INTERVIEW WITH JACQUES LUKASIK, LAFARGE GROUP SENIOR VICE PRESIDENT, SCIENTIFIC AFFAIRS

What research regarding concrete is the most current, in the world in general, and at Lafarge in particular?

Let me first of all say that over the last twenty years or so, there has been an intensification of research into cement and concrete, thanks to an approach based on scientific understanding. Previously, concrete was treated in a very pragmatic manner, developing mix design formulas, trying them out, and observing the results. It was empirical.

The past twenty years have seen a much more scientific approach. We try to identify the physical, chemical and physical-chemical phenomena which govern the behavior of concrete, and to understand them. As you know, concrete is a mixture of cement and aggregates with sand, to which water is added. When the water is added to the mixture, you observe "setting", that's to say that the mixture hardens. All the physical-chemical phenomena that are behind this hardening are very complex. In the past, probably because no suitable tools were available, the very intricate science behind the process was never studied in depth, at least not on the scale we study it today… by which I mean a nanoscale. But it can be done today, because physicists have developed observation tools that function at this scale. I could give you several examples of techniques and instruments developed in the last quarter of a century, such as nuclear magnetic resonance, scanning and transmission electronic microscopy, atomic force microscopy, nanoindentation, synchrotron radiation, and so on. All these tools enable us to observe physical-chemical phenomena of materials at a nanoscale, and understand them better. The benefits for concrete are immense.

But what does a nanometer represent?

The general public find the dimension of a nanometer hard to conceptualize. To try to make sense of the notion, let's take the example of a hair. On average, its thickness corresponds to fifty microns in diameter. As you know, one micron equals one thousandth of a millimeter. If you divide the diameter of a hair by one thousand, you get fifty nanometers. So if you can imagine a hair whose thickness is cut into a thousand parts, you will have an idea of the scale at which we now study physical-chemical phenomena in concrete. This has been made possible thanks to instrumentation and to the work of teams around the world who have decided to take an interest in concrete and in the fundamental phenomena that govern its hardening and the development of its mechanical strength. The results of these studies have enabled us to produce a better structured material with considerably improved properties by comparison with those obtained twenty years ago. Properties that have made it possible to build such exemplary structures as the Millau Viaduct, in which the particularly narrow concrete piers are responsible for the span, stability and resistance.

A number of European academic teams excel in this research, especially several French teams. The Lafarge Research Center, the world's leading center for research on building materials, is contributing to this work. Beyond what we do ourselves in our central laboratory, we work on fundamental research in close collaboration with the academic world. We take part in international networks in Europe and North America, for instance. While the work we do alongside university teams is primarily geared at understanding, in our Research Center located near Lyons we focus more on applying all this knowledge to create innovative new materials and solutions for the benefit of the construction industry and architects in particular, to open up an infinity of new architectural and structural possibilities.

What about Ductal®? How would you describe its performance by comparison with conventional concrete?

Ductal® was born from an industrial collaboration between three major French groups: Bouygues, Rhône Poulenc (today known as Rhodia) and Lafarge. I was privileged to launch the collaboration on behalf of Lafarge in 1994. Twelve years ago, the three groups and their research teams imagined a material capable of spectacular performance. We then suggested collaborations with around ten French university teams, thanks to a subsidy from the French government specifically for fundamental research into innovative materials. At the time, our project was not called Ductal®, but RPC, or "Reactive Powder Concrete". We had to understand the physics of this granular material, its behavior when it was placed or poured. After five or six years of research, we put it on the market and gave it the name of Ductal®. Why call it that? Because it was the first concrete-type material to exhibit characteristics of ductility. Its performance is absolutely exceptional. Its compressive strength exceeds that of conventional concrete by a factor of between five and six, and its flexural strength exceeds that of conventional concrete by a factor of ten. The flexural strength of Ductal® is around 50 megapascals, and its compressive strength is around 200 megapascals. The property of ductility means that under heavy stress, the material does not break abruptly but behaves a bit like a wire, such as a copper wire, that you can keep pulling and stretching without it snapping. To give you an example of the ductile behavior of Ductal®, we performed trials in the United States with the FHWA (Federal Highway Administration), who wanted to use it to build bridges. We produced a beam that was thirty meters in length and one meter in height, and when we put it under high pressure we succeeded in getting it to bend 50 centimeters in the middle without breaking. The thing about the Ductal® beam is that it doesn't contain metal reinforcement bars. It is simply made from a mixture incorporating extremely fine steel fibers, three times as thick as a hair, i.e. around 150 microns, and 12 mm long. These fibers absorb all the mechanical stresses and impart the ductile behavior, but many other elements also contribute to the exceptional performance of Ductal®, particularly achieving exactly the right granular composition of all the mineral and organic components. When Ductal® concrete is placed, it flows like fairly liquid honey and doesn't have to be vibrated. Take my word for it, the development of this material required a high level of effort in terms of very fundamental research, for which the development of innovative analysis tools was to a large extent responsible.

Is Ductal® finding applications in the buildings of today?

There have already been many applications of Ductal® in buildings, but also in other civil engineering structures. The world's first application dates back to 1997. In Sherbrooke, Canada, a footbridge was produced in Ductal®, at the time when it was still known as Reactive Powder Concrete. The bridge was 60 meters long, and was made up of five 12-meter segments. In 2004, a beautiful footbridge was built in Seoul, South Korea, that is 120 meters long and four meters wide, and its deck is only 3 cm thick. Today, several traffic road bridges have been produced in Ductal®, two in the United States, one in New Zealand and one in France. There are also applications for Ductal® in the facades of buildings, because it has a very smooth, attractive surface appearance. I would add that the esthetic qualities of the material have also seen it used today for producing objects of all sorts, such as furniture like desks, tables and bathtubs.

The design of the Hypergreen tower uses a mesh structure in Ductal®. Can you envisage building large structures in Ductal®? What advantages would there be?

The big advantage of materials such as Ductal® is first and foremost the extra volume available. Elements in Ductal® provide equivalent mechanical performance for very much reduced volume, thickness, width and length. If you imagine a pillar in a traditional concrete, even a high-strength concrete, the same pillar in Ductal® will have a much smaller volume overall. The second great benefit is the very attractive-looking surface of such a concrete, because the surface of Ductal® (and the volume as well, for that matter) has extremely low porosity, so there are practically no atmospheric and environmental aggressions. Consequently, Ductal® has an extended durability, and its esthetic appearance is remarkable. I believe it's a material which will stimulate architects' imaginations because, given its capacity to resist mechanical stresses, they can make the most delicate shapes out of it.

Do you see concrete as an ideal material for building towers?
I think that Ductal®-type concrete is a wonderful material for structures of all sorts, whether high-rise structures or other civil engineering applications, from the point of view of their economic, mechanical and ecological performance, and in particular their durability. I would also say that not all aspects of their performance are properly acknowledged at the present time.

That's interesting, I was going to ask you about their performance in comparison to steel, because the performance of Ductal® is close to that of steel.
Yes, of course, but beyond the mechanical performance of Ductal®, which, as you say, is close to that of steel, there are other aspects of its performance that are superior. We all know the fire-resistant capacities of steel, but at a crucial point, a structure in steel buckles, breaks and collapses. We have developed a Ductal® range incorporating suitable organic fibers which has fire-resistant performance that is remarkable. In the event of a severe increase in temperature, the fibers dissolve and the voids that form in their place absorb the pressure of the water vapor generated by the dehydration of certain components. The structural integrity of a building constructed with such a material is thus prolonged considerably in the event of a fire.

For Hypergreen, the structural principle was the association of Ductal®'s capacities to absorb stress and offer fire protection. The interior of the tower has been designed to contain nothing but prefabricated concrete elements. In this context, do you think that this process is currently viable; can it become a prefabricated tower system consisting of elements to be assembled?
It's not easy for me to talk about the structural aspects of construction, because I'm not an engineer by training, but a physicist. What I am sure about is that Ductal® is wonderfully well suited to prefabrication. Its mechanical performance is greatly improved thanks to a suitable thermal treatment, and prefabrication is particularly appropriate for producing all sorts of elements, obviously including structural mesh and towers…

There is considerable research to be performed in this area.
There are already many projects and applications that have been carried out using Ductal® in prefabrication. As far as structures are concerned, the Ductal® bridges in the United States are prefabricated: decks and piers are lightweight elements because the performance of the material means that they don't have the same mass or volume as they would have with conventional concrete. These Ductal® elements are transported by truck, manipulated on the construction site by a light crane and easily positioned next to each other. In very little time, the bridge is in place and is operational. I would say that this kind of process could be envisaged for certain tower elements.

Do you think there is a place for concrete in a sustainable economy? What actions can be taken to reduce the environmental impact of the production and use of building materials?
We are convinced, and it has been demonstrated, that concrete is a key material in sustainable construction.
Quite deliberately, Lafarge is undertaking research to develop what could be qualified as the most sustainable materials possible. Our concerns run in two directions: on the one hand, obviously, reducing the energy used to create or develop concrete, and, on the other hand, reducing the environmental impact of these materials and seeking solutions making it possible to reduce the energy consumption of buildings throughout their active life. The two often go hand-in-hand.
As far as the production of materials is concerned, we are reducing our expenditure on energy in our cement plants. We are also developing cement that can be manufactured with less energy, at a lower temperature. A "traditional" Portland cement is produced at around 1,450° C. The "low energy consumption" cements I am talking about are belite cements, manufactured at temperatures of around 1,200° to 1,250° C. We are endeavoring to raise their performance to the same level as that of Portland cement.
Meanwhile, we are working on making our materials recyclable and possibly reusable. It's obvious that the concrete of the future will be produced using less energy, will have lower CO_2 content, and will be reusable or recyclable. There are categories of waste products that we use to produce cement, both as fuel for our kilns, i.e. as alternative sources of energy, and also to recreate the raw materials that then go into our cement.

Fly ash, which is a by-product of the power generation industry, and slag from steel mills and blast furnaces, for instance, are materials that we use to formulate and produce our concrete. In the past fifteen years, we have succeeded in reducing our CO_2 emissions per tonne of cement produced, and on a global level, Lafarge has pledged to reduce CO_2 emissions per tonne of cement produced by 20% over the period 1990-2010.
According to studies performed by independent bureaus, our Ductal® has lower energy and CO_2 content than many other building materials. We carried out an evaluation of parameters for a bridge between a mixed concrete/steel solution on the one hand, and a Ductal® solution on the other. The comparison was very favorable to Ductal®. The Ductal® bridge entails a 35% saving in natural raw materials, a 46% saving in energy and a 53% saving in CO_2 emissions by comparison with a solution combining steel and conventional concrete.
As far as using concrete in building is concerned, we know that its potential is enormous but it is still largely unexploited. To give you an example, optimizing the use of concrete's thermal inertia properties would help reduce energy consumption in housing and consequently reduce greenhouse gas emissions caused by the operation of the building throughout its active life.

I think that the future is one of mixed concrete-wood-metal structures. Are you going to carry out any research in this direction?
The future is without doubt in certain mixed solutions. This is the reason that Ductal® incorporates steel, in the form of fibers. Personally, I am quite sure that there remains a great deal to optimize, not to say invent, in the association of concrete and steel.

For the Phare project, the idea was to produce a mesh in a mixture of steel and Ductal®. In our project for La Défense, we also thought of a metal structure with a coating of Ductal® for fire resistance. We even thought initially of pouring Ductal® around metal elements in order to take advantage of both characteristics. Do you think that such an approach is possible?
I'm sure it's possible, but we haven't carried out these types of tests. We consider that our material is resistant enough in itself and doesn't need to be juxtaposed to steel.

Do you think that an entirely new building material could emerge in the near future, and what are your future lines of research?
At the level of the materials of today, the field of exploration is still massive. In ten or fifteen years, concrete will certainly not be the same. There are three major reasons for this.
If I had to sum up my vision of concrete in the not-too-distant future, I would first of all say that the new material will have <u>superior mechanical characteristics</u>. It will not need to be reinforced with metal bars for instance. It will have self-placing properties – it will be fluid, as our Agilia® concrete is today. It will also have remarkable esthetic properties – at the very least, it will have no cracks visible to the naked eye. Previously, surfaces in standard concrete were five meters by five, in order to minimize the visible effect of natural cracking, but Lafarge teams recently launched a concrete that can be made into surfaces twenty meters by twenty, without cracking. I am also certain that the concrete of the future will be capable of maintaining its structural integrity in the event of fire much longer than the concrete of today. It will be lighter but have equivalent mechanical characteristics, which will make it possible to reduce the volumes used.
Next, <u>on the level of sustainable development</u>, there will also be significant change. Lafarge recently launched a new cement, for instance, which does not produce dust when it is handled. It is called Sensium®. Once again, it is through science that it has been possible to ensure that all the fine cement particles are so consolidated and agglomerated that there is no dust when you empty a bag. The cement maintains its full mechanical and rheological performance, i.e. it is easy to place, has even greater strength than traditional cement and it requires less water. Such a cement is a very important factor in protecting the environment, improving working conditions for building industry workers and for sustainable development.
I am also sure that the concrete of the future will have less energy content. There will be less CO_2 emissions generated by its production. It will probably offer better resistance to environmental and climatic aggression, to acid rain. It will be produced with recyclable materials, and its own components and formulas will incorporate materials originating from industrial waste. The concrete of the future will be self-cleaning. And it will have what we call a "self-healing" or "self-repairing" capacity. Already today, if a relatively fine crack of up to 100 or 150 microns appears in Ductal® and drops of water are introduced into the crack, it closes up all by itself.

Finally, the concrete of the future will incorporate new functional characteristics. It will be capable of reacting to a signal or external command that will trigger setting. Imagine pouring fresh concrete into your formwork and then giving an external signal to trigger the setting process, which will be extremely rapid. In a very short time, the concrete will acquire its ultimate mechanical strength. A few minutes, perhaps twenty or thirty, will be needed instead of several hours, as today. The concrete of the future could also have new esthetic properties, such as color that changes according to the light, depending on the angle of sunlight or even moonlight. I have no doubt that this is something that will get architects dreaming…

That's a bit like aluminum: there are now aluminums that change with the light, with the sun. Will there be other new characteristics?
Such a concrete could also be translucent, at least partially…
It could also have remarkable thermal insulation performance. It could act as a "phase change material", for instance, storing up the heat during the day, when it is warm and releasing it at night, when temperatures drop.
But let's not forget acoustics, either. At Lafarge, we are interested in the acoustic performance of materials, especially concrete. Once again, science comes into play. A French road building company has collaborated with academic laboratories on developing noise barriers to give people living next to highways and roads with heavy traffic better protection from road and traffic noise nuisance. To do this, they applied a mathematical fractal theory to calculate the asperity and surface form of the noise walls, optimizing it to absorb sound waves as efficiently as possible. Thanks to this very specific scientific approach, I think that concrete will have greater noise absorption capacities in the future, and so will provide better acoustic insulation. That is what the future holds for us.

Do you have any final thoughts?
The future of concrete is immense. Thanks to a resolutely scientific approach, concrete will become a hi-tech 21st century material whose performance cannot but stimulate the imagination of architects, who are at the root of all creativity in construction. Lafarge has every intention of playing a part in this.