Shaping by plastic deformation

I.1 Introduction

The deformation consists in plastically deforming the material until the desired shape is obtained. A plastic deformation is a permanent deformation of the material. The production processes by deformation comprise all the techniques for shaping the materials in the solid state by plastic deformation. There are several techniques that can be classified into two different categories.

- The first category comprises techniques which are carried out hot, i.e. at a temperature below the melting point of the material. They mainly apply to the shaping of solid parts.
- The second category brings together all the other techniques operating at ambient temperature, it is said that the work is carried out cold. There are two kinds of pieces, thin and massive.

In the context of hot shaping, the purpose of heating the material is to lower the elastic limit so that the material becomes more malleable with less intense forces. This allows greater deformation amplitudes without risk of rupture.

I.2 Principle

Basic principle

A force (traction, compression, flexion, torsion) is applied to deform the material beyond its point of elastic deformation, making it malleable.

I.3 Shaping techniques by plastic deformation

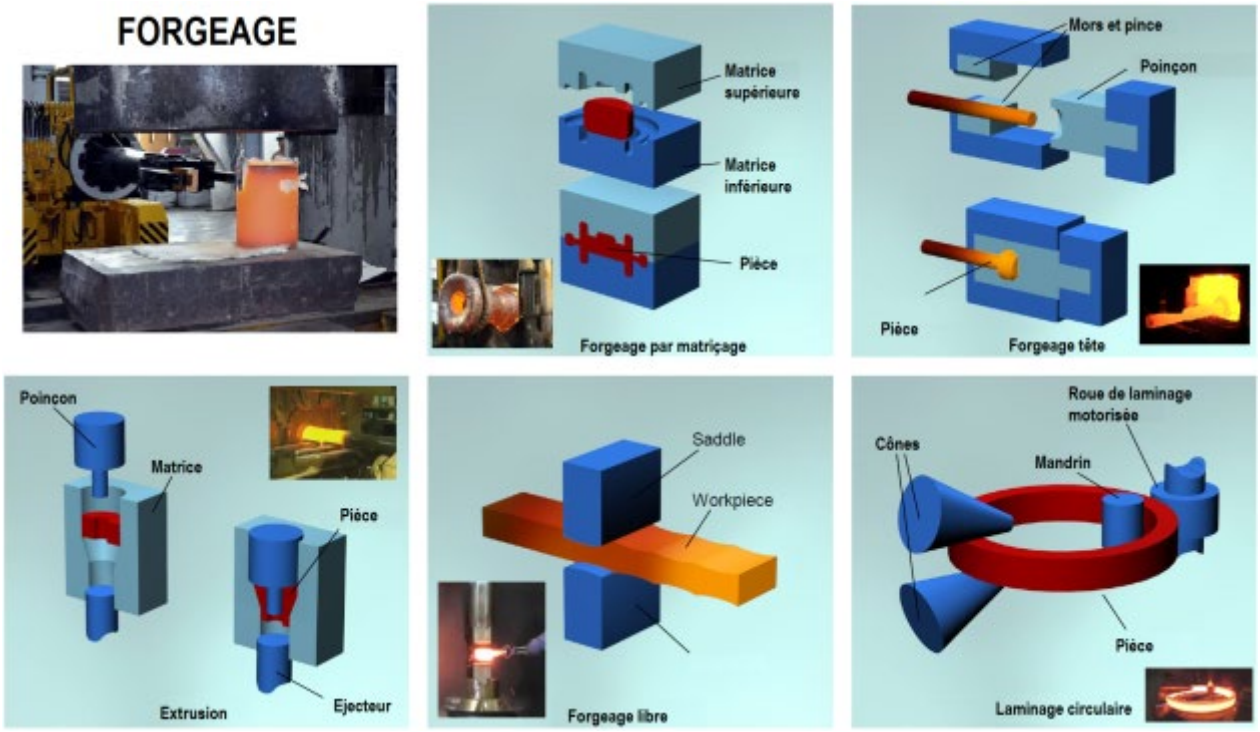
Several parts shaping techniques can be distinguished. FIG. 1.

I.3.1 Forgeage: Hewing of rooms as bolts and nuts by beating or pressing. Forgeage is used to fabricate resistant mechanical rooms, Forging is the set of techniques used to obtain a mechanical part by applying a large force to a metal bar, cold or hot, in order to force it to adopt the desired shape.

Forging comprises several techniques, such as free forging, cold forging (or extrusion forging), forging by stamping, forging by stamping, and finally forging by rolling.

1. **Free forging without matrix**: forging a piece using standard tools. The form is given by the know-how of the operator.
2. **Forging by die-forming**: crushing forging between tools (dies) of specific shape.
3. **Cold striking or forging**: shaping at room temperature or with slight preheating.

Other deformation processes include delivery, which consists in compressing the ends of machine wires within cavities to form, for example, a bolt, and extrusion for the manufacture of cylindrical products and pipes.



I.3.1.1 Free forging

Free forging is the oldest technique: it is carried out hot either manually, by striking the metal placed on an anvil with a hammer or a pestle, or with the aid of a powerful hydraulic press. Thus, blanks or rough mechanical parts are obtained which are ready to be machined and whose strength is improved by the forging process. It is a technique that makes it possible to produce small series or pieces individually, because it requires few tools.

I.3.1.1.1 Characteristics of free forging

The final shape of the part is obtained by a succession of progressive deformations requiring only a low energy expenditure per unit area, from simple tools.

Two Types of parts made:

- Small series of 1 to 10 pieces whose cost of stamping tools would result in a high unit price.
- Large parts (100kg to 500T) can only be made using this technique. The shapes obtained are less complex than in stamping.

Advantages of forging

- Little loss of material.
- Parts stronger than moulded or machined parts.
- Reduced machining time compared to a fully machined workpiece.
- Grain ripening.
- Production of monoblock parts.
- Improvement of the mechanical characteristics (respect of the drawing).
- Parts under heavy stress.

Disadvantages of forging

- Hot forging prevents hardening by cold working and increases the difficulty of carrying out machining operations.
- Large amounts of energy are involved.
- Low productivity, a delay in the manufacture of moulds that can be significant depending on the complexity.
- Tolerances and surface finish of forged parts are no better than in machining in addition to the high costs associated with the process.

Examples of forged parts for different materials:

Composants médicaux (articulations de la hanche) en titane

Carter en aluminium d'automobile

Pales de turbine résistantes à la chaleur en alliages de nickel

Bielles pour moteurs de camions en acier

I.3.2 Rolling process

The term "rolling" generally refers to an industrial manufacturing process in which a material is passed between cylinders in order to reduce its thickness and increase its length. For metals, a distinction is made between hot rolling (deformation at high temperature) and cold rolling (deformation at ambient temperature).

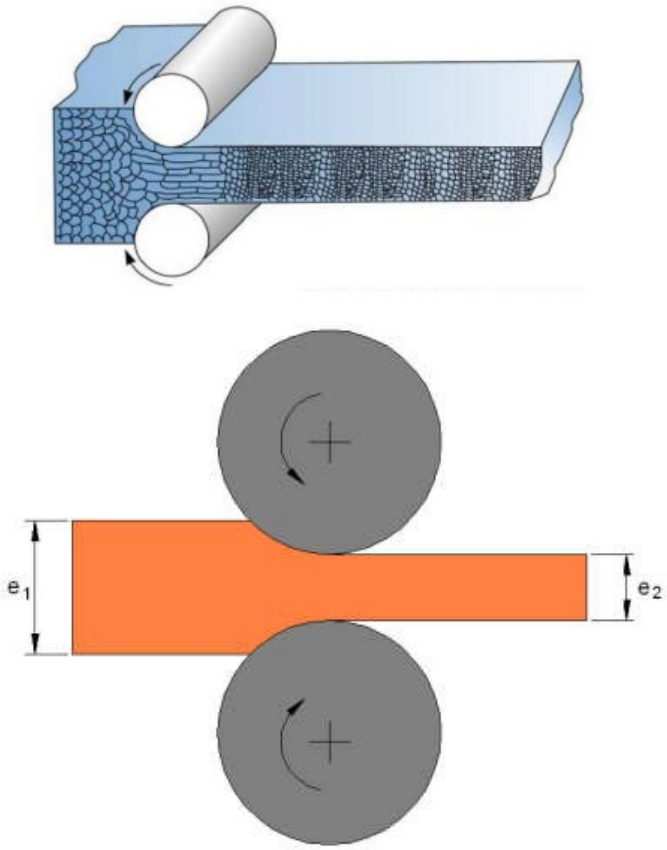


Fig.1 Rolling process

I.3.2.1 Rolling mill characteristics

A rolling mill is characterized by different elements:

- Geometric: cylinder dimensions, maximum spacing
- Mechanical: rolling force, speed
- Energy: drive power, torque

The rolling force or pressure F (N) which the rolling mill must withstand by reaction during deformation of the metal is given by the approximate formula:

$$F = kl\sqrt{D(E-e)/2}$$

k: resistance to deformation (N/mm2)

l: product width (mm)

E: thickness of the product at the inlet, *e*: thickness at the outlet (mm)

D: diameter of working cylinders (mm)

The rolling power can be deduced as an order of magnitude from the rolling torque C (N.m) per cylinder:

$$C = F \,.\, a$$

a (m): distance from the point of application of the resultant forces to the axis of the cylinder. The total power *P* (W) for two cylinders from the rotational speed N in (rpm) is:

$$P = 4\pi\, a\, FN/\, 60$$

The real power is greater than this approximation, in particular in the cold rolling of thin products. The bearings can absorb 10 to 20% of the total power. The installations reach a power of 15,000 kW.

Cold rolling increases the strength and hardness of the steel and reduces its ductility (i.e. its capacity to deform plastically in a lasting manner without breaking), and it is therefore necessary to subject it to a process called annealing.

I.3.2.2 Hot rolling

Hot rolling is a process for forming metals (mainly steel) at high temperatures, generally above 926 ° C, which makes it easier to flatten and model them.

Fig.2 Hot rolling

Hot rolling allows a wide variety of shapes and parts, as well as the possibility to manufacture large parts without worrying about the integrity of the material. This is why hot-rolled steel is often used in structural projects.

I.3.2.3 Mechanical properties

The mechanical properties of steel often depend on its **chemical composition**. For this reason, it is never reliable to make assumptions about the mechanical properties of hot rolling with respect to cold rolling unless their chemical composition is the same.

If we start from the **composition of 1018 carbon steel**, which is one of the most common, we can see that there are key differences between cold rolling and hot rolling.

	Hot rolling	Cold rolling
Tensile strength	67,000 psi	85,000 psi
Elastic limit	45,000 psi	70,000 psi

Volumetric reduction	58	55
Stretching in 2 ″	36	28
Brinell hardness	137	167

I.3.2.4 Appearance

A **hot-rolled steel piece** has a rough surface, without greasy touch and rounded edges.

A **cold-rolled steel piece** has a smooth surface, a greasy feel to the touch and sharp edges.

I.3.2.5 Benefits

Hot-rolled steel, having a higher tolerance, allows greater **malleability**, while cold-rolled steel is limited to certain limited shapes, such as flat, square and round.

I.3.3 Stamping

I.3.3.1 Definition

The stamping of metal parts consists in giving a determined shape to a metal part by applying it to a die. This t**ransformation** technique makes it possible to produce parts of complex shapes from metal coils.

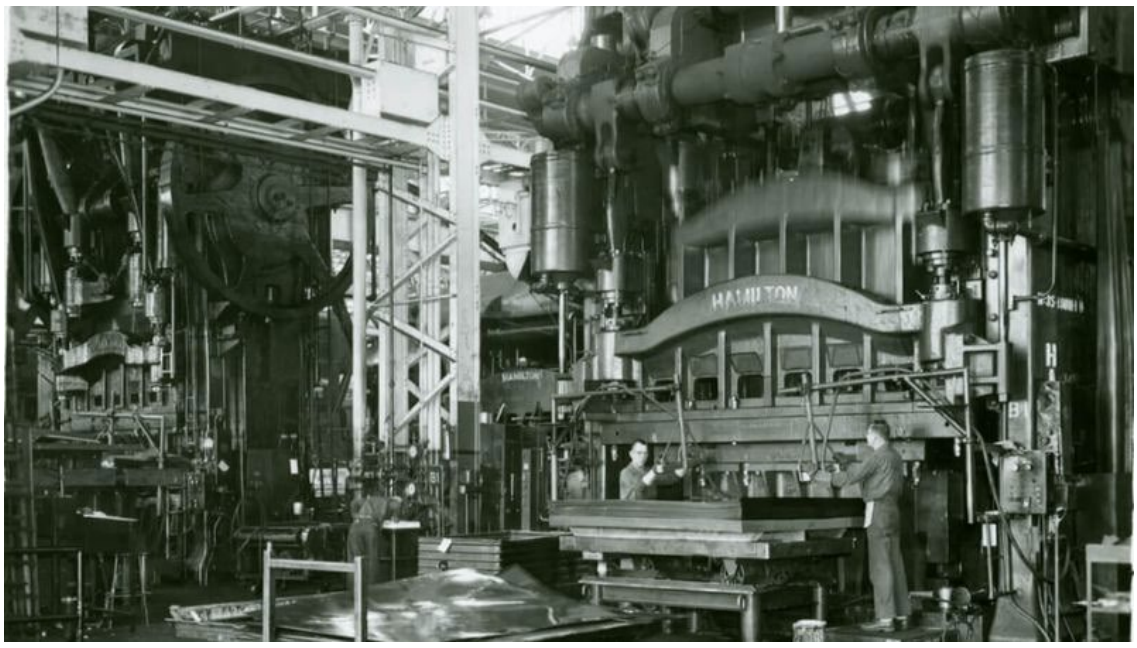


FIG. 1 Metal stamping in the past

The aim of this process is to produce metal parts with specific shapes, designs and dimensions.

The products are manufactured accurately and with a low tolerance. Moreover, is profitable and mass production is possible in a shorter time.

I.3.3.2 Stamping operation

The operation consists of five main stages.

- Tool design: The stamping process begins with the design of the tool or metal mould. CAD software makes it possible to produce precise and complex designs. The next step is manufacturing. Metal **stamping matrix** with a CNC machine and laser cutting.
- Preparation of the material: A sheet suitable for the application and the manufacturing method is selected. It is then cut into shorter lengths to facilitate handling. A metal coil is used for progressive stamping.
- Power supply: The machines and parameters are set. The sheet is then introduced into the automated workstation.
- Stamping operation:This operation consists in applying a high pressure on the sheet to deform it. Several stamping operations can be carried out on the sheet according to the request.
- Finishing and post-treatment: The last step is dedicated to heat treatment or surface treatment of the **stamped part**, if necessary.

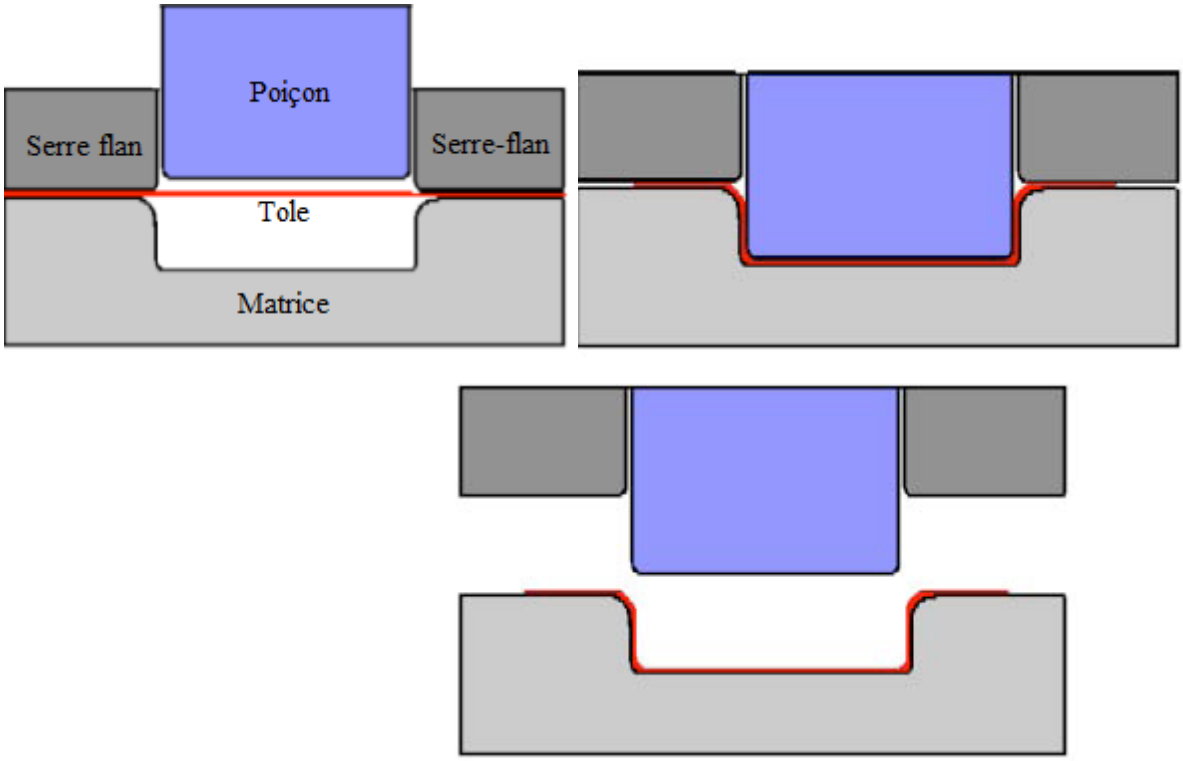


Fig.2 Phases (03) of the stamping operation

I.3.4 Extrusion, spinning

Extrusion is a manufacturing process that involves pushing a material (plastic, metal, food, etc.) under pressure through a die to give it a continuous shape. This process, often carried out hot, makes it possible to produce semi-finished products of various shapes and is used in many industrial sectors.

This shaping method makes it possible to obtain long products, such as bars and tubes**. FIG. 1**, or more parts of complex shapes (profile for aeronautics, for example).

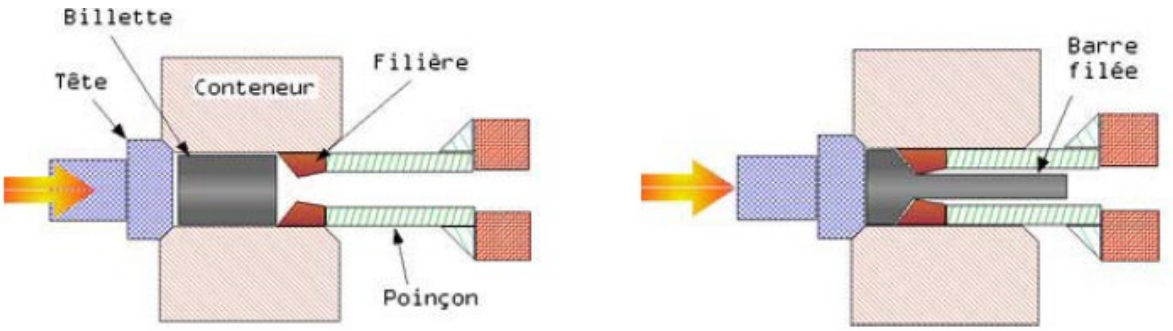


FIG. 1 spinning process

I.3.4.1 General steps in the process

1. **Power supply to the machine**

   The raw material, often in the form of granules, powder or paste, is introduced into a hopper.

2. **Formatting**

   The material descends by gravity into a sheath where an endless screw transports, heats and mixes it into a homogeneous and malleable mass.

3. **Pressure passage**

   The screw pushes the material through an extrusion head provided with a die (a mold) which gives it the desired shape.

4. **Conditioning**

   After extrusion, the product can be cooled, calibrated, stretched, cut and laser marked, depending on the application.