CERAMICS EDUCATION

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Given the task of defining an appropriate educational programme in ceramic science and engineering, it is necessary to establish first what is a ceramic. This is not easy because the word ceramic has a long history and conveys several meanings. Sometimes, ceramic refers to a particular material, ceramics versus metals for instance, and the ceramic training is conceived as an option, a module chosen by advanced students in material science. As shown in the first part of this paper, this approach is indeed too restricted. To define a ceramic, it is more appropriate to consider the specific technologies involved in processing, treated in part II. The dialectic relation between science and technology is discussed in part III and it is concluded that they can be reconciled in research activity. Finally, part IV is devoted to a short presentation of the courses offered at the Ecole Nationale Supérieure de Céramique Industrielle (E.N.S.C.I.).

1 - CERAMICS AND MATERIALS SCIENCE

It is customary in many textbooks to mention three types of materials: metals, polymers, glass and ceramics. Although this list is certainly too limited (what about paper, leather...?), the following remarks can be made. Metals have specific physical properties such as high electrical and thermal conductivities, they deform plastically... In fact, they were model systems to develop many concepts of solid state physics. Polymers have a well-defined identity because they are the fruit of organic chemistry. Carbon is the main constituent of the molecular skeleton and is covalently bonded to other atoms. What about ceramics? Among the various "ceramic materials", are found ionic, covalent and metallic compounds. They belong to various chemical families: oxides, nitrides, silicates.... They have all possible physical properties; for instance, insulating, semiconducting, metallic and superconducting behavior with respect to the electrical properties. They can be crystallized or amorphous if ceramics and glass are considered to belong to the same family. Ceramic materials appear to be those which are neither metals nor polymers. Clearly this definition is not satisfactory from a teaching point of view.

One way to circumvent this difficulty, is to consider that all materials have many aspects in common constituting materials science. Then metals, polymers and ceramics are merely considered as illustrations and lose their identity. As an example, crystallography can be used to describe any material and X-Ray diffraction has proved to be a powerful technique to characterize the structure of a material. However, a unified point of view is not always easy. For instance, the mechanical properties of metals or ceramic materials are very different and so are the corresponding taught courses. This is also true of the electrical properties. The band theory developed by Bloch and Wilson proves to be adequate in the case of metals or semiconductors such as Si or AsGa but this is no longer the case for several significant ceramic materials because of the importance of electron-ion or electron-electron interactions.

It is concluded that a general course in materials science is a necessary basis and will include:

- bonding and structure of matter
- microstructure
- physical properties

However, material is itself a generic term which covers different realities. Materials are mainly defined by their physical properties, polymers by their chemical origin, glass and ceramics by the technologies involved. This justifies the need for a specific training for each type of material, in particular ceramics.

II - CERAMICS AND TECHNOLOGY.

Ceramics are as old as history. At the beginning, ceramics referred to one material, clay. It is present in many places, easily extractable and has a unique property, plasticity. Once fired, it becomes hard, resistant to heat and to corrosion. It was the origin of a profound transformation of living standards in the neolithic age with the production of tiles and bricks for buildings, but also for furnaces, earthenware jars, plates, providing security and comfort. Very rapidly, ceramic products were decorated, expression of humanity's search for beauty. Two steps, forming and firing, are necessary to make a ceramic product. For thousands of years, clay has remained the basic raw material but much progress has been made concerning these two technological processes. They are still today the major signature of ceramics.

In 1860, the spark plug was invented by a Frenchman Jean Jacques Lenoir to improve the combustion of gas engines. It was made of porcelain, the best ceramic material at the time. However, it readily proved to be inadequate because of its low resistance to thermal shock. The evolution of the composition towards a more refractory one was very slow:
- 1914: 80% kaolinite, 10% flint (SiO₂), 10% ortho silicate (K₂O)
- 1916: 55% kaolinite, 30% flint (SiO₂), 15% ortho silicate (K₂O)
- 1920: the quartz content replaced by sillimanite (SiO₂-Al₂O₃).

Increasing the alumina content decreased the ability of the material to be formed. If clay is absent, plasticity is lost and can be regained only by mixing the powder with plasticizers (waxes, paraffins, methylcelulose...). The use of pure alumina was patented only in 1936! This was a major advance in ceramic processing. Since that date, an impressive list of materials can now be made using ceramic technology and this is why they are called ceramic materials. Let us cite for instance barium titanate, zinc oxide, zirconia, silicon carbide, silicon nitride amongst many others.

We therefore conclude that processing has to be the central part of a cursus in ceramic science and technology. The main steps are:
- to obtain the raw material in a powder form, either from natural resources or as an industrial product;
- then forming. Most often, a slurry is prepared from the powder using water or an organic liquid as a medium, followed by casting (slip casting, tape casting...). Even spray drying and granulation which is the best way to obtain a powder suitable for pressing, involves a liquid mix. The use of plasticizers is necessary for injection or extrusion;
- a thermal treatment. The objective is usually double: reaction of the constituents on one hand and densification on the other;
- finally a surface treatment can be applied.

In a cursus on ceramic science and engineering, we expect:
- knowledge of these technologies, from a theoretical and practical point of view,
different realities. Metals are mainly of a mechanical origin, glass and ceramics by the presence of each type of material.

referred to as a material. Clay is a combination of particles, plasticity. Once fired, its properties transform those of stones and bricks for buildings, and safety and comfort. Very rapidly, clay's search for beauty. Two steps, one. For thousands of years, clay has been used to make these two types of ceramics.

Jean-Jacques Lequeu to improve the characteristics of ceramic material at the time. Low resistance to thermal shock. The two very slow:

1.0
2.3
3.6
4.3
5.4

The material to be formed. If clay is mixed with powder with plasticizers, it was patented only in 1936! This is an impressive list of materials can be called ceramic materials. Let us consider the importance of materials science in synthetic applications such as graphite, silicon nitride amongst others part of a career in ceramic science.

natural resources or as an industrial raw material used in water or an organic plasticating agent. Even spray drying and suitable for pressing, involves a liquid extrusion. Selection of the constituents on one hand and technical specifications on the other hand.

practical point of view,
A general background in mathematics, physics, and chemistry is a necessary prerequisite. Students receive this basic education during the two years between their final high school diploma (baccalauréat in the French system) and the beginning of their course at E.N.S.C.I. The three years pursue in ceramic science and engineering can be summarized as follows:

- The first year is mostly devoted to material science (30%) and ceramic processing (50%). For this latter part, students use the facilities of a factory-size technology workshop where they learn by "doing" and "making".
- During the second year, the processing technology is considered to be known and most of the courses concern material science (30%) and engineering (25%). A large block of time is reserved for a project requiring practical resolution of one or two real problems (of an industrial origin) relative to processing.
- The third year is focused on high level materials science courses (30%), on specialized lectures (30%), mainly relative to engineering or ceramic applications and on the general training of an engineer, i.e. management, economy, quality control... (40%).

**Programmes**

**GENERAL EDUCATION OF THE ENGINEER.**

**Mathematics:**
- M1 (18-18-0) Signal processing.
- M2 (22-22-0) Statistics.

**Computing:**
- INFO1 (18-8-44) Software.
- INFO2 (0-0-30) Project.

**Languages:**
- AN (0-130-0) English.
- ES (0-65-0) Spanish.
- AL (0-65-0) German.

**Communication:**
- COM (0-0-40) Written and oral expression.

**Company:**
- GE1 (18-0-0) Accounting and financial aspects of the company.
- GE2 (18-0-0) Accounting: advanced.
- GE3 (18-0-0) Marketing.
- OP (26-0-0) Production organization.
- MA1 (0-24-0) Human resources.
- MA2 (0-24-0) The role of the engineer.
- MA3 (10-20-0) Quality control.
- DR (37-0-0) Company law.
- ST1 (2 mois) Internship I.
- ST2 (5 mois) Internship II.

**PHYSICAL SCIENCES.**

**Chemistry:**
- CH1 (28-12-0) Physical chemistry.
- CH2 (28-12-0) Inorganic chemistry.
- CH3 (24-10-0) Materials chemistry.
- CH4 (32-0-0) Solid state chemistry.

**Structure and microstructure:**
- SM1 (32-12-0) Geometrical crystallography, mineralogy.
- SM2 (22-14-16) X-Ray crystallography.
- SM3 (28-8-20) Materials characterization.
- SM4 (38-4-12) Materials characterization: advanced.
- SM5 (20-0-0) Phase transitions. (From the amorphous to the crystallized state.)

**Materials Properties:**
- PM1 (28-12-0) Electrical properties
- PM2 (28-14-0) Mechanical properties
- PM3 (10-0-0) Thermal properties

**Thermodynamics:**
- Th1 (26-14-0) Heterogeneous systems.
- Th2 (26-14-0) Phase Diagrams.
- Diffusion.
- Th3 (26-14-0) Sintering.

**Research project** 4 months

*optional. (a,b,c)=courses, tutorial, practical in hours/years*

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**CERAMICS, GLASS and HYDROGEN PROCESSING and MATERIALS.**

**Ceramic processing:**
- PC1 (36-0-0) Raw materials.
- PC2 (29-6-12) Mixes.
- PC3 (36-0-0) Forming.
- *PC9 (34-0-0) Forming: advanced.
- PC4 (29-6-12) Thermal treatment.
- PC5 (0-0-72) Workshop practice.
- PC6 (0-0-64) Project I "making".
- PC7 (0-0-48) Project II applied research.
- *PC10 (17-0-4) Surface treatment.

**Ceramic materials:**
- MCI (46-0-0) Silicate materials.
- MCI (60-0-0) Technical ceramics.
- *MC3 (36-0-0) Advanced: electron.
- *MC5 (16-10-0) Hydraulic binder.
- *MC6 (38-0-0) Refractories.

**Fibrous products:**
- PV1 (34-6-4) Glass and ceramics.
- PV2 (38-6-0) Glass technology.
- *PV3 (36-9-0) Special glasses.

*optional. (a,b,c)=courses, tutorial, practical in hours/years*

During their course, students have the opportunity to:
- as a shop floor worker in a factory.
- as an engineer in industry (four years).
- as a researcher in a laboratory (five years).
- Some students (7 to 10 months) study "surfaces" during the third year, which leads to a PhD thesis.

**References**

CERAMICS, GLASS and HYDRAULIC BINDERS. 
PROCESSES and MATERIALS.

Ceramic processing:
PC1 (36-0-8) Raw materials.
PC2 (20-6-12) Mixes.
PC3 (36-0-0) Forming.
PC9 (34-0-0) Forming: advanced.
PC4 (36-12-16) Thermal treatments.
PC5 (0-0-72) Workshop practice.
PC6 (0-0-64) Project I: "making".
PC7 (0-9-88) Project II: applied research.
* PC10 (12-0-0) Surface treatments.

Ceramic materials:
MC1 (40-0-0) Silicate materials.
MC2 (20-0-0) Technical ceramics.
* MC3 (30-0-0) Advanced: electronic ceramics.
* MC4 (32-8-0) Advanced: structural ceramics.
* MC5 (30-10-0) Hydraulic binders.
* MC6 (38-9-0) Refractories.

Various products:
PV1 (34-6-4) Glass and enamels.
PV2 (38-0-0) Glass technology.
* PV3 (36h-0-0) Special glasses.

INDUSTRIAL TECHNOLOGY.
TH1 (28-14-0) Furnaces, combustion and heat transfer.
TH2 (30-0-16) Industrial processes.
* TI3 (40-0-0) Microelectronics.
TH4 (40-0-0) Engineering.
EEA1 (24-8-24) Electronics and power electricity.
EEA2 (24-12-20) Control systems.

Cold sciences:
Utility
(28-12-0) Physical chemistry.
(28-12-15) Inorganic chemistry.
(24-10-20) Materials chemistry.
(32-0-0) Solid state chemistry.

structure and microstructure
(2-12-0) Geometrical crystallography.
(22-14-16) X-Ray crystallography.
(28-8-20) Materials characterization.
(20-0-0) Phase transitions. (From the physics to the crystallized state.)

properties
(36-14-8) Electrical properties.
(24-10-0) Mechanical properties.
(10-0-0) Thermal properties.

heterogeneous systems
(26-14-0) Heterogeneous systems.
(26-18-0) Phase Diagrams.

sintering
(20-14-0) Sintering.

Research project: 4 months

During their courses, students have the opportunity to undertake three traineeship periods:
- as a shop floor worker in a factory (one or two months in the summer between years 1 and 2).
- as an engineer in industry (four or five months between years 2 and 3).
- as a researcher in a laboratory (four months at the end of year 3).

Some students (7 to 10 each year), study for the DEA "Matiere ceraeiques et traitements de surfaces" during the third year, which in the French system is the first step in the preparation of a PhD thesis.

References: