Role of Ceramics in a
Self-sustaining Environment
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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 cursus offered at the Ecole Nationale Supérieure de Céramique Industrielle (E.N.S.C.I.).

I - 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 constituant 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 behaviour with respect to the electrical properties. They can be crystallised or amorphous if ceramics and glass are considered to belong to the same family. Ceramic materials appears 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 correspondingly 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. Metals are mainly defined by their physical properties, polymers by their chemical origin, glass and ceramics by the technologies involved. This justifies the need of 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.[1] 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%weight clay, 10% flint (SiO_2), 10% orthose (K_2O),
1916 : 55%weight clay, 30% flint (SiO_2), 15% orthose (K_2O),
1920 : the quartz content replaced by sillimanite (SiO_2-Al_2O_3).
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, methylcellulose...). 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,

- the scientific basis to understand the processes involved in those technologies.

in addition to materials science.

III - SCIENCE AND TECHNOLOGY.

Ceramic technologies have always evolved through the centuries. This is a continuous process although now at a rapidly increasing pace. In fact innovation has become a major challenge in this end of the XXth century.

The XVIIIth century saw the rapid development of science and in particular of chemistry with important consequences for ceramics. Kingery[2] has very nicely described how porcelain was perfected in Europe and the role played by the physicist Count Von Tschirnhaus. As a further example of the influence of science, let us mention that the Director of the Manufacture de Sèvres at that time was Pierre Joseph Macquer, a chemist and author of "Eléments de chimie théorique" and one of his successors Alexandre Brongniart, a famous mineralogist.[3]

Clearly, the development of science had a profound impact on the development of ceramics posing the problem of the relationship between science and technology. Following Pasteur's doctrine, science has become the source of all applications. Let us develop science and technology will follow. Clearly, this approach is too simple and has been strongly criticized.[4] Foundations of science and technology are in fact very different. Science is a rational intellectual thought process for a better understanding of the world. Technical development is necesssary to improve our living conditions; it originates in the search for a better life. The success of science relies on the fact that it constitutes objective knowledge. Every theory, or concept, can be tested by anyone. Thus the role of the experiment is to validate a scientific theory. In the case of technology, experiment is part of the creative process of innovation. Intuition, which is subjective and personal, plays an important role. Although different, the two approaches strongly interfere and they maintain a dialectic relation. Science constitutes the cultural environment in which technology develops but technology development is the source of new scientific inspiration, questions and theories. As a consequence, theory usually follows and not precedes invention. As an example, ceramists have known for a very long time the importance of chemical composition and temperature but these concepts were clearly established (which means also measurable) only at the end of the XVIIIth and XIXth centuries respectively. Today, they have become the basis of a scientific understanding of ceramic processing with the use of phase diagrams.[2]

This dialectic relation between science and technology can be introduced into the ceramic science and engineering cursus through research activity. It has the following advantages :

- a personal work of the student;
- the occasion to develop a rigorous analysis, based on an experimental approach;
- the necessity to develop creativity

IV - CERAMICS EDUCATION AT THE ENSCI

Let us summarize our discussion and see the consequences concerning training in ceramics. The example of the cursus developed in Ecole Nationale Superieure de Céramique Industrielle (ENSCI) will serve as an illustration. A cursus in ceramic science and engineering must include

- materials science

- materials engineering
- technology

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 (baccalaureat in the French system) and the beginning of their cursus in E.N.S.C.I.. The three years cursus 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.	PHYSICAL SCIENCES.
Mathematic.s	*Chemistry.*
M1 (18-18-0) Signal processing.	CH1 (28-12-0) Physical chemistry.
M2 (22-22-0) Statistics.	CH2 (28-12-16) Inorganic chemistry.
Computing.	CH3 (24-10-20) Materials chemistry.
INFO1 (16-8-44) Softwares.	CH4 (32-0-0) Solid state chemistry.
INFO2 (0-0-30) Project	*Structure and microstructure.*
Languages.	SM1 (32-12-0) Geometrical crystallography, minéralogy.
AN (0-130-0) English.	SM2 (22-14-16) X-Ray cristallography.
* ES (0-65-0) Spanish.	SM3 (28-8-20) Materials caracterization.
*AL (0-65-0) German.	* SM4 (38-4-12) Materials caracterization : advanced.
Communication.	SM5 (20-0-0) Phase transitions. (From the amorphous to the crystallized state.)
COM (0-0-40) Written and oral expression.	*Materials Properties.*
Company.	PM1 (26-12-0) Electrical properties
GE1 (18-0-0) Accounting and financial aspects of the company.	PM1 (28-14-0) Mecanical properties
GE2 (18-0-0) Accounting : advanced.	PM3 (10-0-0) Thermal properties
GE3 (18-0-0) Marketing.	*Thermodynamics.*
OP (26-0-0) Production organization.	TH1 (26-14-0) Heteregeneous systems.
MA1 (0-24-0) Human ressources.	TH2 (26-18-0) Phase Diagramms. Diffusion.
MA2 (0-0-24) The role of the engineer.	TH3 (26-14-0) Sintering.
QUA (10-20-0) Quality control.	*Research project* 4 months
DR (37-0-0) Company law.	
*STII (2 mois) Traineeship I.	
STII (5 mois) Traineeship II.	

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

CERAMICS, GLASS and HYDRAULIC BINDERS. PROCESSES and MATERIALS.	INDUSTRIAL TECHNOLOGY.
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 (26-12-16) Thermal treatments. PC5 (0-0-72) Workshop practice. PC6 (0-0-64) Project I "making". PC7 (0-0-88) 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 (38-0-0) Refractories. *Vitreous products.* PV1 (34-6-4) Glass and enamels. PV2 (38-0-0) Glass technology. * PV3 (36h-0-0) Special glasses.	TI1 (28-14-0) Furnaces, combustion and heat transfer. TI2 (30-0-16) Industrial processes. *TI3 (40-0-0) Microelectronics. TI4 (40-0-0) Engineering. EEA1 (24-8-24) Electronics and power electricity. EEA2 (24-12-20) Control systems.

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

During their cursus, 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 "Materiaux céramiques 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

1. M. BERG, "Aluminum oxide spark plug insulators" pp 211-217 in Ceramics and Civilization, Volume III, Edited by W.D. Kingery, The American Ceramic Society, Inc. Westerville, OH USA.
2. W.D. KINGERY, "The development of European Porcelain" pp 153-180 in Ceramics and Civilization, Volume III, Edited by W.D. Kingery, The American Ceramic Society, Inc. Westerville, OH USA.
3. A. BRONGNIART, "Traité des Arts Céramiques ou des Poteries", 2 vols., rev. ed. by A. Salvetat, Bechet Jeune, Paris, 1854.
4. R. ROY, "The Nature and Nurture of Technological Health" pp 351-381 in Ceramics and Civilization, Volume III, Edited by W.D. Kingery, The American Ceramic Society, Inc. Westerville, OH USA.