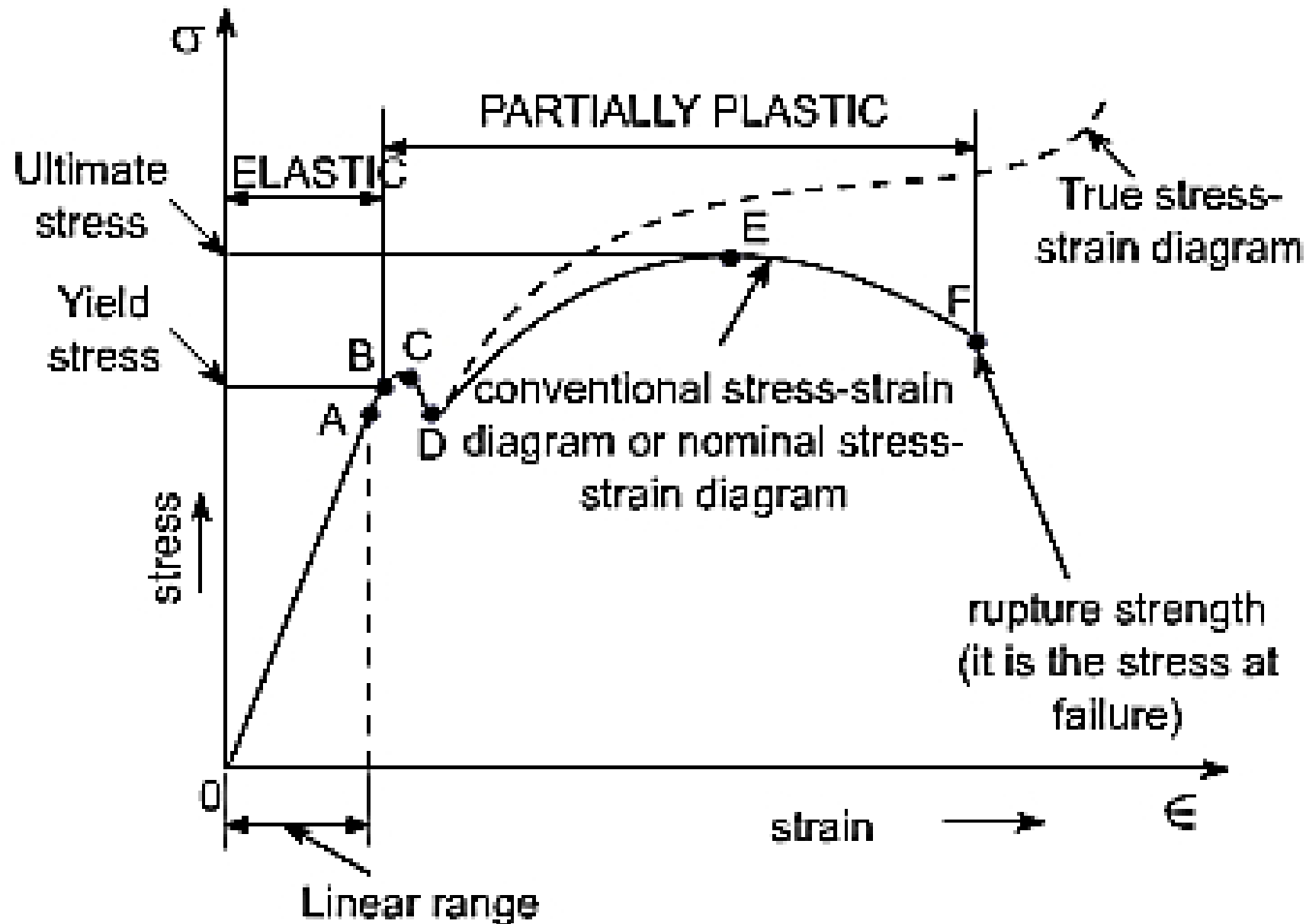
Applications:

- In ship building - to form large plates / parts (up to 25 mm thick).
- Bending thick tubes/ pipes (up to 25 mm thick).
- Crimping of metal strips.
- Radar dishes
- Elliptical domes used in space applications.
- Cladding of two large plates of dissimilar metals.

EFFECT OF HIGH SPEED ON STRESS - STRAIN RELATIONSHIP

- ❑ Yield strength and resistance to deformation increase with strain rate
- ❑ At ambient temperature, general level of the stress strain curve is higher when the load is applied rapidly than when it is applied slowly
- ❑ Yield stress of several types of mild steel gets increased under rapid loading

STRESS STRAIN CURVE OF Mild Steel



COMPARISON OF CONVENTIONAL AND HIGH VELOCITY FORMING

- Comparison in deformation velocity
 - Velocities of conventional machines are usually lower by the order of 10^3 as compared to high velocity forming system.
 - In HVF, velocity ranges from 3 to 300 m/sec and in conventional machine velocity ranges from 0.03 to 9 m/sec

- Comparison in strain distribution

- Strain distribution is much more uniform in a single operation of HVF.
- It is easy to produce complex shapes without inducing unnecessary strains in the material
- In HVF, strains required to failure are much higher as compared to conventional process.
- Ductility obtained is more.

STRESS WAVES

Any material, when it is subjected to a load, stress induced in it is transmitted as waves which travel at a finite velocity and is equal to speed of sound within the material

Two types of waves in metal forming are

- Elastic waves
- Plastic waves

Further divided into two types

- Longitudinal waves
- Transverse waves or shear waves

In plastic waves propagation,

C = Velocity of wave propagation

$$= \sqrt{\frac{\frac{d\sigma}{d\varepsilon}}{\rho}}$$

ρ - mass density of the metal

$\frac{d\sigma}{d\varepsilon}$ - slope of engineering stress strain diagram

For many metals, the stress strain curve is less in the plastic range than in the elastic range. Thus the velocity of plastic wave propagation is less than that for elastic waves.

Velocity of propagation of longitudinal and transverse waves depend on the following factors

- Elastic constant
- Density of material to be deformed.

Velocity of longitudinal wave,

$$V_L = \frac{2K\sqrt{(1-\nu)}}{\rho(1+\nu)}$$

K - Bulk modulus of material

ρ - Density of material

ν - Poisson's ratio

Velocity of shear wave,

$$V_t = \sqrt{\frac{G}{\rho}}$$

G - Shear modulus