CHAPTER II. Processes for obtaining parts without material removal

II.1 Introduction

Since forming processes have a direct impact on the morphological and mechanical characteristics of parts, it is necessary to understand their physical and technological principles in order to design our products effectively.

The choice of forming process depends on the material selected and the product characteristics.

Each process is specific to a family of materials and imposes its own rules for tracing. Similarly, the characteristics of the parts may dictate the process to be used.

II.1 Main processes for shaping metallic materials

There are three main methods of shaping depending on the initial state of the metal material:

- ❖ **Casting** from a liquid state, covered in the section on Foundry and volume casting Metal shaping and foundry;
- ❖ **Shaping** from one or more solid parts. This method can itself be divided into forming, or shaping without removing material, machining, or shaping with removal of material, the main aspects of which are presented in the Machining volume of the Mechanical Engineering treatise, where two or more parts are joined together using the processes presented in the Materials Processing volume.
- ❖ **Sintering** from powders by removing intergranular voids at high temperature and possibly under pressure.

Due, among other reasons, to the socioeconomic classification of the corresponding industrial sectors, we distinguish between the following types of forming:

- ❖ **Working with metals in their solid state**, practiced mainly in the metallurgical and manufacturing industries, and covered, along with sintering, in the volumes on metal forming and foundry work;

- **Sheet metal working**, practiced like machining in the mechanical industries and covered in the volume.

II.2. Processes for obtaining parts without material removal

II.2.1. Molding

The principle behind these processes is to pour the material in a liquid or paste-like state into a mold, and after solidification, open or destroy the mold in order to retrieve the part. Any type of material (plastic, metal, resin) can be molded.

These processes require the creation of a mold and are therefore reserved for mass production, but rapid prototyping techniques can be used to optimize the use of these processes. Molds can be:

- **Permanent:** In this case, the mold is made up of several parts and opens to release the part.
- **Non-permanent:** In this case, the mold is destroyed to recover the part. Depending on the material to be molded and the number of parts required, molds are made of silicone, plaster, sand, or steel.

Certain processes using lost models enable the production of high-precision, highly complex parts. Casting is the most commonly used technique because it is not only economical but also:

- It enables the production of complex shapes (which are difficult to achieve through machining or other processes).
- The series of parts is identical.
- It can be used to produce solid parts such as frames, flywheels, etc.

II.2.1.1. Non-permanent molding (sand casting)

Silica-clay sand casting is one of the most common processes. It remains the most economical due to the simplicity of sand regeneration.

The binder used to make the mold is usually a bentonite-type clay.

Green sand molding generally uses a permanent pattern and a non-permanent mold. A non-permanent mold is a mold that is used only once to produce a part.

Notes on casting:

- The melting point of the molten metal must be lower than the melting point of the material used to make the mold.
- A metal mold is called a “shell.”
- Casting is an economical way to produce complex parts.
- Cast iron is easier to mold than steel. Molten cast iron is more fluid than molten steel.

The stages of molding:

1. Melt the metal

2. Pour it into the mold

3. Leave it to cool.

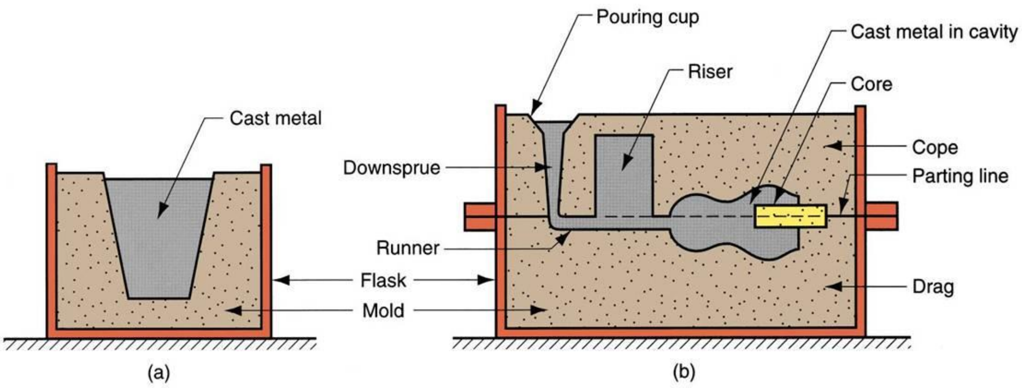


Figure 1. Sand mold

II.2.1.2. Permanent molding

A reusable mold is used for permanent mold casting. The advantages of this process include the following:

- Components close to the ribs;
- Better surface finish;
- Improved mechanical properties.
- Finished products will not have fine details.

In permanent mold casting, a reusable mold is made from metal, usually gray cast iron. It is constructed from
two or more pieces and has a hinge so that the casting can be removed from the mold. The liquid metal is poured into the mold by gravity. Permanent mold casting is used to produce castings from aluminum, magnesium, and copper alloys. Steel and iron parts can be cast in graphite molds.
The terms permanent mold casting and shell casting are often used to refer to the same process.

The molds are made of metal (cast iron or special refractory steels) and can be used to cast a large number of parts. The following processes are distinguished:

- Gravity shell casting;
- Centrifugal casting;
- Die casting.

a- Gravity dies casting:

The die is a metal mold that has the exact shape of the part to be produced. Cooling is rapid.

Advantages of the process

- Excellent material properties;
- Ability to represent complex internal geometries (using a sand core)
- Low tooling costs compared to die casting;
- High degree of automation possible.

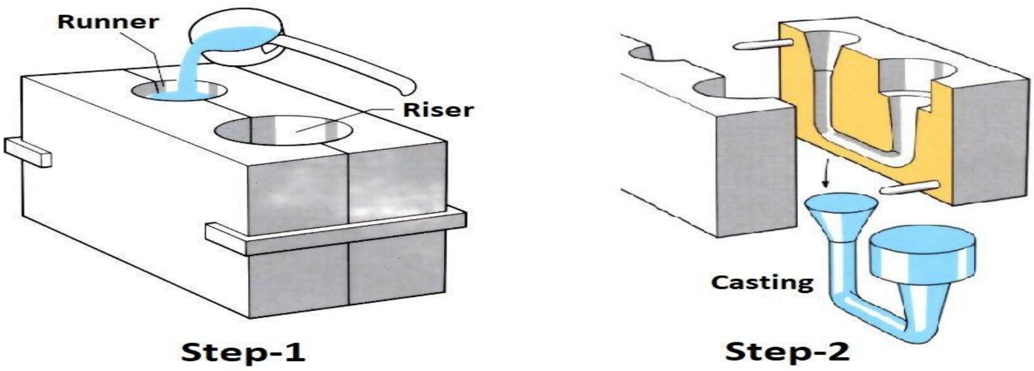


Figure 2. Gravity dies casting

b-Centrifugal casting:

Centrifugal casting uses centrifugal force to create cylindrical shapes. The process uses a permanent mold that is rotated at high speeds (300 to 3,000 revolutions per minute) while molten metal is poured into it. The molten metal is thrown by centrifugal force toward the mold wall. The metal solidifies on the wall after cooling. Used to manufacture pipes or parts with complex shapes of revolution.

Advantages of the process

- Wear resistance;
- High structural uniformity;
- Good mechanical properties.

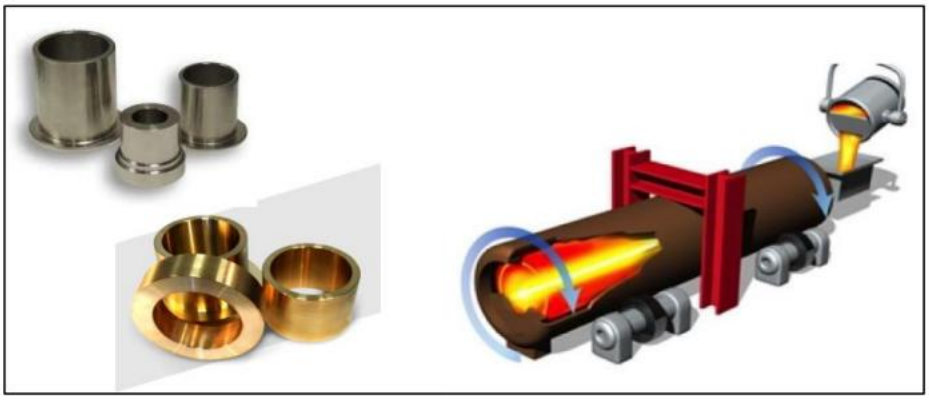


Figure 3. Centrifugal casting

c-Die casting:

(up to 1500 bar) by injecting liquid or paste-like metal into a cold or slightly heated metal mold. This process is used for the mass production of small parts. It is also used to produce large steel plates;

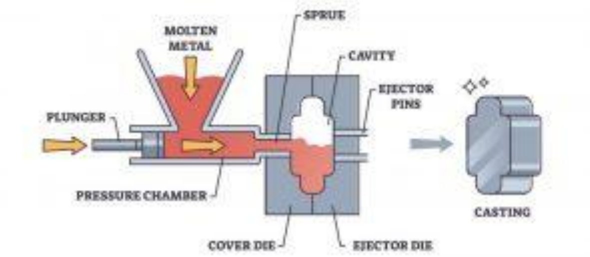


Figure 4. Die casting

Advantages of the process

- Dimensional accuracy;
- Low machining allowance;
- Thin walls;
- High strength;
- Good surface quality;
- High productivity through high automation;
- Density, as the casting membrane is not machined.

II.2.2. Forging

In general terms, forging is the process of shaping malleable metal.

This process is based on a fundamental property of solid metal alloys: plasticity.

The fundamental parameter of the process is the forging temperature, which must be greater than 0.5 times the melting temperature of the metal being worked.

Another important parameter is the forming force, which also depends on T_f.

These parameters depend on the characteristics and quality of the product to be manufactured, for example: dimensional tolerances, surface finish, metallurgical structure, etc.

There are two main forging techniques:

There are two types of forging techniques:

a- Hand forging (blacksmithing)

b- Mechanical or industrial forging

The various forging techniques all involve compressing a material between tools using a machine that provides the energy required for the operation.

Process selection criteria

- Material: Ferrous, non-ferrous
- Type of part to be produced: weight, complexity, precision
- Size of production run: large, small, or medium

- Machines to be used: presses (mechanical, hydraulic, or screw), rolling mills, etc.

c-Free forging

This process allows single parts or very small batches to be produced hot, without specific tools and with short lead times. The metal, which has been preheated, is worked in the form of a metal blank using a hydraulic press or even a drop hammer.

Forging is called "free" because, during forging, the metal is free to move in several directions, unlike stamping or die forging, where the metal is enclosed in a predefined shape and is not free. The metal is therefore crushed between two tools:

- The die (or sub-die), which is fixed and flat in shape,
- The punch (or die), which is movable

The result obtained depends on the skill of the blacksmith.

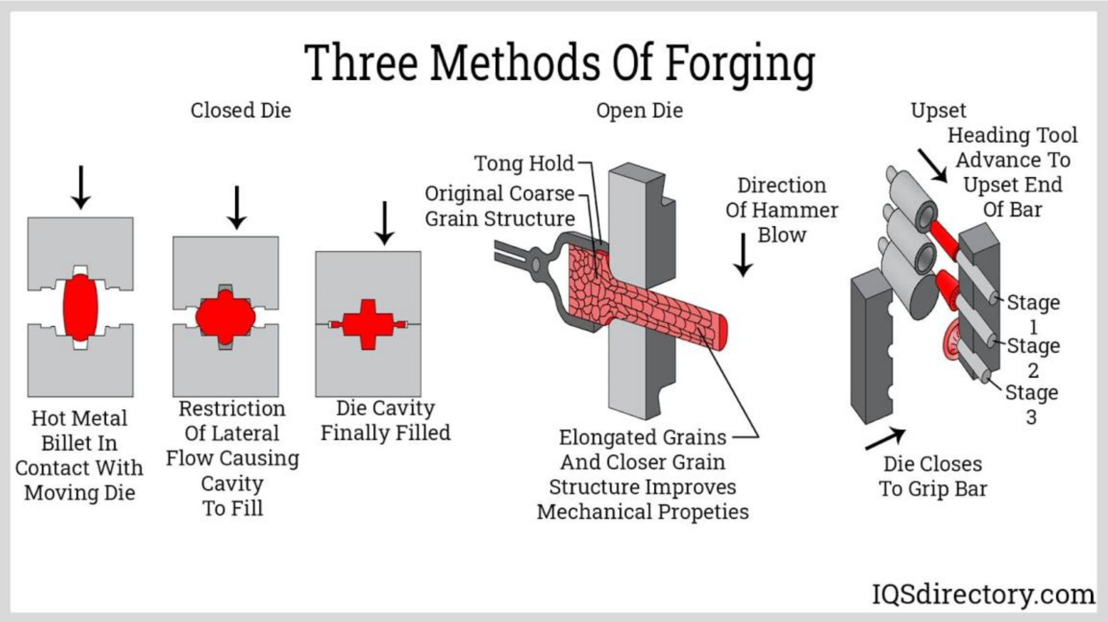


Figure 5. Principle of open-hearth forging

II.2.3. Deep drawing

Deep drawing is a forming process widely used in industry, enabling parts with non-developable surfaces to be obtained from sheets of thin sheet metal mounted on a press. The sheet metal, known as the "blank," is the raw material that has not yet been stamped. The operation can be performed with or without a blank holder to hold the blank against the die while the punch deforms the sheet.

General design of a stamping tool:

Stamping is carried out using high-powered stamping presses equipped with special tools whose configuration determines the effect obtained on the blank:

- Single-action tools: the simplest configuration, consisting mainly of a die and a punch.
- Double-acting tools: in addition to the single-acting tool, include a blank holder.

The tools used in stamping therefore include:

- ❖ A concave die that matches the outer shape of the part;
- ❖ A punch, in relief, which matches its internal shape while reserving the thickness of the sheet metal
- ❖ A blank holder surrounds the punch, is applied against the perimeter of the die and is used to clamp the sheet metal during the application of the punch, preventing the sheet metal from wrinkling and controlling its flow along the punch.

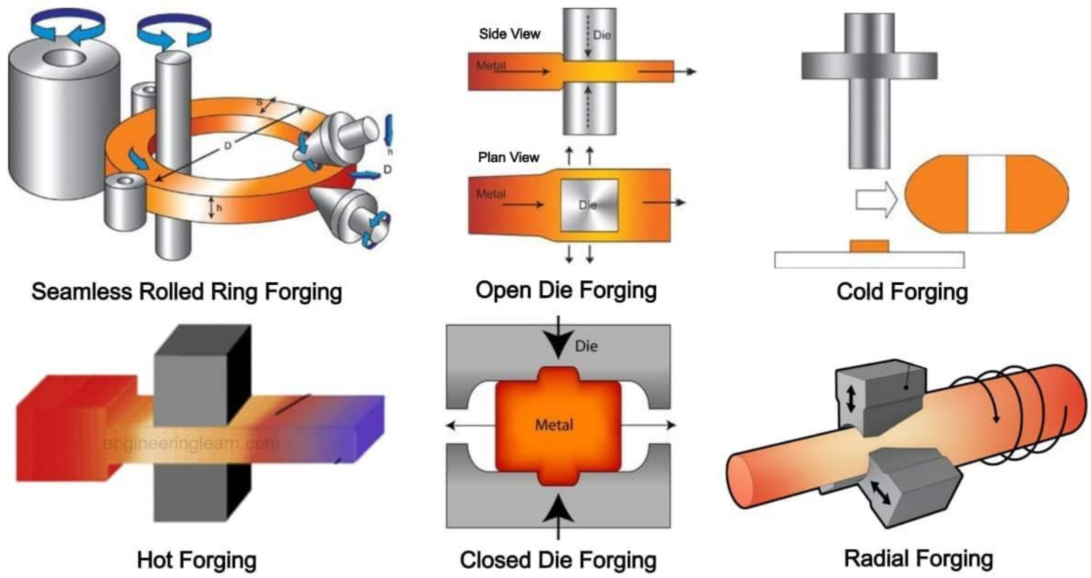


Figure 6. Principle of stamping (forged parts).

II.2.4. Stamping-die forging

The process consists of shaping a piece of metal heated to the appropriate temperature in the engravings of a set of dies that reproduce the shapes of the part to be produced. The principle consists of bringing the two dies together, which forces the metal to conform to the shapes of the engravings.
Generally, in order to completely fill the cavities, the metal may overflow from the engravings, which generates burrs and requires a deburring operation.

The success of die forging stems from three major advantages:
1. Metallurgical properties: excellent compromise between strength, elasticity, fracture, fatigue, corrosion, and resilience.
2. Improved mechanical strength-to-weight ratio of the part.
3. Reduced machining costs.

II.2.5. Rolling

Rolling is a manufacturing process involving plastic deformation. It is used on various materials such as metal or any other material in paste form, such as paper. This deformation is achieved by continuous compression as the material passes between two counter-rotating cylinders called rollers.
A rolling mill is an industrial installation designed to reduce the thickness of a material (usually metal). It also enables the production of shaped bars (long products).

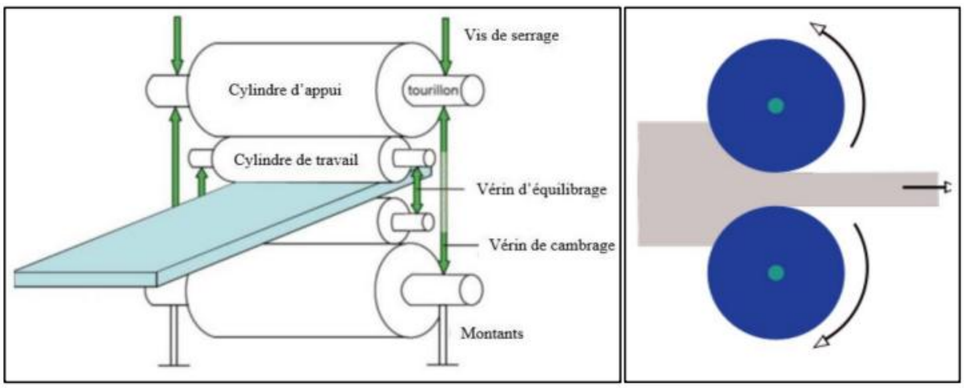


Figure 7. Rolling principle

Cold rolling and hot rolling

Hot rolling is necessary for two key reasons: The first is that the hot strength of metal decreases very rapidly with temperature.

The second is metallurgical. Cold rolling causes work hardening of the metal. In practice, the first series of reductions begin hot in order to easily achieve high deformations of the material and adjust the metallurgical properties of the product.

Cold rolling is then necessary to obtain the appropriate geometric and mechanical characteristics, as well as a good surface finish. Rolling is carried out under a film of mineral oil to facilitate the flow of metal, eliminate the heat produced by rolling, and lubricate the internal equipment of the rolling cage.

When cold, heat treatment can be used to restore the structure and prevent breakage due to damage. In contrast, during hot rolling, dynamic recrystallization occurs during deformation as long as the temperature of the product allows it.

We can see schematically the various phenomena that occur during plastic deformation.

II.2.6. Wire drawing:

The wire rod obtained by rolling is an intermediate product, especially in the manufacture of electrical cables, where the wire must have a smaller diameter. The operation that reduces the diameter of the wire is called wire drawing, and the machine used for this is called a wire drawing machine.

The principle of wire drawing is to use the plasticity of the metal to reduce the diameter of the wire by passing it through a calibrated orifice, called a die, under the combined effect of applying a tensile force T and a radial compressive force P.

The die is the fundamental element of the wire drawing operation. Its shape has been the subject of numerous theoretical and experimental studies. It consists of a hard-core A, usually made of tungsten carbide or diamond, crimped into a steel frame B.

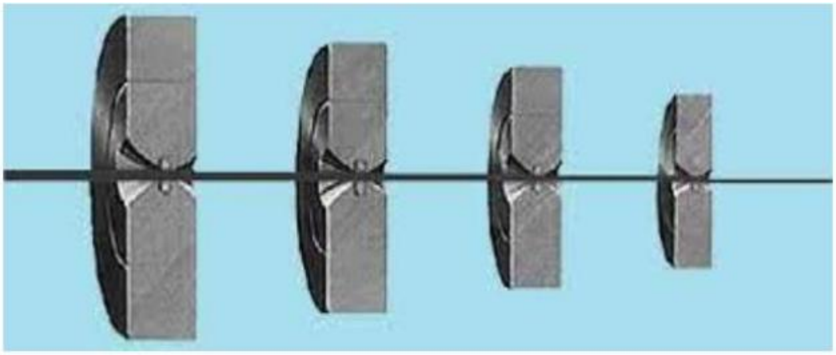


Figure 8. Wire drawing workshop

II.2.7. Bending

Bending is a plastic deformation forming process used to obtain a developable part from a sheet metal blank. It is performed by one or more successive operations under the action of a force exerted on the part. Bending can be performed by rotating a pivoting tool, or on a press brake using a punch and die.

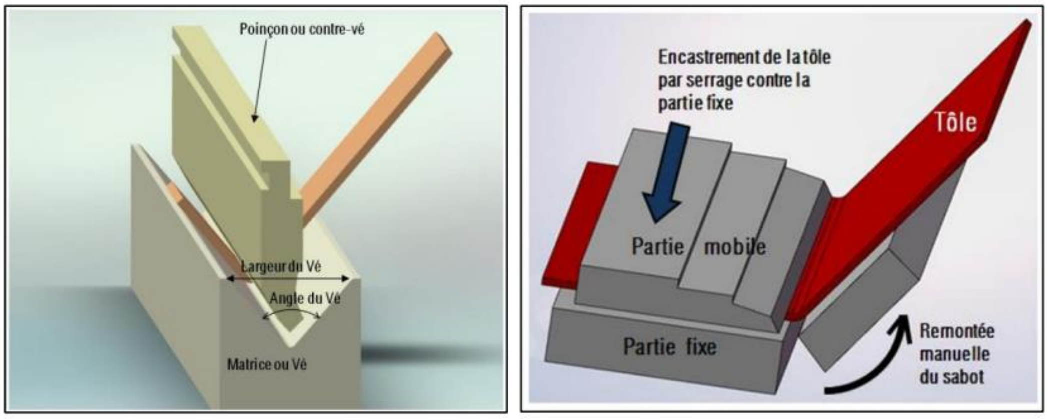


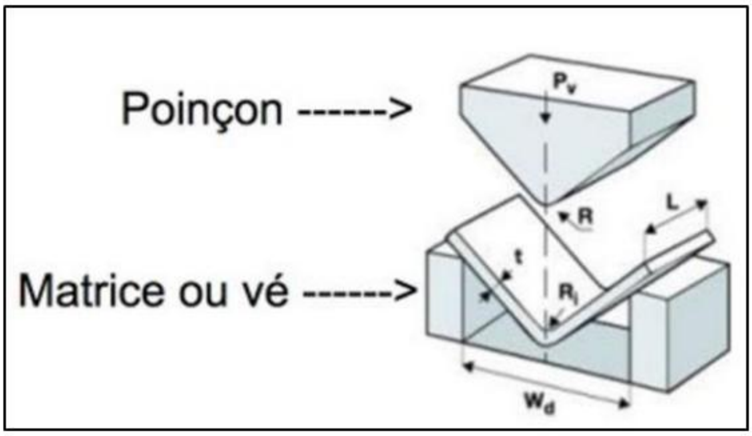
Figure 9. Folding techniques

II.2.7.1. Bending techniques

a- Impact bending

The punch drives the two free legs of the bend until they contact the inner faces of the die, resulting in work hardening of the bent area and an angle that is approximately equal to that of the bend.

This technique produces precise parts, but requires significant bending force (approximately 30 tons/meter/mm thickness). Different tools are required for each angle, and it is limited to sheet metal up to 2 mm thick. Die-cutting the inside of the bend produces very precise angles (±0.5°).



b- Air bending

The free edges of the bend do not come into contact with the inner faces of the die. Limiting the descent of the punch and the spacing of the die allows the desired bend angles to be achieved. This bending method is commonly used because the forces applied are approximately 5 times less than for impact bending.

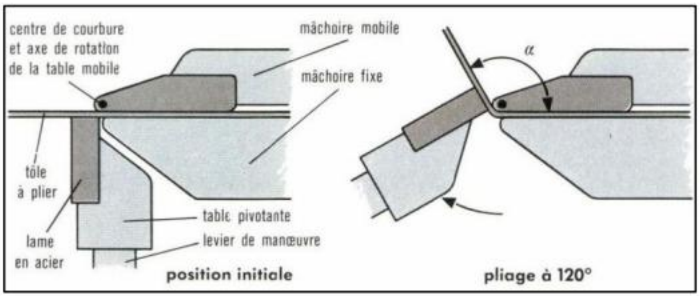


Figure 10. Folding in the air

Folding principle

Under the action of a force applied to a blank (or a blank) resting on two or more supports or embedded at one end, the product is bent.
The elastic limit must be exceeded to obtain the desired angle.

II.2.8. Cutting

The purpose of cutting is to prepare blanks or finished parts by directly detaching them from the mass of the working material: sheets, plates, or bars. It can be done cold or hot.

II.2.8.1. Cold cutting:

Cold cutting is achieved by shearing the metal under the action of the cutting edges of two opposing tools that slide against each other. Shear cutting is a process that is mainly used for straight cuts. It is carried out either by circular sawing (roller or wheel shears) for long straight cuts or large radius curves, or by flat blade shears (guillotine shears) as shown opposite, used for straight cuts. These shears have a fixed horizontal lower blade and an upper blade mounted on a vertically guided slide, while the sheet metal to be sheared is held in a press brake.

The force that must be applied to the moving blade to cut the sheet metal is:

$$F = L * e * RC$$

- F: force that must be applied to the moving blade to cut the sheet metal
- L: cutting length in mm
- e: sheet metal thickness in mm
- Rc: shear strength.

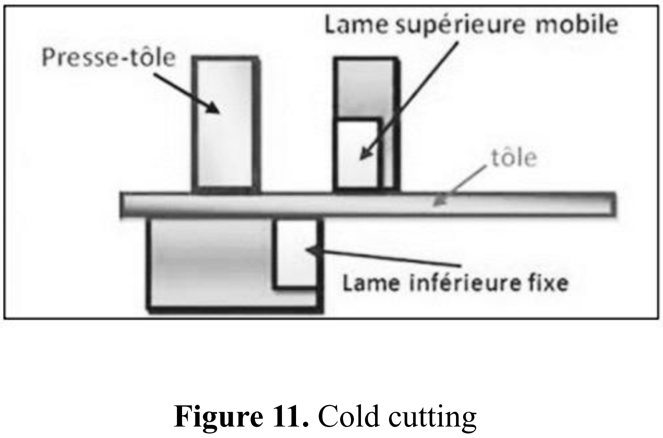


Figure 11. Cold cutting

II.2.8.2. Punching

Purpose: To make holes in sheet metal using punches shaped like the cutout.

Shearing A punch and die replace the shear blades. Same breaking mechanism.

$$F = S_C \times R_C$$

- F: force required for cutting (daN)
- SC: sheared cross-section in (mm²)
- RC: shear strength (daN/mm²)

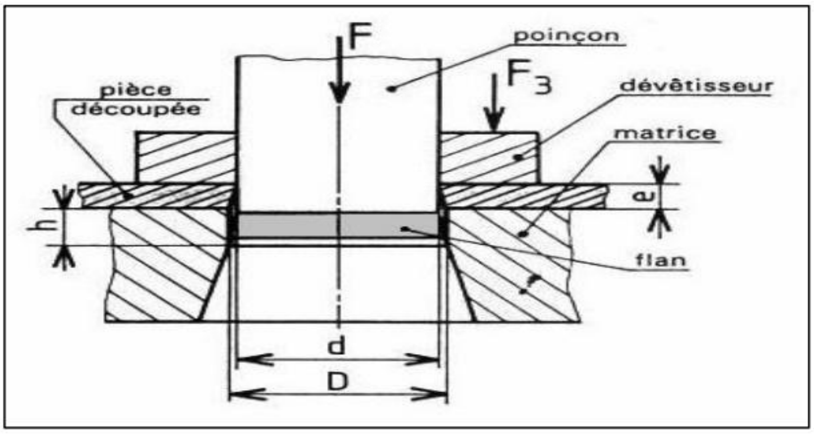


Figure 12. Punching

II.2.8.2. Hot cutting

Hot cutting of thick sheet metal can be performed using oxyfuel cutting or plasma arc cutting.

- Oxyfuel cutting is used for non-alloyed or very low-alloyed ferrous metals.
- Plasma arc cutting is suitable for cutting light alloys and stainless steels.

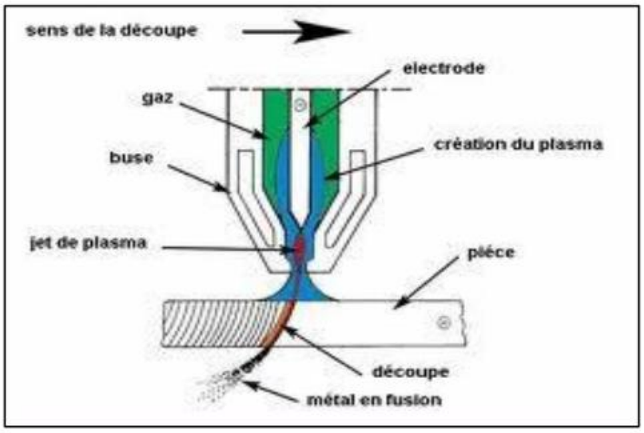


Figure 13. Hot cutting

II.2.9. Bending (Rolling)

Bending is an operation that involves bending wooden handrails, solid bars, or stainless-steel tubes. There are four main bending methods:
rolling, coiling, stamping, and pushing. Each method is suited to specific materials. In industrial bending, bending is
performed cold using specialized machines. In artisanal production, bending is referred to as "hot" because it is done by hand and requires heating the material.

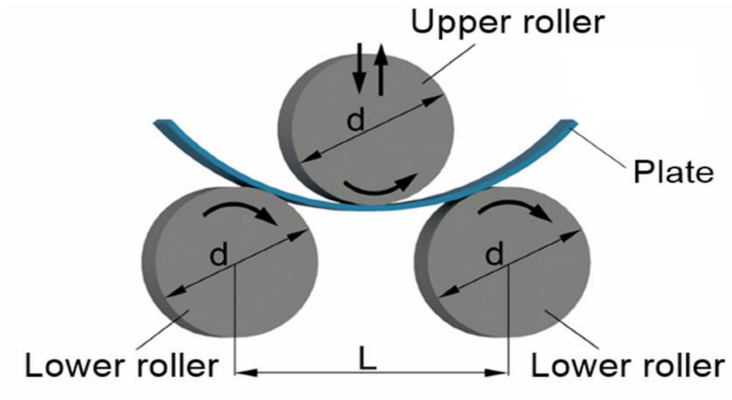


Figure 14. Bending (Rolling)

II.2.10. Extrusion

Spinning (also known as extrusion) is a hot working process for metals and alloys. It involves placing a block of metal, heated to the optimum forging temperature, into a closed chamber and forcing it out through an opening smaller than the entrance, applying high pressure to the metal.

The use of an effective lubricant between the blank to be deformed and the tools, as well as uniform heating, are sufficient to avoid most extrusion defects, sparing the metal from stresses that are locally greater than its breaking strength.

To perform the spinning operation, a cylindrical chamber made of steel resistant to high deformation stresses (pressure and temperature) is used, called a container. This container is closed at one end by a die whose orifice is machined to a straight section similar to the outside of the product to be manufactured. The cylindrical billet, heated to the optimum deformation temperature, is inserted into the container and then pushed against the die by a piston called a ram or punch, to which the force of the press is applied.

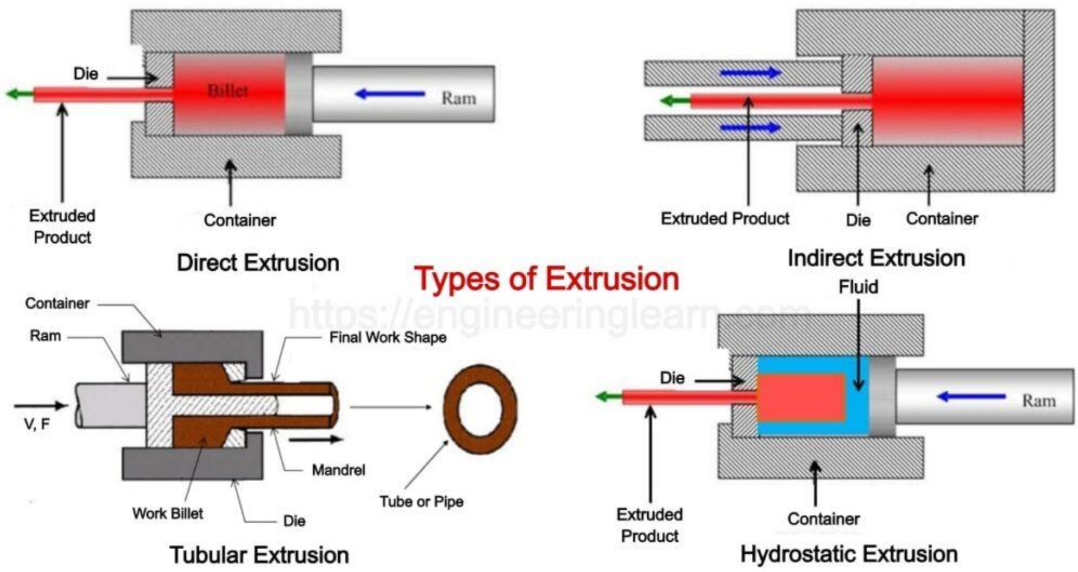


Figure 15. Spinning or extrusion of parts

II.2.11. Thermoforming

Large thermoplastic sheets can be shaped economically by thermoforming. In vacuum thermoforming, a thermoplastic sheet, heated to its softening point, is sucked by vacuum onto the contours of the mold, thus taking its shape; it is then cooled, solidifying on contact with the mold.

Pressure thermoforming uses a pressure of several atmospheres Pressure thermoforming uses pressure of several atmospheres to force the hot polymer sheet into the mold. Male or female molds are possible and, for vacuum thermoforming, can be machined from wood, polymer foam, or aluminum (for larger runs).

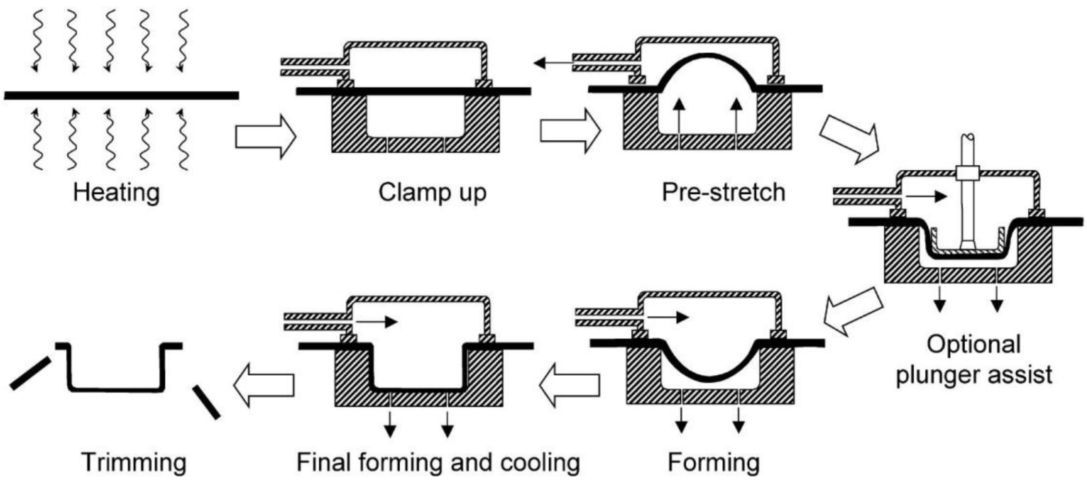


Figure 16. (a) Vacuum thermoforming - (b) Draping thermoforming

II.2.12. Powder metallurgy

This process consists of compacting powdered metal followed by heat treatment to densify the part. This process produces a virtually pore-free part with properties almost identical to those of the original material. These properties are mainly acquired through diffusion processes that take place during heat treatment. This process is particularly suitable for metals with low ductility, since the powder particles require only slight plastic deformation. It is also used with metals that have high melting points, which are difficult to melt and mold. It also makes it possible to obtain low-cost parts with low dimensional tolerances (e.g., bearings and gears).

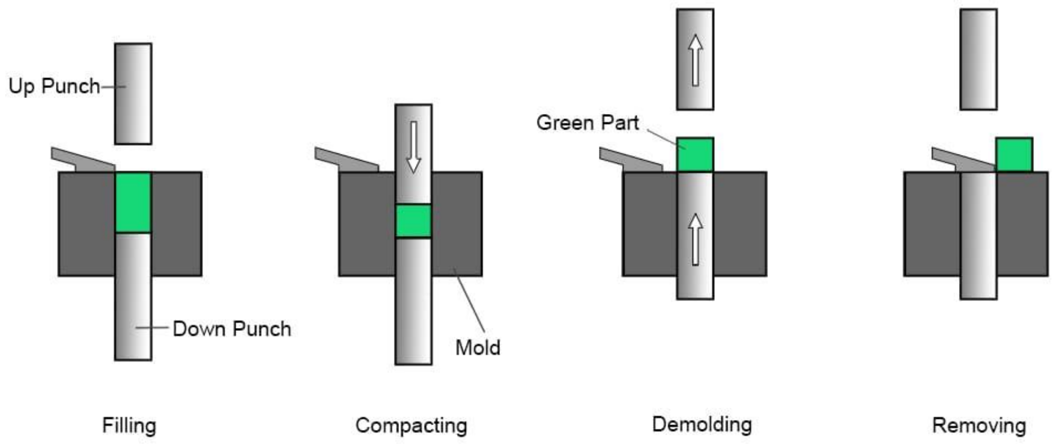


Figure 17. Powder metal compaction process