Organic Materials in Civil Engineering
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Chapter 7

Organic Materials, Civil Engineering and Sustainable Development Prospective Thoughts from Experts

Approaching civil engineering materials from a physico-chemical point of view is probably the simplest way to bring together products that are extremely different in their design as well as in their use. However, it is not just the method but other economic, technological and scientific realities that brings them closer. To do this, we need to add the real environmental and health impacts that they could actually cause or likely to cause in the collective unconscious. We then come straight to the point of sustainable development, the concept which drives development and research in the beginning of the 21st century.

In order to fulfill this need, the best solution was to ask experts to give account of their knowledge of different fields: engineers, teachers, PhD professors, architects, doctors. Their contributions are given below. The authors of the different sections are given in the Introduction to this book.

7.1. Economic reality of synthetic materials in civil engineering[1]

7.1.1. *Preface*

From the point of view of construction materials, plastics and by extension all polymers are in a situation where modesty is in vogue. They account only for 1% of

1 This section was written by Michel DE LONGCAMP, ATOFINA.

the quantity of construction materials bought per annum in Europe. However, we can talk about economic reality today, because even if the tonnage is very small, we find it everywhere and especially in the creation of new materials: polymers become the major “ingredient” for the technological improvement of traditional materials.

We find them in products incorporated into cement or bitumen matrices, in protective coatings, sealing or anti-corrosion, or for the development of new materials like the composites reinforced with glass, carbon or the Kevlar.

Our aim here is to present this economic reality in three major applications where we find polymers: the incorporates, the coatings and the materials themselves.

7.1.2. *Positioning of the plastics: some figures*

The building and public works market is one of the most important market for polymers contributing 20% of the tonnage of all the plastics, with an annual growth of 8 to 9% in the last 10 years in spite of a stagnating or very slow growing building and public works:

Packaging	35%
Building and public works	**20%** or **6,850,000 tons**
Transport	15%
Electricity/electronics	10%
Sport & leisure	5%
Furnishing	4%
Medical	4%
Miscellaneous	7%

We must note that this particularly favorable growth is due not only to “plastics”, substitutes for other traditional products, but also to the increasingly complex requirements where the polymers associated or not with traditional materials can fulfill the requirements from increasingly more demanding specifications. Let us therefore take some examples.

7.1.2.1. *PVC windows*

The production of PVC has dramatically increased. From 100 tons in 1974, we have moved to 780,000 tons in 2000. This progress occurred primarily on a twin requirement: a new standard on energy saving and a requirement of very low maintenance costs. Conclusion: an increase of 49% of market share in 25 years.

7.1.2.2. *Protective sheaths for optical cable networks*

The large plastic markets in civil engineering are (in thousands of tons) in 2000:

Sealing	PVC: 200	LDPE 250

450kt➔Share of civil engineering: 60% = **270 kt**

Additives	486	Including super-plasticizers: 121.5

Share of civil engineering 15% = **73 kt**

Insulation	PSE: 593	XPE: 182	PU: 580

1,355kt➔ Share of civil engineering: 20% = **271 kt**

Conduits	PVC: 1,620	PE hd+bd+LL: 875	PP: 146	UP120

{total = 2,761 kt➔ Share of civil engineering: 40% = **1.104 kt}**

We can see that the plastics' share in civil engineering has reached 27%, i.e. nearly 1,655,000 tons just for the first four markets of plastics in the construction industry. We can therefore be sure that the economic reality of polymers exists in civil engineering.

7.1.2.2.1. Definition of new materials

So, at this level the key words are future and forecasts: what will the future modes of transport be? At what speed will trains run? What is the level of safety that will be required for automobile transport? What kind of endurance will bridges require? What are the maximum risks which they can support in terms of wind resistance or transported weight? How can risks in tunnels be reduced? If we add large volumes, transparency, anti-corrosion, lightness, sealing, soundproofing, thermal or electrical insulation, intelligent materials, electricalpiezzo products, luminous-sensitive products, flexibility and elasticity to all these questions, we can well imagine that the varying presence of a polymer will hold the key to the problem, in the same way that PVC has solved the problem of windows or PMMA the problem of bath-tubs.

7.1.2.2.2. Example of new material: protective sheaths for optical cable networks

These were first created commercially in 1990 in high-density polyethylene, the first instalation was done by Alcatel in 1995 and the global market came into existence in 1998. Today it represents more than 200,000 tons of tubes, with forecasts for 2010 reaching 500,000 tons. But the latest work results have forced the producers to revise these forecasts downwards and to maintain a stagnant market. Again the material was chosen on account of its intrinsic qualities: no underground degradation, very good compression resistance (optical fiber protection) with good flexibility, large lengths between two welds, perfect electrical insulation, very good resistance to termites and other micro-organisms.

7.1.3. *Civil engineering: a place in the construction market*

The market share of the civil engineering in construction is 18% in Europe, including 12% of new structures and 6% of restoration and maintenance. This 6% accounts for the major part of polymers consumption, as they are mostly used as products for repairing: concretes and resin mortars, polymeric cements, reinforcement fibers, glued plates, carbon fiber fabrics, injection resins etc.

New Construction		Renovation and maintenance
24%	Residential	25%
20%	Non-residential	13%
12%	Civil engineering	6%

Table 7.1. *Distribution of the construction sectors in Europe*

We have found in the previous calculation that plastics alone represented nearly 25% of civil engineering, whereas we also noted that civil engineering accounted for only 18% of construction.

So we understand that in this market for public works and major projects, polymers have penetrated significantly.

7.1.4. *Incorporated or built-in materials*

This section concerns organic products which are incorporated within other construction materials. Concrete accounts for 71% of construction materials.

Construction products	Tonnage 2000 (x1,000)	Rank in %
Concrete and the likes	503,000	71%
Tiles and bricks	73,000	10%
Wood	54,000	7%
Irons and steel	24,000	3%
Stone, quarry	16,000	2%
Asphalt and bitumen	16,000	2%
Plastics	**6,850**	**0.97%**
Flat glass	5,200	0.73%
Mineral wool	2,000	0.3%
Copper	1,300	0.2%
Aluminum	900	0.1%

Table 7.1a. *Review on the situation in 2000*

The idea to use chemistry to modify the characteristics of concretes is not new. However, from a few years back, chemists have been able to appreciate the enormous potential that this market represented. With the consent of the cement-manufacturers, they have started searching for polymeric materials exclusively meant for products for the concrete industry.

With the help of the trio formed by the cement-manufacturers, the chemists and the additive producers, not forgetting the companies that took a significant part in this research, this family has made considerable progress in a few years in the following:

– super plasticization;

– reduction of E/C ratio;

– self-leveling or self-placing concretes;

– very high strength concretes (BTHP);

– extrusible concretes;

– ductile concretes;

– ultra thin shells.

The market for polymeric additives incorporated in concretes remains very confidential today: it must undoubtedly be in the range of few thousands of tons, with patent owners remaining extremely discrete on this subject. However, we can assume that in the next 10 years it will become one of the major polymer markets.

The use of the chemicals in concretes as mentioned above is not new. Products like sulfonated melamine, lingosulfonates and stearates are in everyday use, but are used very differently in each European country. We have found that in countries with very strong cement consumption like Italy, England, Turkey and Russia, the admixture in concrete is less; on the other hand, in countries where maximum quality is required, as in Switzerland or in Belgium, the additives are present in 80% of the ready to use concrete. Found between the two are France and Germany, with approximately 25 to 15% admixture in ready to use concrete.

Country	Consumption in tons
United Kingdom	4,600
Italy	6,200
Switzerland	9,800
Belgium	10,600
France	14,800
Germany	47,000
Europe	121,500

Table 7.2. *Consumption of superplasticizers in Europe (1998)*

Considering the new requirements that we have mentioned previously – new environmental standards (clean building site, soundless building site), new calculation Eurocodes – we are of the opinion that almost all ready to use concrete irrespective of its level of strength will contain admixtures. We therefore have a market of 6 million tons opening up for chemicals and polymers.

7.1.5. *Bitumen-polymers*

This case has largely been dwelt upon by Bernard Lombardi; however, the economic reality of polymers in this sector is very important. In this case, we mainly look for flexibility and strength, therefore the products that will be developed will rather be plastomers, polymers with very strong elastic phase, some bitumens strengthened by vulcanizable rubbers (SBR) in the presence of sulfur. The major part, however, is represented by thermoplastic elastomers (SBS, EVA) and in some cases by the use of atactic polypropylenes (APP).

Polymers	Tonnage in kt (2000)
SBS	27
EVA	3
SBR (STYRELF)	15

Table 7.3. *Consumption of polymers for road asphalt (year 2000)*

However, following the example of concretes, polymers are not the only organic materials used in the bitumens. Amines are largely used in France and in Spain to make bitumen emulsions or as adhesiveness dopes.

Additive type	Tonnage (in t)
Emulsifiers	8,000
Dopes	2,000

Table 7.4. *Consumption table of additives for bitumens*

France	1,100,000	Germany	120,000
Spain	400,000	USA	2,200,000
UK	300,000	World	5,500,000
Italy	120,000		

Table 7.5. *European production of bitumen emulsions (in tons)*

7.1.6. *Coatings*

Coating is a type of material, solid or liquid and even in some cases gas deposited as a thin or ultra thin layer on a substrate from any origin, which actively contributes to the value addition of this substrate in order to guarantee the results and the required performances.

Polymers are materials less sensitive to risks of degradation due to aqueous, saline or chemical corrosion and even insensitive to UV like fluorinated polymers. It is therefore in this field that the applications will multiply.

7.1.6.1. *Protection of stays and tension cables of bridges*

The use of HDPE and polyBD in the manufacturing of suspension cables for making "coherent" strands (Freyssinet patent) is a demonstration of the contribution of polymers in the development of new concepts to obtain high corrosive resistance.

As for the protection of the cables for cable-stayed bridges, they are high-density polyethylene sheaths, co-extruded with an external layer specially conceived to resist UV. In some cases a third surface layer of a few microns in PVDF allows the effective flow of surface waters, thus avoiding the risks of wind vibration.

Considered period	**1995/2001**	**2001/2005**
Km of cables	250	200
Number of bridges in this period	30	20
High-density polyethylene	450 tons	300 tons

Table 7.6. *Market for stay sheaths*

7.1.6.2. *Sealing by geomembranes*

There is also a market for geomembranes in the following areas:

– bridges;

– water towers;

– containment basins;

– spoil areas;

– insulation in infrastructure.

In this field, the most widely used polymers are the linear or low-density polyethylenes, plastic coated PVC with or without textile reinforcement, polyurethanes or polypropylenes. This however does not concern liquid sealing compounds (rather small market) and the specific market of complexes with bitumen base.

Polyethylene	60%, i.e. **210**
PVC	18%, i.e. **63**
Filled PVC	15%, i.e. **52.5**
Polyurethanne	7%, i.e. **24.5**
Polypropylene	NS

Table 7.7. ***Market of seals (in thousand tons)***

7.1.6.3. *The "coil coating" market*

In civil engineering, we must mention coil coating because it is related to the large metal coatings of buildings, especially those which are high and thus enter into the domain of civil engineering.

The market for surface treatments, which range from the antifouling treatments for concrete or stone works to lacquering of metal surfaces from epoxies, polyesters or PVDF, is particularly important in terms of surface if not tonnage.

7.1.6.4. *Tubes and pipes*

As we saw earlier, conduits remain the spearhead of polymer volumes in civil engineering with some *1,104 thousand tons*, used primarily in sanitation underground sleeves, and in the composition of pipes transporting gas – either new new pipes or fixed ones (casing). The main materials found in Western Europe are:

Material	**Application**	**Tonnages**
PVC	Sanitation, evacuation, chemical engineering	486⇨30%*
PEHD	Gas tubes, sleeves and networks, petroleum engineering	525⇨60%*
UP	Chemical engineering	43⇨35%*
PP	Large diameter sewerage	50⇨34%*

*Share of the civil engineering with respect to the total tonnage for construction

However, we have noted the development of polyisobutylenes for transporting hot water or vapor (urban heating) in certain countries of Eastern and Central Europe, but tonnages are not very significant.

7.1.6.5. *Noise screens*

The majority of the noise screens are made with "sound porous" materials intended to trap noise. In this field, some approaches with recycled plastics have found sure success on the technical and economic level, but their commercial development still remains limited to date. The main success in this field has been a concrete-wood system where wood enters into the scene like a component playing the part of porosity to sounds. This is an interesting approach of usage of an organic material in concretes.

The most spectacular achievements of plastics in this market are the PMMA screens (methyl polymethacrylate), which are screens which only reflect, whereas the others are “absorbent”. However, they have the following advantages:

– transparent (no phenomenon of confinement);

– do not require maintenance;

– have an excellent resistance to UV;

– have a good impact resistance;

– very light, easily usable on crossing passages.

System	Market share (2000)
Concrete-wood system	~ 30%
Recycled plastic	~ 2%
Transparent plastics	~ 5%
Concrete	~ 10%
Wood	~ 15%
Metal	~ 10%
Vegetable panel	~ 10%

7.1.6.6. *Composites*

The polyester-glass, epoxy-glass or epoxy-carbon composites have made a very spectacular entry into the world of civil engineering:

– load-bearing structures for bridges and building;

– covering of bridge;

– wall cladding panels for large units;

– repair of structures (epoxy/carbon fibers).

But we can also relate mineral composites associated with organic binders to this world of composites:

– mortars and resin concretes for repair;

– protective shells inside tunnels;

– epoxy resins for injection of cracks;

– epoxy/fiberglass systems.

The total European market in this field has been estimated at:

Resin type	Pure resin tonnage
Polyester	150,900 tons
Epoxide	80,000 tons
Phenolic	

7.1.7. *Conclusion*

It will not be appropriate to summarize such an important subject in just a few pages. We offer our readers sincere apologies for having skimmed through the points mentioned here and particularly all omissions regarding the most common materials such as road, decorative or protective paints, coatings, chemical grouts or even glues. For we have tried to present our research in this document on the most emphatic fields either on account of their significance, their excellence or their originality.

To make all types of construction lighter, this would surely open the doors to an architectural revolution in civil engineering structures, which could be all the more remarkable as their durable character would bring about new ambitions, like building today the "historic buildings" of tomorrow.

7.2. Bitumens in civil engineering: their place and their future[2]

7.2.1. *Introduction*

Bitumen is an organic material par excellence. It is the heaviest cut of crude oil (if present in it) to which it gives its black color and viscosity. Crude oil represents the end of a very long process of physico-chemical evolution of marine organisms incorporated in sediments, which have settled and accumulated in sea beds gradually being subjected to an increase in temperature and pressure, resulting from the subsidence of the sedimentary basin.

From the chronological point of view, the use of the bitumen for its hydrophobic properties has clearly appeared before its use on account of its binding properties. It should also be noted that the bitumen content in a waterproofing material is much greater than in a structural material. Sometimes though, the bituminous screen or membrane is a film of pure bitumen, with varying thickness.

2 This section was written by Bernard LOMBARDI, GPB.

In the following part, we will first speak of the bitumen binders in the waterproofing industry, followed by binders used in the construction industry and the road maintenance, which overall account for approximately 3 millions tons (Figure 7.1).

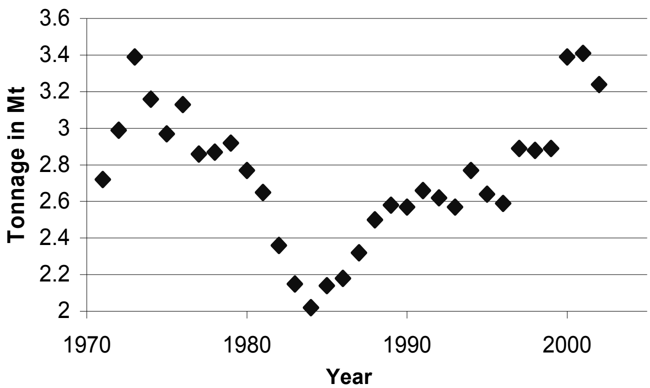

Figure 7.1. *Graph explaining the French consumption of bitumen between 1970 and 2003*

7.2.2. *Bitumens in waterproofing and ancillary industries*

7.2.2.1. *Waterproofing*

Structures concerned by waterproofing requirements belong to the building trade (roofing, coating of foundations in wet ground) as well as to civil engineering (bridges, tunnels, dams, etc.).

The most widely used bituminous material in terms of covered surface is the bituminous sheet, which appears in two main forms, felt and creed. These two products are constituents of the waterproofing complex known as "multi-layer", intended to ensure perfect waterproofing of the building and if necessary to give the final appearance to its cover.

During last 30 years, the development of increasingly efficient bitumen binders has helped the industrialists of the sector to develop bituminous sheets with ever-improving qualities, leading to major changes at the level of complex design and laying. In fact, in the past, sheets were made of a reinforcement frame requiring an impregnation with pure bitumen before receiving the surfacing binder. This bitumen was generally formulated from oxidized bitumen, with varying amounts of fillers. The complex consisted of at least three layers, i.e. two layers of felt and one of creed, glued to each other as well as on the medium using a hot impregnation coating poured at more than 200°C at the time of laying. This coating is oxidized bitumen of type 100/40, or even more viscous.

Research has never stopped, since 1968, when the first industrial tests intended to prepare an elastomer bitumen binder were carried out. The focus was still on the first objective, but other objectives were added. The limited elasticity of the oxidized bitumens did not pose a problem for the complexes well-protected against thermal variations due to heavy protection largely used in the 1950s and 1960s. But the development of new lighter covering techniques with strengthened heat insulation, thus directly exposing the complex to sun rays, showed that the rheological properties of the bitumen binder needed to be modified significantly. The *bitumen-SBS* mixtures with strong SBS content finally asserted themselves as they conferred the expected properties on the bitumen sheets, making them capable of withstanding the most rigorous winters as well as the sunniest summers. An additional step was taken by the development of self-weldable or self-adhesive bitumen binders. These bitumen-SBS type binders contained other polymers, of polyolefin type for example, that was intended to confer these new properties. The sheets thus manufactured no longer required any hot impregnation coating with just a single layer ensuring the waterproofing of the cover.

In 2003, we found that the felts and creeds in non-modified bitumen represented only a small percentage of the market.

The development mentioned here shows that bitumen is capable of receiving macromolecules, which significantly modify its properties in the required direction while at the same time preserving its integrity and its fundamental characteristics, namely its waterproofness, its adhesiveness on many media and its endurance.

Incidentally, the insolubility of bitumen in water is used to make paving of dams designed to retain the water intended for human consumption. From a long time ago, the health department officials wondered about the harmlessness of such material. All the studies undertaken so far according to the most recent protocols confirm that pure bitumen when placed in prolonged contact with water releases neither hydrocarbons, nor metals, nor metalloids.

7.2.2.2. *Ancillary industries*

Many industries with extremely varied activities have developed during the rebuilding of Europe after the Second World War. All these industries called upon bitumen binders for purposes of gluing, protecting, insulating, coloring and compacting. However, as time passed, various synthetic materials gradually replaced bitumen binders or their activity almost disappeared, leading finally to the stop in supply of certain binders.

The following list is just given as a reminder. Bitumen binders that were sometimes very special were used in the following applications:

– protection of underground pipes;

– insulation and protection of electrical equipment such as condensers, cells, batteries, junctions, electric and telephone cables;

– conglomeration of coal fillers;

– protection of storage of powder;

– pigments and fillers in inks and rubbers;

– binders in clay pigeons;

– protective film of semi "bitumen mulch" and arboricultural mastic.

7.2.3. *Bitumens in road construction and maintenance*

For this activity, we must make the distinction between two important functions: the first, which consists of providing or strengthening the load-bearing structure of the pavement and thus affects it on a minimum thickness of several centimeters, and the second, which is limited to the surface of the pavement, ensuring its impermeability and roughness.

7.2.3.1. *Asphalts*

Asphalts, whose formulation varies according to the position occupied in the pavement, confer rigidity on the road foundation and function like a beam. Bitumen, whose strength varies from 3.5% to 6% in weight compared to the dry aggregates, is the element that increases considerably the rigidity modulus of the bituminous mix, subjected to compressive and tensile stresses. The mechanical strength of material under the strains of traffic would be smaller but for the presence of bitumen which is well distributed within the aggregate matrix.

A pavement must be able to support the heaviest vehicles in all climatic conditions, without cracking at the coldest temperatures and without rutting at the highest temperatures. All these behaviors can be quantified through mechanical tests such as the dynamic module, fatigue and creep. These tests, conducted after immersion of the asphalt in water for several days, help evaluate the water resistance of the asphalt. With regard to surface bituminous concretes, an immersion in brines for de-icing followed by freeze-thaw cycles help to adjust the formulation mixes for severe winter viability conditions.

For nearly 30 years, formulations have evolved to face the increase in the general traffic – heavy vehicles in particular – consequently, we have noted an increase in the aggressivity of the wheels related to the replacement of twin axles by single axles with the tires leaving a narrower contact area and inflated with higher pressure. The last trailers equipped with three very close single axles apply considerable tangential stresses to the road surface in short radius curves like the many traffic circles located in restrictive space.

Modifications of formulae related at the same time, to the grading curve of the aggregate, the rigidity of the bitumen as well as its content. Selecting a bitumen belonging to class 35/50 by also optimizing its strength and the filler-bitumen ratio was the answer to the normal evolution of requirements. On the other hand, pavements with heavy channeled and aggressive traffic required the development of mixes using binders modified by polymers, either in physical mixture or by chemical cross-linking.

With regard to physical mixtures, there are two schools of thought with conflicting views. For one the solution lies in elastomers and for the other in plastomers.

We must recall that the main objectives of the modification consist of widening the plasticity interval of the binder, i.e. by increasing its resistance to high operating temperatures (softening point) and by lowering its brittle temperature to low temperatures (Fraass breaking point). By using the concepts of rheology, this is reflected in the search for a binder having a complex modulus less variable with respect to operating temperatures and strain frequency.

In the current state of works, a good trade-off would be a combination from the two polymer families taking care of using a bitumen in its pure state, with good characteristics at low temperature.

The case of the cross-linked binders is special because since it is a specific process, the manufacturer can choose the basic polymer(s) and carry out cross-linking so as to obtain the best trade-off. The cross-linking reaction brings a significant transformation of the binder properties at the cost of reasonable additional work.

As we have just seen, solutions are available but the techno-economic context existing in France for around 10 years did not support the development of the polymer-bitumen type binders for the road. The share of these binders remains lower than 10% of the bitumen tonnage consumed and the experts do not forecast any notable change in the short run.

7.2.3.2. *Surface dressing*

This technique, exclusively intended to treat the surface course, is composed of alternative layers of binders and aggregates. The binder is used here to stick the aggregates directly on the medium. It must be able to resist the mechanical strains imposed by the tires in all climatic conditions, from the lowest temperatures to the highest temperatures, very often in the presence of water.

As in the case of the asphalts, decision makers require binders that are able to support all operating aggressions for the longest possible period without exhibiting major disturbances like delamination or bleeding.

Polymers based binders meet the needs well, but an additional difficulty must be taken into account. It is true that binders for surface dressing are either fluxed bitumens or emulsions.

In case of the fluxed binders, the nature and the content of flux must be optimized so that after application the binder finds its optimal consistency rather quickly.

In case of emulsions, the presence of macromolecules in bitumen strongly changes the behavior of the binder at the time of emulsification. The grading distribution of the binder globules dispersed in the aqueous phase is broader than in the case of pure bitumen and this greatly influences the viscosity and the sheer rate of the emulsion.

Notable progress has been made on this, but other phenomena still remain to be discovered.

7.2.3.3. *Cold mixes*

These are materials that help to structure a pavement but in which the binder is not hot mixed with dry and hot aggregates.

The grave emulsion, the cold bitumen concretes and the slurry-seal or slurry surfacing are prepared by mixing cold and moistened aggregate with a cold emulsion.

As in case of the hot mixes, the formulations continued to evolve to face demand and especially to be used on heavy traffic roadways, replacing in certain cases the solution initially proposed, based completely or partially on hot mixed materials.

With particular regard to slurry surfacings, the achievement of such a surface course capable of supporting traffic approximately twenty minutes after its placing, makes use of modified binder emulsions or latex added emulsions.

7.2.4. *Conclusion*

This rapid overview highlights the major part played by bitumen in civil engineering. It is a *natural* adhesive, at a reasonable cost and for exceptional performances.

In addition to the suggested properties, we must also mention that bitumen can be entirely recycled. We just need to heat the bituminous material to rework it, and to correct its formula if required – aggregate grading on the one hand, and regenerating agent added binder on the other - before placing it again.

7.3. Organic polymers in building: development and tendencies[3]

The most important applications of synthetic organic materials in the building industry are related to plastics. These are usually used for making many products and structures, particularly:

- tubes, pipes, joints;
- insulators;
- floor wall coatings;
- shell and roofing products;
- millwork frames;
- sanitary and electrical equipment.

The development of plastics took place through substitution of traditional materials: steel, copper, wood, ceramic and by following new specifications, in particular in the field of the heat insulation.

The two major tendencies of the use of plastics in the building industry are:

- to satisfy high requirement level specifications. For example, in the field of plumbing we have found that the first uses of plastics were related to draining and that current developments are related to conduits at high temperature and pressure: heating, supply;

3 This section was written by Robert COPÉ, CSTB.

– to find new applications for exposed products outdoors: weatherboarding, wall panels, bays, translucent elements and cover parts. In these different fields, the technological capability to control coloring and their durability is a fundamental asset.

Furthermore, beyond plastics, synthetic organic materials have multiple uses that are often less well-known but promoters of technical progress: paints and varnish, fibers, elastomers, mastics and resins.

These applications of synthetic organic materials do not replace products or structural components, but are integrated into a structure or a product in order to improve performances:

– anti-cracking fibers for coatings;

– additives for mineral materials (mortar for coating, HP concrete, etc.), bitumens;

– treatments of joints between components and products;

– various assemblies: double glazing, bonded glass, etc.

Figure 7.2 showing the position of various polymers on their life curve helps us to perceive the general dynamics of this family, since the position of synthetic organic materials in the building industry is not markedly different except for longer appearance/penetration duration when compared with other sectors of application.

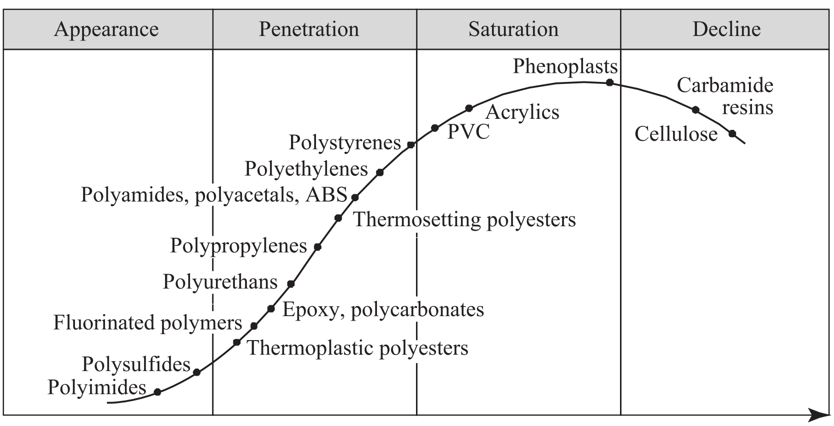

Figure 7.2. *Current state of the presence of main polymers in the building industry*

7.3.1. *Current usage tendencies*

Polyvinylchloride (PVC) remains the main polymer used in the building industry; its main applications in decreasing order of importance are:

– conduits for fluid conveyance or drainage, electric cable ducts;

– floor or wall coverings;

– sections: shutters, windows, and weatherboardings;

– sealing films.

For these different applications, PVC has replaced metals or wood gradually. Its growth prospects are in the area of material with great color diversity, more efficient at the thermomechanical level or with long term stable optical properties (transparency).

Polymers used for heat insulation rank second as per their tonnage: they are either the expanded or extruded polystyrene used in the form of flat plates and molded components, or cellular polyurethane used in the form of flat plates projected *in situ*.

These expanded polymers are in certain cases a substitute for fibrous insulators on account of their hygrothermal and mechanical performances. Important structures are done today aimed at improving not only their thermal characteristics but also other parameters which form weak points such as fire behavior, dimensional stability and acoustic performances.

Polyolefins can be divided into several categories: low or high-density polyethylenes, cross-linked polyethylene, and polypropylene, which occupy an important place in the fields of pipes and films. The common formulations are characterized by a limited lifespan, when these products are subjected directly to the external climatic environment.

Reinforced plastics are especially made of polyester resins reinforced with fiberglass that are used for manufacturing corrugated sheets, weatherboardings and various sections.

It is possible that in the near future, thermoplastic matrix composites find new openings in the building trade, especially in the technology of thermoplastic impregnated fibers which can be developed on a large scale for manufacturing structural parts.

The term organic glass includes three types of polymers: polymethyl-methacrylate (PMMA), polycarbonate and PVC. PMMA has optical properties that are equivalent to mineral glass and has a good durability: polycarbonate is well-known for its mechanical behavior and its great impact resistance.

These organic glasses are presented in the form of flat homogeneous or architectonic plates and can be transformed to a significant degree into ribbed sheets related to the optical function of mechanical and thermal functions. Their durability remains very variable as per the various formulations.

Many polymers are used in the building industry, but their quantitative development remains limited:

− well-known epoxy resins in the fields of assembling, resurfacing and in the composite form (with carbon fibers) for strengthening structural elements;

− elastomers like polychloroprene or the EPDM and even more generally thermoplastic elastomers (ETP) used in the from of sealing sections or expansion bellows;

− technical polymers (polyaceta, polyimide, etc.) that are used in joinery hardware, valves and fittings or in the field of reinforcement fibers;

− phenolic resins in the form of laminates or cellular foam that are characterized by a rather less unfavorable behavior in fire.

7.3.2. *The polymers of tomorrow?*

Like composites, the future polymers will be synthesized to satisfy a combination of prior defined properties. This is why a very large number of new polymers will just be existing materials but modified: particularly in the case of alloys or polymer mixtures obtained with the help of very sophisticated techniques.

The usage of synthetic materials in resistant structure could open a new field of application of significance. Experiments for creating elements subjected to strong mechanical strains do exist, in particular in the field of naval architecture. When used for making large building structures we need to take into account their behavior in temperature and their specific deformability. Perhaps this will form the “second wave” of development of synthetic organic materials in the Building industry.

Prospects for development of synthetic organic materials in the Building industry could finally be influenced by possible regulatory restrictions related to the management of the life cycle of these materials, when their magnitude of development in all the industrial sectors poses ecological problems related to destruction or recycling at their end of life. But the challenge has already been accepted and for materials that were specifically targeted, their environmental and sanitary impacts have been put into perspective.

7.4. Importance of a physico-chemical approach in the behavior of the materials – with damage as an example

7.4.1. *Introduction*

To approach the behavior study of construction materials by a physico-chemical approach is not the usual way to proceed. The behavior constitutive laws belong primarily to the macroscopic field where mechanics is the reference science. It is true that this assertion is no longer completely true with problems of durability, aging or simply (if we may say) damage coming into play.

On this last point, however, there are researchers who approached the problem under the physico-chemical angle, using in particular thermodynamics and chemical kinetics. Unfortunately, with respect to our study, their application field remained centered on traditional materials, i.e. metal and concrete. We find here once again the difficulties stated in the Foreword concerning the lack of data on the properties of organic materials generally in the field of civil engineering and construction in general.

So, we thought it would still be interesting to present this physico-chemical approach of the phenomena of damage, even if it applies to mineral materials because it refers here to a model approach. It opens up numerous viewpoints, which go beyond the nature of these materials and can also very well inspire designers of organic materials, as well as the users, in civil engineering and construction in general.

7.4.2. *Problem overview*[4]

Let us consider a porous solid in which a gas or an aggressive fluid circulates, for example air with a little sulfuric acid content. While circulating, this fluid attacks the bonds that ensure material cohesion. The material gets gradually damaged. Even if this damage is slow, it is inevitable and can lead to the destruction of the material and to the collapse of the structure in which it is located. The temperature is indeed a factor that greatly influences the speed of damage. In a hot and oxygenated atmosphere, if the temperature is about 1,000°C, a Zirconium sample can be totally destroyed in less than 24 hours!

We mean to say that the engineers who make predictive theories must take into account the physico-chemical phenomena. This can be done at the microscopic level: we can write all the equations that govern the phenomenon at the pore level. It

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4 This part was written by Michel FRÉMOND, Laboratoire Lagrange.

gives a particularly fine description of the life and the evolution of this small material element. But to use these results in engineering, we must come back to the macroscopic level: the engineer's level. It is a delicate task but is never out of reach: the homogenization theory has made it possible to summarize or synthesize microscopic properties at a macroscopic level. This developing theory cannot always be applied in practice. Another approach would be to take into consideration macroscopic variables directly related to the microscopic phenomena and to apply carefully the basic laws of thermomechanics. In our case, we can choose the volume fraction of active bonds: i.e. a function of the material point $\vec{x}$ and time t. Its values lie between 0 and 1: when it is 1, the material is sound; when it is 0, all the bonds are destroyed and the material is no longer cohesive. We know that the speed of β, dβ/dt is a macroscopic representation for the destruction speed of the microscopic bonds. By applying the fertile idea of mechanics, which consists of defining the generalized forces by their power, we choose as power of the forces that take part in the destruction of the bond a linear functional of dβ/dt:

$$P = \int_{\Omega} \left(B \frac{d\beta}{dt} + \vec{H} . \overrightarrow{grad} \frac{d\beta}{dt} \right) d\Omega$$

where Ω is the domain occupied by the considered structure. The principle of virtual power leads to the equation that describes the microscopic motion:

$$-div\vec{H} + B = A$$

where A corresponds to the energy generated by the chemical reaction, and B and $\vec{H}$ are the internal stresses related to β and dβ/dt by constitutive laws.

Physical chemistry should be able to estimate the external action A that then gives the evolution of β. In the example of a break in bonds by chemical reaction, A corresponds to the energy provided by the destructive reaction. In other situations, this can be physical energy: for example, we know that radiations damage metals. So, A corresponds to the energy provided by the neutrons that destroy bonds ensuring the cohesion of the irradiated metal.

The source of damage can also be mechanical: each one playing with a paper clip, which when twisted repetitively ended up breaking. A good expression for the source of damage is in this case $w - e(\vec{x}, t)$, where w is a quantity that represents the cohesion of the material and $e(\vec{x}, t)$ is its elastic energy. The material will be damaged if elastic energy is greater than w or if the distortions are large. It will not be damaged if this energy is small ($w - e(\vec{x}, t) > 0$), i.e. if the material is not deformed very much.

These phenomena must be observed for purposes of gaining a better understanding. This is not easy but again thermomechanics opens a new window of observation: infrared thermography. In fact, the various phenomena that we have just mentioned have thermal repercussions. For example, mechanical damage is dissipative, i.e. it is exothermic. The measurement of the rise in temperature gives information on the evolution in β.

7.4.3. *Application in case of a damagable elastic material*[5]

Information on such an approach is provided by the study of thermomechanical behavior in a compression cycle of ordinary concrete (considered as a damagable elastic material). Combining mechanical tests with a follow-up of the temperature chart of the material obtained by infrared thermovision, we can quantify the associated thermal effects with respect to the elastic behavior (thermoelastic coupling) on the one hand and with respect to the evolution in damage on the other. Through the previously mentioned line of operation, we can present the observed phenomena in a satisfactory model.

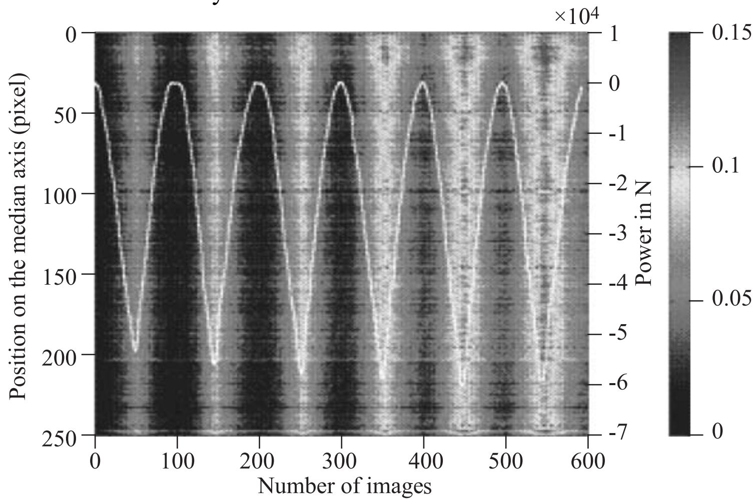

Figure 7.3. *Time evolution of the temperature profile of the median axis of the test specimen (1s = 5 pictures, 256 pixels = 80 mm). Superimposed white curve: load evolution*

Figures 7.3 and 7.4 reflect the time evolution and the evolution at each median point of the observed face of the test specimen of the variations in temperature as a function of load evolution. The latter is made up of six load-unload compression cycles, carried out at a more or less constant deformation speed and up to a stress of about 35 MPa.

5 Sections 7.4.3 and 7.4.4 were written by Olivier MAISONNEUVE, LMGC-Montpellier University.

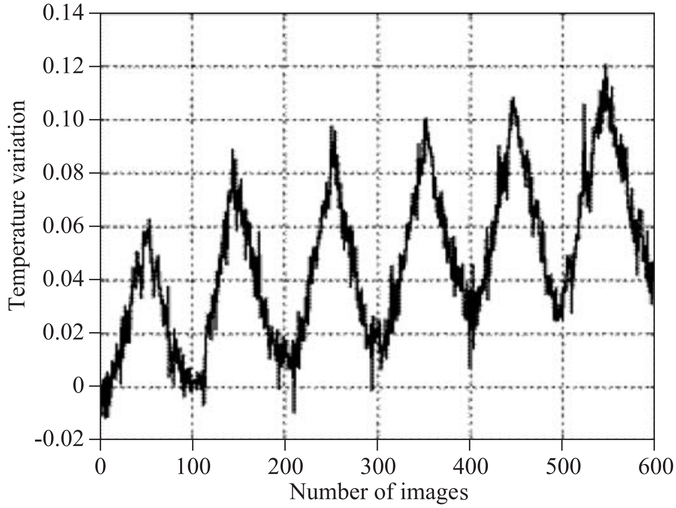

Figure 7.4. *Time evolution of the temperature variation at the median point of the test specimen*

We can note the superposition of the two phenomena:

– a positive temperature variation, constant along the test specimen, in phase with the load evolution. The maximum amplitude of the observed variations is 0.08°C for a stress of 35 MPa;

– a small progressive heating of the test specimen reaching 0.04°C at the end of the test (see Figure 7.4).

The first phenomenon corresponds to thermoelastic coupling. The second is related to the evolution of the material damage, the stress reached at the time of each cycle being very close to the rupture strain.

Modeling takes into account the power of the internal forces respectively related to the damage and its gradient, whence laws of state, complementary laws and an equation for evolution of the original damage variables.

Figures 7.5 and 7.6 show the simulation of the previous tests.

Figure 7.5 shows that we find on the mechanical level the classic behavior of concrete in compression.

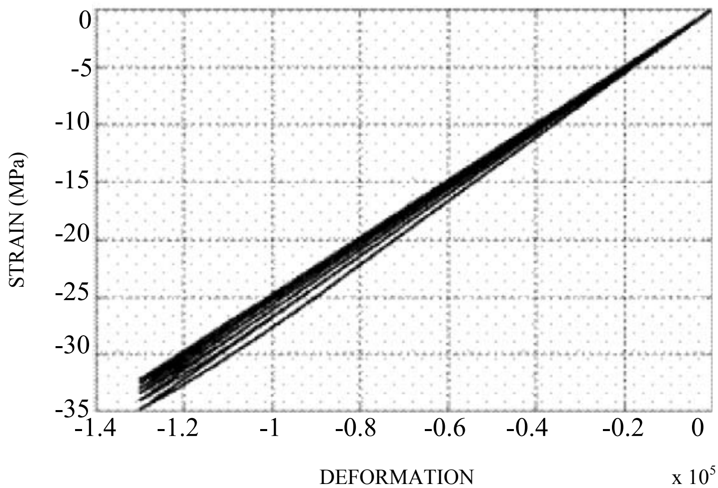

Figure 7.5. *Stress-deformation response*

With each loading cycle the material is damaged a little more, Figure 7.6 gives the evolution of damage. Since the thermal phenomena involved are small, there is no notable difference between the isothermal mechanical behavior and the modeled behavior.

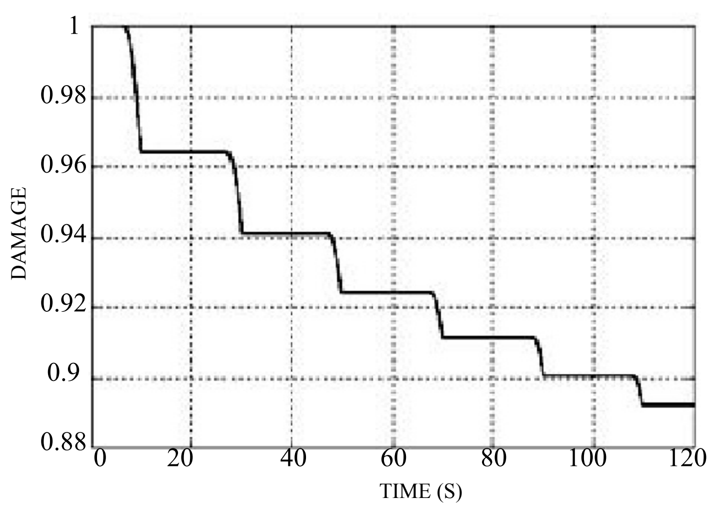

Figure 7.6. *Evolution of damage*

For thermal behavior, the model can simulate the evolutions of intrinsic dissipation, of terms representing the link between temperature and damage, the term for combining temperature and deformation as well as the variation in material temperature (Figure 7.7).

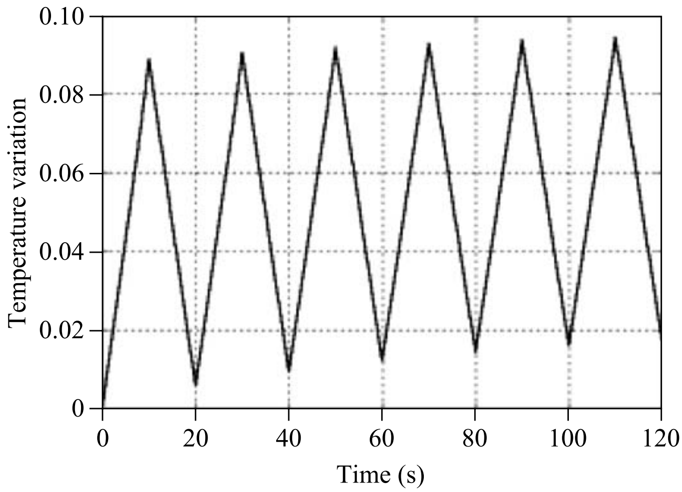

Figure 7.7. *Variation in temperature*

The latter should be seen side by side with the simulated evolution of the heat sources (Figure 7.8).

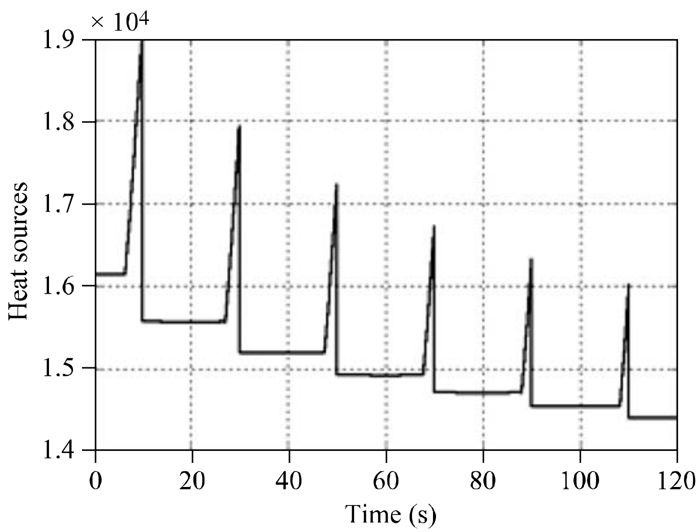

Figure 7.8. *Evolution of the heat sources*

We note that it is very easy to locate the experimental results on this model.

However, the effectiveness of these macroscopic approaches should not hide the physico-chemical dimension of the damage phenomena that is crucial from the point of view of sustainable development. We can mention the case of concrete damage by freeze-thaw cycles with its effect on the thermomechanical behavior of the material. Today's engineer is conscious of the fact that the control of design and use of materials will increasingly go through a thought process and a physico-chemical analysis of the phenomena conditioning the mechanical and/or thermomechanical behavior of materials and therefore structures.

7.4.4. *Case of organic polymers*

The thermomechanical approach of polymers is also possible through energy balances based on measurements obtained by infrared thermovision. The results supplement or corroborate the results stemming from a physico-chemical approach. The notions of entropic elasticity and thermoviscoplasticity help to illustrate this subject. Certain thermoplastic copolymers, of low shore hardness, can undergo deformation of considerable percentage (rubberized hyperelastic behavior). To this hyperelasticity is added, for higher grades, not only effects of viscosity but also effects of threshold as in plasticity. The analysis of the behavior of these materials is all the more delicate when these are very sensitive to the effects of the environment like temperature or hygrometry. J.L. Saurel *et al.* have studied more specifically a "rigid" grade corresponding to a high density of cross-linking points and a more "flexible" grade.

The mechanical behavior of the rigid grade was found first to be of viscoelastic type, and then plastic beyond a certain threshold. Dissipation was evaluated in the viscoelastic domain, and later in the plastic domain. For viscoelastic behavior, a model was proposed, whose relaxation spectrum was identified from creep tests. Predictions of this model were found to be matching with the thermomechanical observations made during the fluctuating axial tension tests.

In the case of the flexible grade, intrinsic irreversibilities were less obvious. The thermomechanical couplings were found to be dominating with respect to dissipation, heat sources changing directions with the stress. Further, we observed that the quantity of heat involved was equal to the mechanical energy provided. It was shown that for this purpose, whatever the evolution of the state variables chosen to describe the behavior of the elastomer, the internal energy should be a function of temperature only, as for a perfect gas. Thus, we found again a fundamental hypothesis of molecular models having been used to define rubberized (entropic) elasticity from statistical thermodynamic results.

7.5. Organic chemistry and molecular engineering: the future of cementing materials?[6]

Is it reasonable to think that fine organic chemistry, molecular engineering, and even biomimetism and soft nanotechnologies – everything well-established in pharmacology, microelectronics or in the world of advanced materials – have their place in civil engineering? We will hereby defend our point of view that the answer is “yes”. Specificities of civil engineering are by no means incompatible with an approach aimed at controlling matter on the finest scale with the help of the organic molecular world and by using, if necessary, the materials and the structures of the living world as sources of inspiration.

7.5.1. *Mastering complexity*

Can we imagine a better example than biological fabrics or even just the cytoplasm to illustrate, with all proportions kept, what fresh cementing materials are in the process of becoming with the development of self-placing concretes or even coatings of all kinds? The part played by the physico-chemistry of interfaces, polymer solutions, gels and colloids is constantly increasing, just like the thought process on the structure-function relationship of (the macro) molecules of additives. This culture of molecular engineering and *composites* or, to be more precise, the formulation of complex mixtures of mineral grains, polymer particles (latex), associative colloids (micelles), microgels or soluble polymers is already well-established in petroleum engineering and the civil engineering world is acquiring the same at a high speed.

The evolution followed by the various families of superplasticizers is a perfect example. Superplasticiers have evolved gradually from badly defined by-products, with almost nil value-addition which they were originally with the lignosulfonates, to simple and elegant molecules, wherein a precise function is assigned to each group. The first important milestone of this evolution was the transformation from a by-product to a synthetic molecule, in a context where the dogma as regards dispersion was based on electrostatic repulsions. The second was the awareness of the existence and the advantages (hardiness) of dispersion known as “steric” dispersion, followed by the design of molecules using this mechanism, with a main chain in charge of the anchorage of the molecule on the surface and the neutral side chains in charge of dispersion. The last stage has been to some extent the refinement of the concept, with the overall simplification of the anchorage function.

This evolution is undoubtedly not over. The polyphase character of clinker grains and the resulting surface heterogeneity are not really taken into account at this

6 This section was written by Henri VAN DAMME, ESPCI.

juncture. The same applies to the distinction between the separation function of grains and the lubrication function of contacts, which we assume will be of greater importance with increasing grain size. Without the fear of being wrong, we can also add micro-encapsulation to the list of possible evolutions. The controlled release of active ingredients is as interesting in civil engineering as in pharmacology, not only to prolong the action of an additive but to also stop its action, if required. Undoubtedly the dream of a "chemical trigger", likely to light the fuse, is not far from taking shape …

To improve workability by controling the interactions between grains is not sufficient to control rheology and the segregation phenomena in grouts or self-placing concretes. The interstitial solution must itself be adapted just like the cytoplasmic solution is adapted in the intracellular medium. The required properties are mainly related to the aptitude of the solution to form a light gel, with given mechanical resistance and being reformed with specific kinetics during flow stoppage.

The whole physico-chemistry of the self-assembled networks of the cytoskeleton is here to suit and adapt to the cementing medium. Hence we are close the design of *stimulable* interstitial gels likely to inflate, deflate, rigidify or fluidify under the action of an electric stimulus for example. The "artificial muscles" currently being studied show that the concept is feasible.

7.5.2. *Using hybrids*

The impact of (macro) molecular engineering on cementing materials and more generally construction materials is not limited to the soft states of the material. The core of the applicative properties – the mechanical properties – could be affected. Even if primarily organic, the living world also frequently integrates mineral to its architectures. Certain tissues, like bone tissues of mammals or shells of mollusks, drive this integration to very fine scales and to a stage where the mineral is in majority, in a material that can be qualified as *hybrid* or *nanocomposite*. The presence of a small proportion of macromolecules – proteins or polysaccharides – judiciously placed modifies deeply the mechanical properties, the toughness and the bending strength in particular. The exploration of this path in cementing materials is not recent. MDF materials ("Macro Defect-Free") are quite an old illustration (but not outdated) of this approach, which if refined, with finer control of polymer distribution in the cementing matrix, it could open the doors to specific applications, from which cementing materials are excluded for the time being.

7.5.3. *Molding and molecular imprints*

It is perhaps in the intermediate phase between the fresh state and the hardened state, where the material is literally built at the microscopic level, that the contribution of the organic chemistry will be most innovative. The synthesis of porous material was revolutionized in the last decade by what is now known as *templating* or *molecular molding*. The idea is to carry out the synthetic reactions of the inorganic solid in a self-organized molecular structure – spherical micelles, cylindrical micelles, lamellar phases, sponge phases, etc. – of amphiphilic molecules. When the inorganic solid is built in this matrix, it moulds itself to some extent into the geometry of the molecular system and freezes it. Thus the molecular assembly rules mainly determine the texture of the final inorganic solid and hence its properties of adsorption and transfer. In a different form, the alliance of an organic molecular architecture can also direct the inorganic growth towards specific crystallographic forms by *molecular imprints*. For example, a polyelectrolyte film, synthesized in contact with an aragonite crystal, is capable of, after having removed it and placed it in a calcareous solution, initiating the crystal growth of aragonite while, in its absence, calcite would have been obtained. In this case, it is the load distribution on the surface of the polymer film that directs the structure of the crystal nuclei.

In more simple terms, this use of organic molecules to direct the inorganic growth at the level of the crystal lattice is already practiced and mastered relatively well in the case of plaster, when the essence lies in controling the shape of the gypsum crystals. It is still almost non-existent in the case of the cementing hydrates. The use of molecular molding, which would direct texture, is itself totally non-existent. So, a lot remains to be done …

7.5.4. *Towards a green and intelligent concrete*

We will discuss below the possibilities for fresh materials which would be adaptive, stimulable and programmable, in short “intelligent”; hardened materials which would present original mechanical properties, like non-negligible ductility or a great toughness; or even materials which would present combinations of properties usually considered to be irreconcilable, like good strength and good porosity, connected or not connected. It would be futile to conceal that an important obstacle for the generalization of this approach is the additional work that it would imply. This is why it should first make its appearance in the area of the *surface* – horizontal or vertical – of the structures and buildings. The coating trade is here to prove this point. Moving from surface organo-mineral to mass organo-mineral represents a tougher challenge. However, the circumstances there too are particularly favorable. The generalization of the judicious use of waste, slags, pozzolanas, and ashes, etc. gradually introduces the conditions to ensure the development of a basic soft organo-mineral chemistry (the pH of materials containing calcic binder will be never very acidic). If it is proven that the game is worth the candle and if it is done, then concrete and concreting materials in general will also become genuine "green" materials, with the help of molecular contribution.

7.6. Synthetic organic materials and architecture[7]

7.6.1. *Contrasting relationship during the 20th century*

Since their appearance in the 20th century, synthetic organic materials have placed architecture in a dilemma. Different architectural trends have alternately accepted or rejected them. Why? Their appropriation by designers obviously highlight a range of choices based on contradictory cultural values, which we will examine rapidly.

A very strong trend founded on the cottage industry tradition and exalted by the *Art and craft* movement at the beginning of the century, reflected later in *Bauhaus* architecture and still very alive, values "natural" material and the use of its intrinsic qualities. Thus woodwork should remind us that it was once a tree and that the craftsman through his skills knew to take advantage of its defects as well as its qualities. In the same spirit, concrete should remind us that it was framed and thus present the marks of this process, even if mediocre, as is the case of the immense wall of the chapel of La Tourette by Le Corbusier, without which the wall would not have been so interesting! This challenging attitude thrown towards nature goes hand in hand with mistrust when facing artificiality. But this last notion remains prone to many debates and the artificiality of materials can be measured in so many ways that both brick and plastic can probably be regarded as equivalent.

Another trend, also existing within Bauhaus architecture and magnificently showcased by Jean Prouvé, values the industrial process more than the material itself. We have written much in connection with the influence of the famous sheet-folding machine of the Maxéville Workshops, on the aesthetic evolution of building and furniture in the 1950s. Close to this vision of material are found the approaches of a number of plastics technicians who – like Moholy-Nagy even before the war – turned away industrial productions in favor of artistic expression. Synthetic materials were welcomed here for the increase in productivity they brought about and for the aesthetic universes that they inspired.

This way of approaching material should not be confused with the *high-tech* movement, which started with the attempts of the *Archigram* group in the 1960s. Its

7 This section was written by Michel PAULIN, ENSAL.

promoters rather consider the industry like the tool of a new-found freedom of a constantly evolving urban society. For this reason, they recommend wide-ranging technology transfers and display of the industrial object everywhere, both for its use and its plastic value. Piano and Rogers were the first to dare to apply this approach on a national palace: the George-Pompidou Center. The separation of the technical functions consequently results in the design of distinct skins for the frame structure and for the internal parts of buildings. These skins must ensure precise and possibly interchangeable performances; synthetic materials are particularly suited, due to the infinite variability of their formulation and the futuristic nature that we generally assign to them.

7.6.2. *A harmony in the making*

At the beginning of 21st century, it seems that all the trends exist together with none debarred, and that the explosion of the new communication technology has contributed to popularize – in the wake of the virtual reality – the sense of effect, appearance, change, ambiguity, etc. So plastic materials are no longer just "cheap plastics". They have become so familiar in the daily environment that they have overcome the most radical reservations in several building structures. However, in today's collective conscience, major fields still remain where plastic is still to be accepted, particularly in heritage and ecology.

The French have a rather conservative approach with respect to their architectural heritage, even in its most ordinary state. Far from regarding it as a live object representing the ages of life till the present, as do the English or the Japanese for example, they look for the reassuring image of a past Golden Age as proof of the old roots of their national culture. In these conditions, what is needed are materials with the "antique" stamp and new materials are tolerated only if they go unnoticed. This absence of social demand is undoubtedly the reason for the low range of synthetic organic materials targeted at this market by industrialists. However, no longer do we find any renovation in groundwork, improvement or replacement of structures that do not require resins, composites or organic binders.

At the same time, the growing concern of the public for environmental protection is accompanied naturally by a distrust with respect to the products made from non-renewable material or as a result of dangerous manufacturing processes. The silence of synthetic materials with respect to their genesis is seen as an admission of guilt. So, these demand a greater level of information and if necessary greater levels of safety when compared to traditional materials. Organic materials profit objectively from important assets. Wood and many other organic materials are made from renewable or almost inexhaustible material (like salt). Their production channels are less heavy than metals and less localized than cements; they can evolve constantly and can adapt more easily to variations and demand constraints. The biomaterials produced by biological processes are also promising. In addition, the need for environmental quality is accompanied by a rise in performance standards and especially their fine-tuning in the global balance. There again, on account of their variability, organics can offer a more fitting response when compared to their mineral competitors.

Finally – and perhaps most importantly – synthetic materials need to create a consistent cultural image. In fact, contrary to traditional materials, they are not easily identifiable by the unspecialized public. Indeed, their physical, economic and environmental characteristics are so varied that we cannot assimilate them once and for all. This endows them with a certain strangeness that can both repel and fascinate. The cultural heritage related to plastics cannot be of the same type as that of wood or iron, for example; it is not based on some prior knowledge of materials or trades, but on the memory of perceptions and the effects produced by the objects that are made from it. It is therefore up to the designers to arouse the appetite: this is well-done by artists and interior designers, but architects still have to catch up!

7.6.3. *A necessary partnership between architects and industrialists*

The question of collaboration of various experts is crucial for the emergence of all new materials, and particularly so for those that require advanced industrial technology. On one hand, the products designed in the industrial design departments in the hope of meeting a potential demand are often disappointing because they are too dependent on the production tool and do not have enough cultural value. On the other hand, the ideas of the individual designers are often in vain, as they are not easily taken over by the industrial research organization. Small projects must start with the support of laboratories and independent experts till a stage of development is reached wherein we can find some resonance in the industrial processes. This will lead to the need for a larger reciprocal openness on the part of producers and applicators right from training and a very early collaboration in projects. This again requires effectiveness of technology transfer starting from the clothing industry, the automobile industry, the military, aeronautics, etc. or the withdrawal of series products to have them reintegrated into new ranges. We must also highlight the promises held by the systematic inventory of a mixing of materials, the combination of which transforms in a spectacular manner the most ordinary components, but which also requires at the same time that producers look beyond their narrow sphere of activity.

We should not forget that strict building regulations are applicable, as a background to these debates, and these will undoubtedly weigh on innovation. A standard approach on the basis of performance is obviously more favorable, though there always remains some scope for freedom before each regulatory wave. The fact remains that the promoter of ideas must be remunerated and that the applicator of the invention must be guaranteed, for example within the *Atex* framework.

7.6.4. *Organic materials at the core of the mega-technological choices in architecture*

The contemporary approach of architectural constructions favors wall over structure; this led to an explosion in the ranges of claddings and roofing directly available in the market or designed on demand.

For roofing purposes, the traditional black products are softened by elastomer resins, reinforced with synthetic fibers, protected from the radiation by organic films. The diversification of polymer membranes and the development of its semi-adherent gluing techniques have enabled its application on a broad range of slopes. The practice of the reversed roof drives the development of waterproofing, insulating and weather resistant materials: here again the possibility of changing the manufacturing processes of the organic foam helps in the search for specific solutions. The roof concept is increasingly threatened by the concept of "fifth facade". The techniques for covering meet the techniques for facades, going through the same path taken from shingle roofs to weatherboards but in the reverse direction. Thus, "all slopes" products have developed, where stabilized wood is found as wall panels, snow-bearing or sun decking, but where the composites also have their place in troughs and draining modules. We have not yet spoken about canopies and translucent over roofs where organic glasses have made a notable impression.

In case of facades, the changes are even clearer. The oil crisis as well as changes in taste led architects to think of the wall as a vanilla slice where each layer must ensure its specific performance and its continuity. In the pre-war period, the curtain wall that Prouvé developed for the Maison du Peuple of Clichy was thin and light, but their performances were poor. Then the wall complexes became thicker and even heavier. Now these are becoming thin again and still improving their performance due to increased rigidity of low density materials and development of insulators, microporous or waterproof films, sound proofing, anti-UV protections … all fields where organic materials are found by themselves or in composition with minerals and metals. Alternatively, the wall is split into two to project on the outside the facade-screens saving an intermediate space, a climatic buffer and a transition of intimacy. A place is thus created where the aesthetic functions of outer skins can be made by designers who can play freely with color, texture and volume by making use of the possibilities of pigmentation, calendering, thermoforming, gluing, co extrusion of simple or composite polymers as well as their resistance to the chemical agents, tags and shocks, etc. without forgetting wave-permeability required by our hypercommunicative society.

Concepts related to the bay have also changed a lot. From the rhythmic opening of the Haussmann facade, we moved to the modern framing of the field of vision and now to the ludic transition between the inside and outside, the window concept being erased in front of a transparent wall. This releases first and foremost the geometric part giving the advantage to molding over lamination. It can introduce a large variety into the characteristics of transparency and permeability: glazing is no longer made simply of glass; screen-printing is already common, photo-reactive films are developed in laboratories, we work on dirt-proof surfaces, transparent-breathers, etc. All these products require as a matter of importance organic chemistry. Moreover, glazing attempts to fit every kind of support without requiring cumbersome mechanical fixing; this belongs to the field of primers, glues and interfacings etc.

The space inside is also changing. The ceiling, wall and floor linings are mostly based on organic material. If wood makes its return, it is in a large variety of forms like stabilized, laminated and treated form. Textiles also use non-flammable, anti-static, anti-UV and even bioactive fibers. Developments in printing techniques using computer graphics can customize decor; inclusion techniques in transparent resins can introduce any material into the wall to evoke foliage growth as well as champagne bubbles; paints are adorned with silky finishes, spangled, lustrous, microbeaded and already thermochromic. The arrival of fiber optics and photoconductive plastics offers to the designer and the user the possibility of creating their space in keeping with their moods.

All these techniques fortunately develop in an environment henceforth more demanding with respect to pollution and safety and health risks; industry is increasingly under scrutiny from the public and user groups. We can hope reasonably well that this surge in new materials will be more and more compatible with our vital needs. Anyway, it is up to the motivated professionals to take charge.

7.7. Assessment of environmental impact of organic materials[8]

7.7.1. *Problem overview and available tools*

The use of organic materials in the field of civil engineering requires, as for other potentially polluting materials, the performance of a prior check to ensure that they have no impact the environment. As of now, at the European level, there are no

8 This section was written by Yves PERRODIN, ENTPE.

procedures for environmental assessment suited to these materials. Further, material inspection procedures nowadays mainly deal with the characterization of the materials themselves and do not significantly reflect their behavior and impact when placed in their environment. It is therefore necessary to develop methodologies which help to study the environmental behavior of organic materials "*in situ*" or "in scenario".

For this purpose, two types of approaches can be envisaged:

– The first is based on observations and studies *in situ*. This is an inevitable stage required to understand the way ecosystems respond, when subjected to anthropic disturbances. However, due to the complex nature of natural surroundings, it provides only a global answer and only ends in a finding (before and after comparisons, before and after disturbance, etc.), making it difficult to identify the different mechanisms involved and to predict future impacts on the environment due to the use of a particular material.

– The second approach, the purpose of which is this prediction, corresponds to evaluation methodologies of ecological risks (or ecotoxicological, if we speak of the impact of pollutants). These methodologies, being developed presently in other fields, make it necessary to work in simplified surroundings, more often in laboratories, where all or part of the environmental factors are controlled. These include the successive study of the "source term" of pollution (characterization of intrinsic ecotoxicity of the materials used, quantification and study of space and time variability of polluting flows emitted by the structures, etc.), the fate of these pollutants in the environment (identification and quantification of mechanisms of transfer, dispersion, retention and transformation of pollutants) as well as the study of the response of the communities living in the specific conditions of exposure of the scenario studied.

The development of a procedure adapted to organic materials used in civil engineering is to be established with respect to an interdisciplinary work (chemists, geotechnicians, hydrogeologists, biologists, etc.) and can draw on works which have been carried out recently for the study of environmental behavior of potentially pollutant materials used in civil engineering or placed under controlled conditions. We can mention in particular the European methodology ENV 12-920 for the behavioral study of waste in specific conditions, the ADEME methodology for the study of ecocompatibility of mineral wastes recovered as material, the CETMEF/VNF methodology for the assessment of ecological risks linked to the deposition of sediments as well as draft master standards of the AFNOR X31-E and ISO/TC-190 Commissions, which correspond to the operational tools for the application of national methodologies for the assessment of ecological risks associated to polluted sites.

A synthesis of these four methodologies is given in Table 7.8 below.

	Master standard on the behavior of wastes *in situ* (ENV 12-920)	**Ecocompatibility of waste**	**EDR contaminated sediments**	**Master standard for diagnostic of polluted sites**
Holding organization(s)	CEN TC 292	ADEME (France)	CETMEF/METL/ VNF (France)	AFNOR X31-E
Design	CEN TC 292/WG6	INSA-POLDEN + 9 French teams	ENTPE + Cemagref Lyon (France)	AFNOR X31-E/GT "cap standard"
Year	1997	2000	2001	2001
Statute/Role	European standard	Methodology for assistance in waste management	Methodology for assistance in management of contaminated sediments	French standard. Tool for application of EDR methodology for polluted sites of MATE
Evaluation of emission of pollutants	Parametric tests, modeling, simulation tests, calibration/validation of model	Same as ENV 12-920	Percolation tests in columns, sediment ageing tests	Multi-parametric tests followed by parametric tests
Evaluation of pollutant transfers		Parametric tests + complete test	Percolation tests in columns	Multi-parametric tests followed by parametric tests
Assessment of the impact of pollutants on the ecosystems		Tests on microcosms and on mesocosme	Tests on ecotoxicity + microcosms	
Final characterization of risk		Comparison pollutant flow emitted or convoluted with the acceptable flow	Calculation of quotient (PEC/PNEC) + expertise	Not defined (outside scope)
Nature of materials	Mineral	Mineral	Mineral and organic	Mineral and organic

Table 7.8. *Summary of the four methodologies mentioned*

From these, only the method for assessment of ecocompatibility of wastes of the ADEME, and the method CETMEF/VNF for evaluating the ecotoxicological risks associated to contaminated sediments are real methods for assessing ecological risks. The other two correspond to master standards, referring to one or more stages of risk assessment (emission of pollutants in the case of ENV12-920, emission and fate of pollutants in the case of AFNOR X31-E) and defining the adequate standardized tests to be implemented for a given situation or scenario, as well as their general structure. These standards neither deal with the impact of pollutants on the target ecosystems nor with the final characterization of the ecological risk.

Both the methodologies meant for wastes concern only mineral pollutants, but have been considered for the expansion of their field of application. The methodologies for evaluating sediments and polluted sites concern mineral pollutants as well as organic pollutants. Both the standardized methodologies are international tools or are in the process of becoming international tools (CEN standard for wastes, AFNOR standard soon to be ISO for polluted sites). The methodologies for risk assessment dealt with are the French national methodologies. Lastly, all these methods share a common point: they deal with the evaluation of environmental risks produced by pollutant materials, with water as pollution vector. None of these methods deal with the risks resulting from gaseous pollutants, with air as pollution vector.

7.7.2. *Perspectives for organic materials used in civil engineering*

Methodologies for assessment of ecological risks presently in use refer mainly to mineral materials or materials other than organic materials used in civil engineering.

For the latter, we can make use of existing tools:

– by going back to the general methodological approach expounded (definition of a scenario, on line study of the terms “source”, “transport” and “impact”, etc.) as well as to the structure of experimental tests and stages of modeling that these proposed;

– then by adapting the methods concerning organic materials by taking into account their specificities.

One of the specificities of these materials resides in the extent of biodegradability (or biodeteriorability), which can significantly influence the “source” term of pollution, as well as the fate of pollutants in the environment. This biodegradation is therefore one of the fundamental parameters to be taken into account for the evaluation of the global ecological risk of organic materials. We can also base this study on existing tools, like the many standardized procedures existing in France (AFNOR, 1961, 1968 and 1981) and elsewhere (ASTM, 1976, 1990, 1993), meant to evaluate the resistance of various types of organic materials (mainly plastics and paints) to biological agents. These procedures can, through a certain number of modifications, be adapted to the study of microbial deterioration of most other organic materials used in civil engineering.

The tests recommended in these procedures, can be divided into three categories:

– tests in solid artificial culture;

– tests in liquid artificial culture;

– simulation tests (with various degrees of complexity, carried out in a real or a simulated medium).

The classical approach consists of, as we do for characterization of the biodegradation of chemical substances (OCDE, 1992), placing the material in contact with a microbial agent for a few weeks (generally an inbred strain or a mixture of inbred strains of micro-organisms) in laboratory conditions favorable to microbial growth. Then, after the incubation period, the parameters which help to describe the material are measured and compared to the initial parameters. Biodegradation is therefore measured by the deterioration of the essential characteristics of the material.

These tests provide only partial information, which is often difficult to use to correctly predict growth in real conditions. In fact, the influence of the external medium may be significant in the biological evolution of a material, particularly because of the indirect biodeterioation mechanisms which could prove to be dominating. It is therefore often necessary to try to reproduce or simulate the real environmental conditions which will be the conditions of the material during use. We therefore move towards "simulation tests" which are generally longer and more complex than the accelerated tests.

We can think of the adaptation of procedures developed for a type of material (generally plastics or paints in the standardized procedures) to suit another type of organic material only after adapting the experimental conditions. The main factors which need to be reconsidered are the nature of the inoculum, the method of inoculation, conditions of incubation, and the composition of the incubation medium.

Another particularity of organic compounds is their sensitivity to substances possessing the nature of an organic solvent. Thus, when organic materials are used in civil engineering, we will have to take into account the fact as to whether they are subjected or not to rain water rich in hydrocarbon (urban rain water for example) that could play the role of a co-solvent and favor making solutions of potentially polluting organic substances.

7.7.3. *Conclusion*

The use of organic materials in civil engineering has probably little impact on the environment in many cases. On the contrary, in certain situations, it could significantly disturb the terrestrial or aquatic ecosystems, as well as contribute to the degradation of drinking water resources.

The parameters that could lead to one of these two situations depend not only on the material itself, but also especially on the method and context of utilization. This is why the assessment of ecological risks that they generate requires first and foremost, like for the other potentially polluting materials, the precise definition of the scenarios in which these will be implemented. Once these scenarios are defined, we will be able to develop the methodology for the assessment of ecological risks adapted to their specificities, based on the existing methodologies. These will particularly take into account the extent of biodegradability of the organic materials, as well as their sensitivity to organic solvents.

7.7.4. *Useful standards*

ADEME/Direction de l'Industrie, 2000. Document de présentation de la méthodologie d'évaluation de l'écocompatibilité de scénarios de stockage et de valorisation des déchets, 15 p. (Presentation of the methodology for evaluating the ecocompatibility of storage scenarios and waste recovery).

AFNOR (Association Française de NORmalisation) X 41-513, 1961. Protection des matières plastiques, 1ère partie. Méthode d'essai de résistance des constituants aux micro-organismes, 8 p. (Protection of plastics, part 1. Test methods for resistance of constituents against micro-organisms).

AFNOR X 41-520, 1968. Protection. Méthode d'essai de résistance des peintures aux micro-organismes et de leur pouvoir de protection, 23 p. (Protection. Test method for resistance of paint against micro-organisms and their protective power).

AFNOR X41-514, 1981. Protection des matières plastiques, 2ème partie. Détermination du comportement sous l'action des champignons et des bactéries; évaluation par estimation visuelle ou par mesurage des variations de masse ou de caractéristiques physiques. 16 p. (Protection of plastic materials, Part II. Determination of behavior under the action of mushrooms and bacteria, visual evalution or evaluation by measuring mass variations or physical characteristics).

AFNOR X31-E, 2001. Projet de norme cadre pour l'étude du comportement à la lixiviation des sols pollués. Document de travail, 5p. (Draft of master standard for behavioural study of leaching of polluted soils).

ASTM (American Society for Testing and Materials), 1976. Standard Practice for Determining Resistance of Plastic to Bacteria. ASTM G22-76. Annual Book of Standard, Part 35.

ASTM, 1990. Standard Practice for Determining Resistance of Synthetic Polymeric Materials for Fungi. ASTM G21-90. Annual Book of Standard, Part 35.

ASTM, 1993, ASTM Standards on environmentally degradable plastics. P.C. Fazio *et al.*, Eds, Library of Congress Cataloging-in-Publication Data, 64 p.

ENV 12-920, 1997. Caractérisation des déchets. Méthodologie pour la détermination du comportement à la lixiviation d'un déchet en conditions spécifiées, CEN TC 292/WG6. (Characterization of waste, Methodology for determination of the behavior of waste leaching under specific conditions).

ISO/TC 190/SC 7/WG 6, 2001a. Resolutions of the meeting "Soils leaching", Paris, 17-18 May 2001. Document N62 of the AFNOR X31-E commission.

ISO/TC 190/SC7/WG 6 N 23, 2001b. Up-flow percolation test for (contaminated) soil.

OCDE, 1992. Lignes directrices de l'OCDE pour les essais de produits chimiques. Section 3, Dégradation et accumulation. Adoptées le 17-7-92. (Guidelines from OCDE for chemical products tests. Section 3, Degradation and accumulation. Adopted 17-7-92).

US-EPA, 1998a. Guidelines for Ecological Risk Assessment. EPA-630/R-95/002F. U. S. Environment Protection Agency, Washington D.C., USA.

US-EPA, 1998b. Ecological Research Strategy. EPA/600/R-98/086. U.S. Environmental Protection Agency.

7.8. Assessment of health hazards of organic materials[9]

7.8.1. *General problem and definitions*

As for environmental impacts, the use of organic materials in the field of civil engineering requires an assessment of risks to the health of the different involved populations involved. For this, it is therefore useful to adopt a methodology for assessment of risks as developed in the last few years in the field of polluted sites or in the impact studies of industrial settings.

Different terms should be defined beforehand: health, risk, hazard, etc.

9 This section is written by Guy AUBURTIN, Cnam-IHIE.

The field of health[10] is vast: when we are interested – like now – in materials, our first thoughts are for "chemical risks", but we should not forget other possible effects on health arising out of the development, the processing and the fate of these materials. Practically, when we think of health, we usually refer to the state of "illness", i.e. sickness or consequences of accidents. The effects on health could be immediate and of short duration or, on the contrary, delayed and permanent, or even transitional in terms of occurrence and persistence of the effect.[11]

A very general definition of risk is the probability of occurrence of damages. In the field of health, risk is the probability of occurrence of an effect(s) harmful to the health of a particular population.[12]

There are several definitions each quite different for the word *hazard*. In the spirit of the European directive for chemical agents (98/24/CE), hazard is an intrinsic property of a chemical agent[13] likely to have a harmful effect. The danger is neither the effect by itself, nor the possibility of appearance of this effect. This intrinsic property could be directly linked to the physico-chemical properties of substances (corrosive nature, explosive nature, etc.) or could prove to be something more complex. Thus, for example, a carcinogenic substance is a substance which, by itself or in association with other substances, is capable of causing or provoking the occurrence of tumors or cancers.

Hence, when considering of health hazards, it is necessary to talk about population(s) and exposure. The expression of this hazard, i.e. the realization of the risk, is closely linked to the circumstances of the exposure, i.e. the way in which the agent (chemical, physical or biological) and the concerned humans are brought face to face. Risk assessment therefore takes into account the modalities (qualitative aspects) and the importance (quantitative aspects) of the exposure in details such as: who, when, where, exposed and how much?

10 "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (Preamble of the constitution of the World Health Organization).

11 As an example, generally cancers appear several decades after the first exposure.

12 Is it necessary to mention that when we study populations, we are dealing with people, i.e. individuals, but particularly groups, in a collective approach?

13 But this also true for physical (noise, radiations, etc.) or biological agents.

7.8.2. *Health hazards of organic materials in civil engineering*

While considering health hazards related to organic materials in civil engineering, it is possible to start from materials or from populations.

If materials are our starting point, then we would follow the fate of the materials, determine the methods of use, the concerned populations and their exposure and then determine the risks. Such an approach is often used for materials taken individually: bitumen, plastic, etc.

If population is our starting point, like for example the workers in building and public works, we can then provide an overview of exposure patterns of different materials. In all cases, it is desirable, for the purpose of analysis, to distinguish the populations professionally exposed and the environmental population, susceptible to a potential exposure outside the workplace or site.

In theory, these two approaches merge and help in the overall assessment of risks; in fact these complementary approaches reflect cultural and methodological points of view, which is a part of a field of research on public health.

As an example, taking the case of bitumen, the four stages in the life of materials are quite easily distinguishable (Table 7.9):

– the production of bitumen which starts from the residue of vacuum distillation directly concerns the petrochemical producing industries. The population concerned at this stage are refinery workers and neighboring residents. Pollutants involved are mainly in the gaseous form;

– deployment as bituminous coats on pavements or water proofing compounds on roofs. Related industries are public works and buildings, target populations are mainly workers in industries who are exposed to bitumen in the form of fumes, sometimes containing polycyclic aromatic hydrocarbons (PAH), sulfur derivatives, mineral aggregate, solvents, aliphatic amines and aldehydes;

– the productive life of the material, i.e., the pavements or roofs themselves. The populations involved are the users or the neighborhood and the eventual harmful effects of bitumen, probably very small, will only be an element, which is often difficult to identify. Therefore, the increase in PAH in the proximity of roads will often be linked to vehicle exhausts;

– at the end of its life, a pavement needs to be reconditioned. The industries and population concerned are again the public works agencies. According to the technique employed and the age of the pavement (with the possible presence of old coal tar), exposures and therefore risks vary.

	The 4 stages in the life of materials.			
Key questions	**Production of Materials**	**Processing**	**Service Life**	**End of service Recycling**
What are we talking about?	Basic precursors of materials	Material itself or included in the process	Materials incorporated	Waste Recycled product
Related industries	Producers (chemical, petrochemical)	Building and Public Works	Construction and Public Works User Industries and Communities	Construction and Public Works Scrap industry
Chemical Parameters				
Composition	of finished product and each of its constituents	of materials in the process	of materials in the object and its fate	of waste
Processes	Production, formulation	Processing procedures (Building and Public Works)	Use of the object, *natural* fate, interactions with the environment	Demolition, recycling, waste treatment, abandoning
Concerns	materials, precursors, by products, intermediate products.	materials, object, agents released during processing (gas, fumes, etc.)	materials in the object, agents released during the life of the object, directly or by interactions	Materials in the waste, agents released during recycling, during waste treatment
Populations concerned	Workers and neighborhood of production sites	Workers and neighborhood around processing area	Workers and neighborhood around usage area	Demolition and scrap workers, neighborhood
Modes of exposure				
Form	Gas, fumes, dust … water, food chain (differentiated as per populations)			
Via	Road workers: mainly inhalation, through skin Neighborhood: mainly inhalation, imbibing (differentiated as per populations)			
Health hazards	Critical effects, different toxicological reference indices as per agents concerned, exposure media and time			
Regulation and standardization				
Regulation **Standardization**	Workers and Environment International, European and National			
Players in France and Europe				
Parties involved	Producers: individual companies and professional bodies Trade Union and User Unions French and European Administrations Associations			
Research	Institutions, Researchers, Consultants			
Evaluation and Risk Management	Public Bodies, Private Organizations, Consultants			
	Main Parties, Administrations, Standards Organizations, Consultants			

Table 7.9. *Health hazards in the four stages in the life of materials – an approach*

7.8.3. *Methodology for assessment of health hazards*

Two complementary approaches can be envisaged: epidemiology and quantitative health risks assessment:

– epidemiology is the study of the distribution of the state of health and health events of the populations, and its contributive factors. For example, in the case of bitumen cited earlier, numerous studies have been undertaken worldwide, conveying lots of information and now widely discussed, on the risk involved for professional populations;

– the risks assessment is a methodical approach of risk forecasting in a field of uncertainties.

The quantitative assessment of risks has a codified approach. As per the National Academy of Sciences of the United States (1983), the standard practice consists of four stages:

– potential hazard identification, which consists of identifying for each relevant modality of exposure the possible after-effects. It is at this stage that we ask questions such as "Is this substance susceptible of provoking cancer?"[14] for which possible replies are "certainly", "probably", "possibly", "not decided" and "no" on the basis of national or international classification parameters;[15]

– the study of the dose (level of exposure) – response relationship. Starting from the data arising out of scientific research, national or international committees and agencies propose, following a discussion about typical assessment of risks, toxicological reference values (TRV)[16]. The modality for elaborating and using the different TRV are beyond the scope of this document, but it is necessary to distinguish situations with threshold effect levels[17] and the situations with no-threshold effect levels where only non-exposure corresponds to no risk. The same substance can provoke threshold effects, no threshold effects and different effects for different modes of exposure (medium and time);

– estimation of the exposure of populations. This stage consists of studying exposure indicators on a qualitative and quantitative level. It takes into account all the phenomena which contribute to exposure, including various means of transfer in different media. It calls on measurement and modeling. Measurement can be carried out in the exposure media (air – inside or outside – water, food, etc.) as well as in

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14 We can ask this question for any type of effect.

15 Classification by the IARC (International Agency for Research on Cancer, which belongs to the (in the EU), the EPA (in the USA), etc.

16 Which are either "daily acceptable doses" for effect thresholds or "excess of unit risk" for no-effect threshold (see below).

17 An effect threshold is a level of exposure below which there is no effect and above which an effect is possible.

the biological media (exhalation, blood, urine, saliva, etc.) integrating different modes of exposure and individual mechanisms of absorbing pollutants. There is no fundamental conceptual difference between estimation of professional and environmental exposures, nor between estimation of exposures in epidemiology and in risk evaluation. But, of course, in actual reality different situations require different methodologies leading to the appropriate indicators;

– the characterization of risk consists of the summary of the preceding stages. It results in the introduction of "values" representing the risk(s) (a probability is a number) and in the discussion of uncertainties of this evaluation which come from different sources (scientific uncertainties, hypotheses concerning exposure, uncertainty/non-reliability of toxicological reference values, etc.). Risk characterization should enable production of useful information regarding risk management to the decision makers.

The assessment of health risks in organic construction materials is a new field under development. Some partial evaluations have been made for certain phases in the life of materials (processing of bitumen for example) or in an extensive manner for materials on their life cycle as a whole (some plastics) but without particular reference to their use in the construction field. These will be developed in the implementation of the European REACH (Registration, Evaluation and Authorization of Chemicals) program.

7.8.4. *As a conclusion: why assess health hazards?*

The assessment of health hazards, under "epidemiology" and "quantitative evaluation of risks", is not (merely) an academic exercise. It should be useful to:

– the generation of knowledge and new scientific hypotheses. The assessment of risks rests on scientific knowledge,[18] but there is a scientific dimension in its approach and its results. The methodology is of the same nature as in all scientific approaches and its evaluation criteria are scientific publications at the international level and peer recognition;

– risk management, the main aim of which is to provide answers to questions such as: "Is the risk associated with a particular project/particular situation acceptable or not?" and "what are the conditions of its acceptability?". This belongs to the domain of industry, of politics and, more generally, of society. It is a field for the application of principles of risk management (precaution, proportionality, etc.) and logic such as consistency in decision making. The acknowledgement of the validity of decisions is political, economic and administrative in nature.

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18 The principle of precaution brings about the "absence of certainties, report of scientific and technical knowledge of the times".

The acceptability of risk is by nature societal and is entrusted by society to either the authorities (sovereign role of the state), or consensus groups (social partners in the case of professional risks – consensus committee for environmental situations). This question of acceptability of risk is an important issue in environmental health and includes sociological concepts such as the perception and representation of risk.

No human activity can henceforth avoid considering and examining the eventual risks related to its development. Despite a constant improvement of the state of health of populations in developed society, health factors such as the ever increasing incidence of cancers, notably that of infantile cancers, or the marked difference in life expectancies depending on the social and professional origins, become worrisome. Moreover, in the perspective of sustainable development, new responsibilities arise at social and environmental levels and at the level of globalization. Organic materials used in construction cannot escape this movement. In a broad way, the approach is progressing as needs be, but requires a structuring which is only in its infancy.