CHAPTER I. MATERIALS

I.1. Definition of a material

According to the Larousse dictionary, the definition of a material is: Any substance used in the construction of objects, machines, buildings, etc.

Therefore, the term “material” refers to any substance used to make an object in the broadest sense. The latter is often a part of a subassembly. It is therefore the commercial form of a raw material chosen for its specific properties and used in appropriate techniques to obtain an object with a given geometry and a predetermined function.

However, it is important not to confuse equipment (materials), which is an object shaped or manufactured by humans, with materials (material), which are used to manufacture that object.

I.2 Major families of materials

The classification of materials into solids, liquids, semi-solids, etc., is primitive and sometimes invalid. In rheology, it is possible to observe liquid-like behavior in a solid material and solid-like behavior in a liquid material (viscoelasticity, yield point).

However, many of the physical and chemical properties and functional properties of materials are closely linked to the nature of the chemical bonds between the atoms that make them up. It is on this basis that the distinction between the main classes of materials is established. We distinguish between:

- **Metallic materials**, involving a metallic bond: hard, rigid, and plastically deformable materials. These are metals or metal alloys : iron, steel, aluminum, copper, bronze, cast iron, etc. Metals and their alloys are usually good conductors of heat and electricity, opaque to visible light, which they reflect;
- **Organic materials or polymers—covalent bonds and secondary bonds:** materials consisting of molecules forming long carbon chains, easy to shape, theyrarely withstand temperatures above 200°C. These are materials of animal,
- **plant, or synthetic origin:** wood, cotton, wool, paper, cardboard, plastic, rubber, leather, etc. They are almost always thermal and electrical insulators.

- **Mineral or ceramic materials – ionic bonds and covalent bonds:** inorganic materials characterized by their mechanical and thermal resistance (refractory). These include rocks, ceramics, and glass: porcelain, natural stone, plaster, etc.
- **Composite materials:** These are combinations of at least two of the three types of materials mentioned above, which are immiscible: plastics reinforced with fiberglass, carbon fiber, or Kevlar, plywood, concrete, reinforced concrete, etc.

I.3 Metals, Alloys and their Designation

I.3.1. Generalities

The choice of material used in industry depends on a number of criteria:

- Mechanical characteristics: yield strength, mass, hardness, impact strength, etc.
- Physical and chemical characteristics: corrosion behaviour, ageing, etc.
- Processing characteristics: machinability, weldability, hardenability, etc.
- Economic characteristics: price, availability, industrial experience, etc.

A. Volumic mass

Materials	Steel	Aluminium alloy	Bronze	Nylon	Class Fibre	Carbon Fibre
kg/m³	7800	2700	8900	1000	2500	1750

B. Electrical properties

Type of material	**Resistivity en Ω.m**	**Electrical behaviour**
Polystyrene Nylon Glass	10^{20} 5.10^{12} 10^{17}	INSULATION
Ferrous alloys Aluminium Copper	$9,8.10^{-8}$ $2,8.10^{-8}$ $1,7.10^{-8}$	CONDUCTORS

C. Thermal properties

Type of material	Conductivity W/(m/K)	Thermal behaviour
Glass wool	0.04	THERMAL INSULATION
Concrete	1	
Nylon	0.25	
Glass	1,2	
Iron	80	THERMO CONDUCTOR
Aluminium	237	
Copper	390	

D. Corrosion resistance of some materials

Gold	Aluminium	Stainless steel	Copper	Zinc	Steel
Less susceptible to corrosion					More sensitive to corrosion

I.3.2. Standard designation of metals and alloys

The materials used are rarely pure or perfectly homogeneous mixtures, but more often in the form of alloys with standardised designations.

The designation of materials is subject to 'standards' which enable a coding system to be adopted for use by manufacturers. These standards are evolving and we need to evolve with them.

There are several types of materials:

- Ferrous metals and alloys
- Non-ferrous metals and alloys
- Plastic materials
- Composite materials
- Other materials .

I.3.2.1. Ferrous alloys

A. Steels (standard NF EN 10025)

Steels are alloys of iron and carbon [**Fe + (0.08 to 1.7%) C**], possibly with additional elements:

- General purpose steels (example: **S235 / E360**)
- Tool steels (example: **42Cr Mo 4** / **100 Cr 6**)
- Heat treatment steels (example: **C 50 / 20 Ni Cr 6 / 42 Cr Mo 4**)
- Stainless steels (example: **X 30 Cr 13 / X 5 Cr Ni 18-10**)

Steels classified into two groups:

1. Non-alloy steels (ordinary and special steels, etc.).
2. Alloy steels (low and high alloy).

Job classification

The designation begins with the letter '**S**' for general purpose steels and the letter '**E**' for engineering steels, followed by the minimum yield strength value in Mega Pascal (MPa).

Example :

- **S235** (general-purpose steel, yield strength 235MPa)
- **E320** (mechanical engineering steel, yield strength 320MPa)

In the case of cast steel, the letter «**G**» precedes the designation, (example: **GS235**)

❖ **Classification by chemical composition**

➢ **Non-alloy steels**

They contain a low carbon content; they are widely used in mechanical engineering. Most are available as merchant rolled products (sections, beams, bars, etc.) in standardised sizes.

Application: These steels have been not produced for a specific application.

Designation: The letter '**C**' followed by the percentage of carbon multiplied by 100.

Example: C 35 (steel with 0.35% of carbon)

- **Low-alloy steels**

For these steels, no additional element reaches 5% by mass.

Application:
They are chosen for their high resistance characteristics.

Designation :

- A number equal to 100 times the carbon content,
- The chemical symbols of the addition elements in order of decreasing content,
- The contents of the main addition elements multiplied by 4, 10, 100 or 1000 (see table below)
- Any additional information concerning weldability (S), mouldability (M) or cold formability (DF).

Example : 35 Cr Mo 4 S

- Steel with 0.35% of Carbon,
- 1% of chrome,
- The letter **S** indicates that this steel can be welded.

Table of chemical and metallurgical symbols Multiplier factor

Elements	Chemical symbol	Metallurgical symbol	Multiplier factor
Aluminium	Al	A	10
Nitrogen	N	N	100
Boron	B	B	1000
Chromium	Cr	C	4
Cobalt	Co	K	4
Copper	Cu	U	10
Magnesium	Mg	G	10
Manganese	Mn	M	4
Molybdenum	Mo	D	10
Nickel	Ni	N	4
Phosphorus	P	P	100
Lead	Pb	PB	10
Silicon	Si	S	4
Sulphur	S	F	100
Titanium	Ti	T	10
Tungsten	W	W	4
Vanadium	V	V	10

- **High-alloy steels.**

High-alloy steels have at least one additive element with a content ≥ **5%** by mass.

Application: These steels are reserved for specific uses.

Example:

In a humid environment, we use stainless steel, which is highly alloyed with Chromium (**Cr > 11%**).

Dans un environnement humide, nous utilisons l'acier inoxydable fortement allié avec (Cr >11 %).

Designation :

- The letter « **X** »,
- A number equal to **100** times the carbon content,

- Chemical symbols of the addition elements in order of decreasing content,
- In the same order, the levels of the main elements.

Example :

X6 Cr Ni Mo Ti 17-12

- *High-alloy steel with 0.06% of Carbon,*
- 17% of Chromium,
- 12% of nickel
- Molybdenum (< 12%),
- Titanium (< 12%).

X4 Cr Mo S 18

- *High-alloy steel with* ***0.04%*** *of Carbon,*
- **18%** de Chromium,
- Molybdenum (**< 18%**),
- Sulphur (**< 18%**).

B. Cast iron (Alloy of iron with 1.67% to 4.2% carbon).

➢ Les fontes (Alliage de fer avec (1.67% à 4.2%à de Carbone).

Cast irons are alloys of iron and carbon [**Fe + (1.67% to 4.2%) C**], they have excellent castability. They can there for be used to produce castings with complex shapes. They are must fragile (brittle), difficult to weld and have good machinability.

Lamellar graphite cast irons / Les fontes à Graphite Lamellaire

Lamellar graphite cast irons, known as 'grey cast irons', are widely used because they:

- They are economical
- They absorb vibrations well,
- Good castability and machinability,
- Have low oxidation,
- Good resistance to wear caused by friction,
- Good resistance to compressive stress.

Applications: Crankcases, frames, engine blocks, parts with complex shapes, etc...

Designation :

- **EN** : prefix,
- **GJL**: symbol for lamellar graphite cast iron,
- ***Number****: designating the value of minimum tensile strength by extension in* ***MPa*** *(mega Pascal).* /

Example :

- EN-GJL-300
- Cast iron with lamellar graphite
- Minimum elastic strength: **Re mini = 300Mpa**

Spheroidal graphite malleable cast irons

Spheroidal graphite cast irons are obtaining by adding a small quantity of magnesium before casting. They are lighter and have better mechanical strength than grey cast iron.

Applications: *Brake callipers, rocker arms, crankshafts, piping subjected to high pressure.*

Designation :

- **EN :** prefix,
- **GJMW :** symbol for spheroidal graphite cast iron,
- **Number:** value of minimum tensile strength in MPa.
- **Number:** value representing the percentage of elongation after rupture.

Example :

EN-GJS-400-18

- Spheroidal graphite cast iron
- Minimum elastic strength: **Remini = 400Mpa**
- Elongation : **A% = 18**.

I.3.2.2. Non-ferrous alloys

A. Aluminium and its alloys

Aluminium is obtaining from an ore called Bauxite. It is light (density = 2.7) and a good conductor of electricity and heat. It has low mechanical strength, is ductile and easy to machine. It is highly resistant to corrosion. Application: aerospace, due to its lightweight.

- **Designation:**

The designation uses a numerical code. It may be following by a designation using chemical symbols.

Example :

EN-AW-2017 (Al Cu 4 Mg Si) Aluminium alloy with 4% Copper, Magnesium and Silicon (less than 4%)

B. **Copper and Copper alloys.**

There are many different copper alloys, the best known of which are:

1. Bronze,
2. Brass,
3. Cupro-Aluminium,
4. Cupro-Nickel,
5. Nickel Silver.

Bronze	Copper + Etain
Brass	Copper + Zinc
Cupro-Aluminium	Copper + Aluminium
Cupro-Nickel	Copper + Nickel
Nickel Silver	Copper + Nickel + Zinc

Brass is easy to machine and has good corrosion resistance. They can be casting or forged. They are using for turned parts, tubes, etc.

…

Bronzes have good corrosion resistance, a low coefficient of friction and are easy to cast. They are using to make bearings and friction rings, among other things.

Designation:

This is a numerical code. It may be following by a designation using chemical symbols.

Example:

CW612N (Cu Zn 36 Pb 3): Copper alloy with 36% Zinc and 3% Lead

I.4 Plastic

A plastic, or in everyday language a plastic material, is a mixture containing a base material (a polymer) that can be molded or shaped, usually under heat and pressure, to produce a semi-finished product or an object.

Plastics cover a very wide range of synthetic or artificial polymer materials. Today, it is possible to find properties in a single material that were never before combined, such as transparency and impact resistance.

Generally, industrial polymers are not used in their "pure" state, but are mixed with substances that may or may not be miscible in the polymer matrix.

Typical structure of a formula: plastic = raw polymer(s) (base resin(s)) + fillers + plasticizer(s) + additives.

There are many different types of plastics, some of which are hugely successful commercially. Plastics come in many forms: injection-molded parts, tubes, films, fibers, fabrics, sealants, coatings, etc. They are used in many sectors, even the most technologically advanced ones.

Different types of plastics:

- Thermoplastics

In linear or branched polymers obtained by addition, the macromolecules are only linked together by weak bonds (Van der Waals bonds). The overall behavior of the material therefore depends on the mobility of the chains in relation to each other and on the rotation around the C-C bonds. An increase in temperature facilitates the movement of the chains in relation to each other, and the behavior, which is initially glassy, becomes rubbery between the glass transition temperature (Tg10 or Tv) and the melting temperature Tf. The reversibility of behavior allows these materials to be shaped in their molten or rubbery state.

- Thermosetting materials

Plastics obtained by condensation of monomers consist of a three-dimensional network of macromolecules. These are amorphous and infusible materials; there can be no movement of chains relative to each other. When the temperature rises, the material does not become viscous, but retains its rigidity until it degrades. These plastics are called thermosetting because, in general, an increase in temperature promotes the polymerization reaction and the degree of cross-linking, and therefore rigidity.

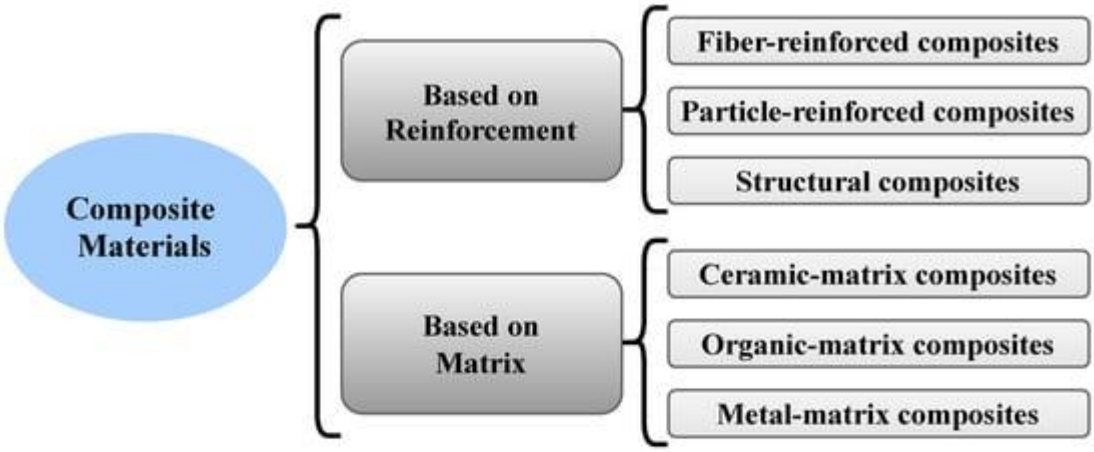
I.5 Composite materials

I.5.1. Definition of a composite material

A composite material is an assembly of at least two immiscible components (but with a high penetration capacity) whose properties complement each other. The new heterogeneous material thus formed has properties that the components alone do not possess.

This phenomenon, which improves the quality of the material for certain uses (lightness, rigidity under stress, etc.), explains the growing use of composite materials in various industrial sectors. Nevertheless, the detailed description of composites remains complex from a mechanical point of view due to the non-homogeneity of the material.

A composite material is composed as follows: matrix + reinforcement + optionally: filler and/or additive.



Examples: reinforced concrete = concrete composite + steel reinforcement, or fiber glass composite + polyester resin.

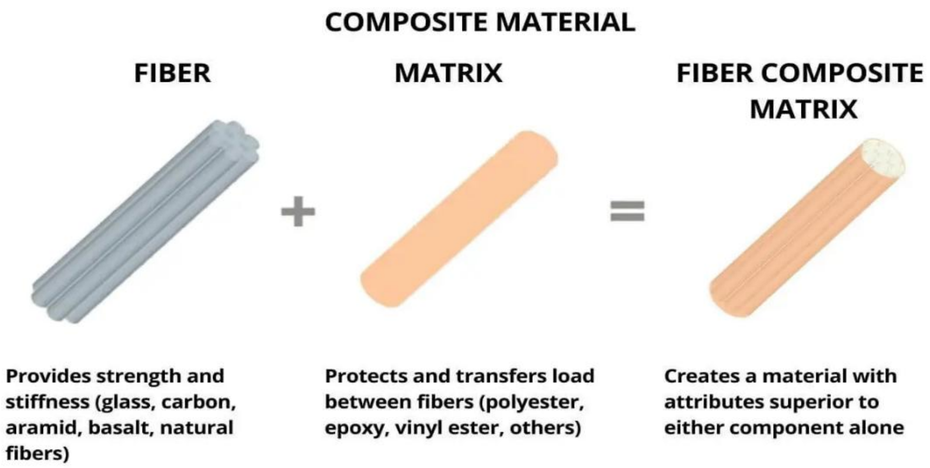


Figure 2. Exemple of Fibre composite matrix

I.5.2. Composite materials

Composite materials consist of a protective layer called the "matrix" and a structural layer called the "reinforcement." The fiber reinforcements are strategically arranged within the matrix, which maintains their geometric configuration and transmits stresses to them.

I.5.2.1. Reinforcements

Reinforcements ensure the mechanical properties of the composite material and come in the following forms: linear (strands, roves), surface fabrics (fabrics, mats), multidirectional (braids, complex fabrics, three-way or multi-way weaves).

The different types of reinforcements are listed in the flowchart below.

Fibers come in several forms: either continuous or discontinuous (cut fibers, short fibers, etc.), and it is their arrangement and orientation that allow the mechanical properties of composite materials to be modulated.

The mechanical properties of composite materials are determined by the type of fibers used, their orientation, and the type of matrix used.

I.5.2.2. Matrices

The matrix is one of the basic components of composite materials. It is a lightweight, easily deformable organic material whose role is to: bind the reinforcing fibers, ensure uniform spatial distribution of the reinforcements, transmit external forces to the reinforcements and distribute them, provide chemical resistance to the structure, and give the product the desired shape. The matrix must have a low density in order to maintain the composite's high mechanical properties.

I.5.2.3. Fillers – additives

Products (inert substances), mineral or vegetable, which can be incorporated into the resin to reinforce its mechanical properties (reinforcing fillers). Non-reinforcing fillers can also be used to reduce the cost of resin matrices, and additives such as colorants and release agents are widely used in the design of composite structures.

Structural composite materials are generally classified into three categories:

- Monolayers;
- Laminates;
- Sandwiches.
- Other structures (3D structures).