Innovative Solutions for Construction
The following book is intended to promote Lafarge solutions by highlighting the use of our products in innovative design scenarios. While this book is not a design manual, it provides information on elements of design as well as technical product information. The combination of project highlights, product information and building systems facilitates an interconnection of the components of construction and provides the reader with ideas for future projects. This can be considered as a reference book providing an understanding on the use of cement, aggregates and concrete in diverse projects.

Further technical information on our products and solutions can be obtained online (www.lafarge.com) or through our commercial organization and our Construction Specialists in the countries where we operate.

The book was prepared for architects, professional engineers, contractors and builders. The material contained in this handbook is intended for use by professional persons capable of evaluating the significance and limitations of the reported data and who will accept responsibility for its proper application.
A world leader in building materials, Lafarge employs 64,000 people in 62 countries, and posted sales of €15.2 billion in 2013. As a top-ranking player in its cement, aggregates and concrete businesses, it contributes to the construction of cities around the world, through its innovative solutions providing them with more housing and making them more compact, more durable, more beautiful, and better connected. With the world’s leading building materials research facility, Lafarge places innovation at the heart of its priorities in order to contribute to more sustainable construction and to better serve architectural creativity.
The cities of the 21st century will see a rapid increase in their populations. Urbanization is the challenge of our century. This situation means facing new issues: improving the living conditions of city-dwellers, making sure they have access to decent housing as well as to energy and raw materials without depleting resources.

**INNOVATION SERVES OUR AMBITION “BUILDING BETTER CITIES”**

We support the development of cities through innovation and contribute with solutions which play a role in providing cities with more housing, making them more compact, more durable, more beautiful and better connected.

- **GIVING CITIES MORE HOUSING**
  by helping provide housing for all, particularly affordable housing

- **MAKING CITIES MORE COMPACT**
  by helping build taller buildings to limit urban sprawl

- **MAKING CITIES MORE DURABLE**
  so that buildings resist both the passage of time and natural disasters, and protect the environment

- **MAKING CITIES BETTER CONNECTED**
  through roads, bridges and tunnels that improve traffic flow

- **MAKING CITIES MORE BEAUTIFUL**
  by encouraging architectural creativity and audacity
FOUR MAJOR ASSETS
FOR INNOVATION

01
A POWERFUL R&D NETWORK OF MORE THAN 1,000 EXPERTS, THE WORLD’S LARGEST BUILDING MATERIALS RESEARCH CENTER

Our innovation hub: the Central Research Center at L’Isle d’Abeau, near Lyons (France).

240 engineers and technicians from all over the world developing new solutions to correspond to the specific needs of construction projects.

Local development laboratories adapting our building solutions to specific local requirements.


> Objective: 10 local development laboratories by 2015

LAFARGE R&D IN 2013

116 new patent applications filed

€122 M devoted to R&D

140 new cement and concrete products launched

02
NEW SOLUTIONS AND NEW SERVICES

Beyond product innovation, we have developed global and local solutions designed for foundations, floors, walls and building facades. These construction systems offer remarkable properties in terms of cost, durability, strength, insulation, appearance, and ease of application. Innovation also means new services. We are involved in the design phase of projects, working with architects and construction companies on solutions that have to meet an increasingly complex set of challenges, both technical and esthetic. We also offer our customers a turnkey service of both supplying and applying our concretes, and also, at the other end of the chain, recycling demolition products for use as embankments in road building.

03
DEDICATED ORGANIZATION AND SALES FORCE TO BETTER ANSWER YOUR NEEDS

We have a market-based structure to better respond to the needs of its customers: building, infrastructure, industry and retail. This organization exists in every country, to provide customized constructive solutions to each of these sectors. More than 60 Construction Specialists and International Key Account Managers have been deployed in each country in 2013. Their role is to liaise with architecture firms and decision-makers, as early in the process as possible, in order to analyze their needs and offer them appropriate solutions.
GLOBAL BRANDS AND INNOVATION BREAKTHROUGHS

AGILIA®
The self-placing concrete
Islamic Arts department in Le Louvre Museum, France

HYDROMEDIA®
The pervious concrete to prevent flooding
International Expo Center in Chongqing, China

ARTEVIA®
Our range of decorative concretes
Beachfront walkway, South Africa

CHRONOLIA®
The concrete boosting construction sites
Port Mann Bridge, Canada

THERMEDIA®
The insulating concrete
Apartment buildings close to Angers, France

EXTENSIA®
The high strength - low shrinkage concrete
Mountain Equipment Retail Store, Burlington, Ontario, Canada

DUCTAL®
The ultra-high performance concrete
Rabat-Salé airport, Morocco

► All these brands guarantee the best and the same level of quality throughout the world. This is unique in our industry. Through our R&D leadership, we are also at the source of some technological advances such as Aether cement and depolluting concrete.

AETHER®, A NEW GENERATION CEMENT
Aether® is a revolutionary cement reducing CO₂ emissions by 25% to 30%. Industrial trials successfully performed at the end of 2012 confirmed that Aether® cement achieves performance equivalent to that of our conventional cement. This progress has benefited from a grant from the European Union’s “Life +” program intended to support environmental projects.

DEPOLUTING CONCRETE
The new depolluting concrete developed by our Research Center absorbs polluting automotive gases, even within confined spaces without sunlight (eg. tunnels). Today, this new concrete moves to the prototype stage, with a full scale testing in 2014 in Lyons (France). This new concrete has a patented new process: depolluting micrometric mineral particles are added to the concrete formula or directly to cement.
The freedom of architectural expression arises from the potential of the materials. Lafarge understands this potential and improves its products and their usage through joint experiments and innovative projects. The following section represents the results of the Group’s close collaboration with architects, specifiers and users of its materials and the answer to the Group’s ambition to build better cities by providing them with more housing, and making them more compact, more durable, more beautiful and better connected.
MuCEM, France
The architectural marvel by the Mediterranean

Jean Bouin Stadium, France
Pushing the envelope

Podium at Menlyn, South Africa
Geometric precision and architectural flair

Absolute Towers, Canada
Grace through technical prowess

The Hepworth Wakerfield, United Kingdom
A gallery that inspires

Port Mann Bridge, Canada
Engineering a world first

Chongqing International Expo Center, China
First Hydromedia pervious concrete application in the country

Olembe low-cost housing, Cameroun
A new technology to reduce the cost of construction
MuCEM
FRANCE
THE ARCHITECTURAL MARVEL BY THE MEDITERRANEAN

The new Museum of European and Mediterranean Civilizations (MuCEM) in Marseille showcases the amazing performance delivered by UHPC. Created by architect Rudy Ricciotti, it uses the structural strength and aesthetic properties of Ductal®. This lightweight building, resistant to the salty atmosphere of the ocean, is an architectural masterpiece that introduces new construction methods and new opportunities for creativity.
“There is nothing purely decorative in the product. Everything is structural, in the style of a fish’s skeleton. We move forward to a dematerialization of the concrete structure, which becomes delicate, spindly, fibrous like a coral rock cut. We don’t know how far this material will carry us. We can reinvent the world.”

RUDY RICCIOTTI,
Architect

LOCATION
Marseille, France

FUNCTIONALITY
Museum

COMPLETION
Mid 2013

OWNER
French state

The first vertical structure made of pre-stressed concrete

Lafarge’s Ductal® UHPC elements:
• Facade and roof lattices
• Columns
• Two footbridges
• Brackets
• Peripheral walkway

> 15,000 m³ of concrete
> 384 self-supporting Ductal® lattice panels, 1,500 m² of latticework
> 308 Ductal® columns

Construction of the MuCEM required 5 ATEX (Technical Experimental Assessments), conducted by France’s CSTB*.

* CSTB: Centre Scientifique et Technique du Bâtiment – The French Scientific and Technical Centre for Building is an independent public organization serving innovation and research in the field of construction.
OVERVIEW
Located at the entrance to Marseille's Old Port, the MuCEM consists of a modern J4 cuboid building linked to the iconic Fort Saint-Jean by a footbridge. It represents the centrepiece of Marseille's transformation as the 2013 European Capital of Culture. It is the first museum in the world dedicated to the Mediterranean civilization and culture and the first French national museum to be located outside of Paris.

The J4 mineral cuboid measures 72 m per side and encases a parallelepiped structure that has 52 m sides and is 18 m high. It constitutes the body of the building – what its designer calls a vertical kasbah. This mineral cube has a total surface area of 15,000 m² and is surrounded by latticework made from Ductal®, which acts as a windbreak while allowing light and air to flow freely through an internal walkway system.

MATERIAL
Ductal® is an ultra-high performance fiber-reinforced concrete that is the result of Lafarge research. Thanks to its composition, it has three essential properties: compressive strength six to eight times greater than traditional concrete, impermeability and a malleability that allows it to be used in the most complex molds. As its name suggests, it contains metal and/or organic fibers finer than hair, giving it excellent tensility. This low porosity product is impervious to chemical aggression and perfectly suited to both the design of the building and its maritime setting.

STRUCTURE
Close collaboration between concrete chemists, structural engineers and a succession of prefabrication and preconstraint specialists was required to build this original structure. Each prefabricated piece had a studied casing. Prototypes were manufactured for this purpose and tests were conducted in the laboratories of France's CSTB.

The structural design complies with fire safety regulations and the new French seismic zoning (seismic zone 2), while maintaining the integrity of the original project. It is a highly unified concrete-encased box-like structure, with pre-stressed concrete floors as single elements and the load transferred to the surrounding columns.
**THE FOOTBRIDGE**

The classic footbridge design consisting of an assembly of arches or cable-stays, beams, crosspieces and a deck was substituted with a single form of prefabricated segments, which were molded, monolithic and represented a mechanical optimum. Without reinforcements in the flanks, the segments are quite thin (12 cm). The prestressing is situated in the lower part of the segments and the 4 cm thick deck is made of Ductal®. Its rigidity comes from two diagonal ribs, laid on the lower-side crosspieces. The contact surfaces between the elements are vital to obtaining perfectly distributed stress. The accepted prefabrication tolerance is 0.2 mm maximum for perfect flatness of surfaces and optimal contact between segments.

The slender footbridge is stabilized against the wind with dampers under the crosspieces of the central segment to avoid resonance phenomena from wind loads.

The segments were placed on a scaffold during the installation of both footbridges, and each one was firmly attached to the preceding section. Pressure of 0.3 MPa was ensured by prestressing bars. Once the elements were tightened, the main post-constraint was applied and the scaffold removed.

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<table>
<thead>
<tr>
<th>TWO FOOTBRIDGES IN DUCTAL®</th>
<th>JA/FORT SAINT-JEAN FOOTBRIDGE</th>
<th>FORT SAINT-JEAN/ESPLANADE SAINT-LAURENT FOOTBRIDGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENGTH</td>
<td>115 m</td>
<td>69 m</td>
</tr>
<tr>
<td>SPAN</td>
<td>76 m</td>
<td>69 m</td>
</tr>
<tr>
<td>DECK THICKNESS</td>
<td>4 cm</td>
<td>4 cm</td>
</tr>
<tr>
<td>SLENDERNESS</td>
<td>1/40</td>
<td></td>
</tr>
<tr>
<td>SEGMENTS</td>
<td>25 segments - 4.60 m long, 1.80 m tall and 1.88 m wide - assembled by post-tension</td>
<td></td>
</tr>
</tbody>
</table>

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**THE COLUMNS**

The 308 Ductal® columns located along the four sides of the MuCEM provide the vertical structural elements for the building. They were designed and adapted to seismic risk using Freyssinet ball-and-socket joints. The polypropylene fibers were added to ensure approximately two hours of fire resistance.

Three types of columns were used: upright, Y-shaped and N-shaped. They were produced using customized plastic molds. The columns’ different shapes, diameters (25 cm to 40 cm), heights (2.89 to 8.79 m) and possible orientations (at 0 or 180 degrees) resulted in 20 basic designs and 80 different configurations.

The columns were poured in a cast vertically such that the fibers were positioned in the direction of the exertion taken up by the structure. Fiber orientation and distribution on all columns were carefully verified, and a special fiber-counting technique was used to check for possible fiber segregation.
The latticework Surrounding the 18 m high building in concrete lace, the Ductal® latticework was designed to shield the southern and western facades from the strong Mediterranean sun.

There are two types of latticework in this project. The first, known as strands, is laid out on the ground. The strands are UHPC branches measuring 7 cm x 8 cm. The latticework is held in place horizontally by bi-articulated braces, with a universal joint at each end to avoid creating interfering efforts. They can warp and expand freely.

The roof latticework, also made out of UHPC strands, is laid out on a metallic framework and on exterior UHPC brackets, detached from the framework by means of polyurethane springs. The resulting self-supporting panels measure 6 m x 3 m.

The latticework is manufactured according to strict specifications. Despite its mere 7 to 10 cm thickness and level of perforation higher than 50%, it is able to support extreme loads. This is especially the case for the facades, which are exposed to prevailing winds. Installation commenced with the roof lattice panels, followed by the Ductal® T-columns, which were installed with two runner rails. Each panel was individually cradled, and the peripheral walkway was used to install the two 72 m long facades and access the lattice connection points.

THE FLOORING

Contrary to conventional construction, the pre-stressed concrete floors were installed first to meet the project schedule. Once the installation of all elements was complete, the floors were connected to the independent columns. The supports were dismantled after the final load was transferred onto the columns. A sealant was applied to all Ductal® elements after demolding. They were then thermally-treated to achieve nominal mechanical performance.
Ever since it was first built in 1925, the Stade Jean Bouin, located in Paris, France, has been an integral part of French rugby history. Designed by architect Rudy Ricciotti, its capacity has increased from 9,000 to 20,000 spectators – and its undulating lattice-style envelope is made of Ductal®.
“The use of these new construction systems means adopting new design methods, combining theoretical studies with prototypes, conducting digital wind-tunnel tests, 3D modeling, etc. They involve high-level engineering at the design and construction stages, requiring a close partnership between engineering offices, precasters, installers, contractors, the inspection office (Qualiconsult) and, of course, CSTB*. This is the type of teamwork I am convinced will make UHPC a vital material in the future.”

ROMAIN RICCIOTTI, Engineer
Lamoureux & Ricciotti Ingénierie

ARCHITECT/PROJECT MANAGEMENT: Rudy Ricciotti
Lamoureux & Ricciotti Ingénierie

STRUCTURE AND ENVELOPE ENGINEERING: BERIM

GENERAL ENGINEERING: ALTO Group/Marc Malinowsky

FRAMEWORK ENGINEERING: Leon Grosse

CONTRACTOR: Cabrol

FRAMEWORK: Bonna Sabla

PRECASTER: Lafarge

LOCATION
Paris (16th arrondissement), France

FUNCTIONALITY
Stadium

COMPLETION
August 2013

OWNER
City of Paris

Architect/Project Management:
Rudy Ricciotti, Lamoureux & Ricciotti Ingénierie

General Engineering:
BERIM

Framework Engineering:
Leon Grosse, Cabrol

Owner:
City of Paris

1ST PERFORATED ROOF STRUCTURE
in UHPC with glass inserts

3,560 TRIANGULAR PANELS
light grey roof panels in Ductal®: 8 to 9 m long by 2 to 2.5 m wide and 3.5 to 4.5 cm thick
and
self-supporting lattice panels in light grey Ductal® with metal fibers; 9 m long x 2.5 m wide and 11 cm thick

A unique “cathedral of concrete”

* CSTB : Centre Scientifique et Technique du Bâtiment – The French Scientific and Technical Centre for Building is an independent public organization serving innovation and research in the field of construction.
OVERVIEW
Located in the largely residential 16th arrondissement, the new Stade Jean Bouin has increased its capacity from 9,000 to 20,000 spectators. It nevertheless respects Rudy Ricciotti’s vision of being light and fully integrated into urban landscape. This was achieved by creating a concrete cocoon: a totally asymmetric envelope that uses a triangular mesh to create a three-dimensional wave effect.

MATERIAL
The project was faced with a wide range of technical challenges. The complex architectural form had to have a watertight envelope to protect spectators from the elements and an acoustic screen able to accommodate the enthusiasm of 20,000 spectators. It also needed to be able to drain and discharge water effectively. These quality requirements had “UHPC solution” written all over them.

The traditional process of construction by a number of trades was replaced by a unilateral approach with a single construction system. Each section incorporates the primary and secondary structures, water drainage, the architectural skin and, above all, the waterproofing via glass that is incorporated in the mold before pouring.

In addition to this smart technology, rolling all the construction stages into one resulted in significant cost savings. The use of a single material, Ductal®, reduced the number of interfaces, generating greater durability, fewer joints with intermediate parts to be covered, less implementation time and greater safety, since all the construction elements were manufactured in a workshop.

French precaster Bonna Sabla manufactured the panels at a rate of 18 per day. They were then delivered to the site as needed and affixed to the beams of the metal framework in a specific order, using ball-and-socket attachments able to withstand wind.

STRUCTURE
The stadium’s structure is a concrete grid of inclined columns, shear walls and pre-stressed beams, all connected by floors of variable thickness and multiple stairs. The 12 km of precast stands are supported by 74 concrete racks. Bracing is provided by shear walls in the basement and shear walls and portal frames in the superstructure. Piles and peripheral walls – “Parisian walls” (piles plus cast concrete) – were used for the infrastructure, and the lowest basement is tanked.

Ductal® covers several levels of the stands. The roofing is a steel framework canopy composed of 74 spans.

Two temporary plants were set up to produce 80% of the C40 concrete, which made for top-quality siding.

ENVELOPE
The stadium is covered by an asymmetric curved envelope made from 3,600 self-supporting light-grey triangular Ductal® panels with metallic fibers. Two types of panels form this unique structure: open-lattice panels on the facade and perforated panels with glass inserts on the roof.
Designers of building envelopes are constantly addressing new challenges as the list of functions and project requirements increases with each new architectural innovation. Numerous design elements – such as roof systems, single and double facades, water tightness, sound protection and heat insulation – inspire new construction methods that integrate cutting-edge technologies, durable materials, industrialized processes, custom solutions and expertise.

Lafarge heeds all players in the construction industry. That way it can offer a full range of solutions to enable architects to develop high-performance sustainable creations that meet the expectations of project owners and end users. The achievements presented here illustrate how Lafarge’s ingenuity and custom solutions are contributing effectively to the design of highly functional and extremely durable buildings for the future. They also demonstrate the importance and value of collaborative efforts, which have led to a new era in building envelopes with unrivaled aesthetic and technical identities.”

Jean Martin-Saint-Léon General Director Ductal® - Lafarge Group

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**LINK**

**Product:** Ductal® made the fabrication of thin lattice panels with a high perforation ratio possible. The use of the same material on the roof and on the facade ensured a global aesthetic for the building, generating greater durability, fewer joints with intermediate parts to be covered, less implementation time and greater safety.

**EFFICIENT BUILDING SYSTEMS:**
- **ROOFS:** Light aesthetic UHPC roof  
- **NON STRUCTURAL WALLS:** Lightweight, insulated UHPC  
- **WINDOWS AND DOORS:** UHPC Sunshades

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**THE ROOF** panels are 8 to 9 m long, 2 to 2.5 m wide and 3.5 to 4.5 cm thick, creating a waterproof system made with 20 to 27% glass. After three years of research and several months of experiments on full-scale prototypes at France’s Scientific and Technical Center for Building (CSTB) to identify a solution incorporating glass, the roof system was evaluated by a Technical Experimental Assessment (ATEX), a technical assessment procedure developed by the CSTB.

The panels were cast flat from one side in steel molds. The glass pieces were incorporated during casting and sealed with preformed silicone joints: the rigidity of the joint was designed to insure overall watertightness and allow shrinkage of the material. The glass angles were rounded to minimize constraints and the possibility of breakage. Each roof panel was fabricated with reinforced ribs on both sides and designed to enable it to be connected to other panels. The triangles are installed on a thin steel structure that cantilevers up to 40 m. They are connected at each corner by ball joints to allow for deformation in the event of high winds. The panels are interlocked at the ribs to guarantee the roof’s watertightness and proper drainage of rainwater.

**THE FACADE** is made up of panels 9 m long, 2.5 m wide and 11 cm thick. The 11,000 m² surface has more than 50% open space. Its panels were cast flat on one side in a silicone mold. Two small molds and three large molds were used to manufacture them. The blockouts in the molds were arranged in ten different settings to create a variety of panels. After an initial curing, the panels were demolded and thermally treated to increase their strength.

Specific modular molding systems allowed the production of panels with angles from 8 to 16°. The triangular lattice panels were attached to steel columns. The base of the triangle is fixed to a metallic profile, whereas the opposite corner is fixed to the column via a connecting rod.
Located in Pretoria, South Africa, this new business center has been announced in July 2013 as the deserving winner of the Fulton Award for Innovative Construction. This award has been granted by the Concrete Society of South Africa.
“The construction company WBHO (Pty) Ltd. approached Lafarge, knowing we could find a solution that would achieve the best results. We suggested they use an innovative self-compacting concrete called Agilia® Vertical and tested it on a mock-up wall. The results met the expectations of the architect and the construction company, and it was decided that this specialized concrete be used on all off-shutter walls.”

JOHAN DELPORT, Key Accounts Manager, Lafarge ready mix Gauteng

ARCHITECT: Boogertman & Partners
MAIN CONTRACTOR: WBHO Ltd
SUBCONTRACTORS: Peri SouthAfrica, Lafarge South Africa Holdings-Concrete, DG Consulting Engineers

A synthesis of mathematics, symbols and art

LOCATION
Pretoria, South Africa

FUNCTIONALITY
Business center

COMPLETION
2012

OWNER
Emira Property Fund

22 m
height of the building

22,000 m²
of reinforced concrete frame

4.5 m
height of the first floor
LOCATION
Located at the intersection of Atterbury and Lois Streets in Pretoria, South Africa, the new building Podium at Menlyn has helped buoy the transformation of a 300,000 m² area of mixed-use development into a prosperous first-class business hub. Inspiration was drawn from ancient engraved artwork in the Blombos Caves on the Southern Cape coast and the ancient Chinese Tangram dissection puzzle. Triangular geometric patterns were created in both glass curtain walls and off-shutter concrete as a metaphorical bridge between South Africa’s prehistoric past and its future.

STRUCTURE
The building stands 22 m tall, with five stories and three basement levels. Its multi-story reinforced concrete frame covers an area of 22,000 m². The first story is 4.5 m high, while the other ones are typically 3.5 m high. The structural elements form a regular grid of beams, columns, perimetric walls and elevator shaft walls, all connected by a plate forming a rigid diaphragm.

As the structural engineer required the concrete feature walls to be part of the structural framework of the building, portions of the facade wall had to be cast with the main frame of the building. The contractor proposed an interesting design solution: cast portions of the feature wall simultaneously with the main frame of the building. The downstand portions of the feature walls were cast at the same time as the first floor slab, using regular premixed concrete due to budget constraints. The second cast (first floor to second floor) of the feature wall was completed using self-compacting concrete. In the top portion of the feature wall, a polystyrene pocket was left on the floor slab, serving as a permanent shutter for the concrete of the second floor slab. The regular pre-mixed concrete was used for the latter to ensure it worked structurally. This procedure was repeated for the pours for the other floors and the underside of the roof slab. Construction joints had to be carefully planned so as not to impact on the building program.

To avoid excessive heat buildup, a double curtain-wall system was designed. The facade is therefore made up of two curtain walls 1 m apart, which naturally ventilates and disperses the building’s heat buildup. The top and bottom of the curtain walls are open to assist the stack effect of heat dissipation within this void.

FACADE
Achieving the seamless three-dimensional shape of the concrete facade through the use of 35 mm-deep recesses was a construction feat in itself. Different methodologies were explored in sample panels to ensure the required final effect. After testing fiber-reinforced concrete, ready-mix concrete with a small aggregate and Agilia® (self-compacting concrete), it was agreed that Agilia provided the desired aesthetic. Efficient planning and a good construction methodology were essential in respecting the contractor’s program and keeping within budget.

Despite time and cost constraints, the team managed to make the triangular grid of the feature walls apparent from the interior and not merely an external surface treatment. A single set of shutters was used for both the eastern and western facades’ feature walls, while two sets were used for the construction of all three feature walls. The eastern and western feature walls were phased by levels, i.e., once the first downstand was complete on both the eastern and western facades, the first wall cast on the western wall’s shuttering was used on the eastern wall’s first cast, and so on. The designs of the walls are therefore mirror images of each other. The second set of shutters was used for the construction of the fire escape stairwell on the southern facade. The geometric grid continues throughout the interior of the building. The team saved 40% on shuttering costs by utilizing the same shutter for the construction of the two walls.

As the building’s northern facade is exposed to direct sunlight throughout the day, it is divided into two main sections. The first section has affectionately become known as ‘the egg crates’. They are simplified off-shutter sunshade devices, created by a combination of concrete overhangs that protect the office space from the midday sun throughout the year. Equally deep concrete sunscreen walls also provide shading from the early morning and late afternoon sun.

The dark, powerful exterior geometric grid continues in a dramatic lighter contrast throughout the interior, reminiscent of a black and white 70’s science fiction movie, designed by Boogertman and Partners Interiors.

Custom cladding was used on the underside of the stairs and lift lobby walls to overcome the acoustic challenge of high volumes and hard surfaces.
PRODUCT
Creating the 35 mm-deep recessed lines that define the triangular geometry was no easy task. Once the shutters were removed there was a risk the concrete could break out and leave the face of the walls looking ragged, requiring patching. This is something the entire team wanted to avoid at all costs.

The contractor and design teams turned to Lararge ready mix Gauteng for a solution. In the end it was decided to use Lafarge’s Agilia® Vertical self-compacting concrete solution because of the intricate yet appealing design. “The architect specified off-shutter finishes on all vertically exposed walls, with unusual imprints. We had to mirror, in concrete, the same effect that was prevalent on the modern glass facades,” comments Johan. “It was important to get it right the first time on every wall and ensure a good off-shutter finish to enhance the visual appeal. Due to the steel reinforcing, the difficulties inherent with the use of conventional vibration, along with the importance of off-shutter finishes, standard concrete was out of the question.”

Agilia® Vertical has been created around flow and viscosity rather than slump, making it ideal for these challenges. It requires no vibration and is easy to pour, especially within congested reinforced structures and areas of poor accessibility. It is designed for superior off-shutter concrete finishes and better color consistency. What’s more, from a technical perspective, every pour ensures accuracy and consistency. Ultimately, the concrete produces aesthetically pleasing structures and allows for intricate design work. Lafarge ready mix supplied a total volume of 11,500 m³ of concrete (360 m³ of Agilia® Vertical) over the nine-month period it took to construct the building.

The final results are impressive: the Podium at Menlyn now stands as a testament to great architecture and the innovative, aesthetic use of concrete.
Absolute Towers is a residential condominium twin tower skyscraper complex in the five tower Absolute City Center development in Mississauga, Ontario, in Canada. The two towers – Absolute World 4 & 5 – were topped off at 50 and 56 stories.
“The winner displayed remarkable creativity, as well as respect for the environment and a connection with the place and the urban surroundings.”

RICHARD COOK, CTBUH awards committee Chairman and founding partner COOKFOX Architects

LOCATION
Mississauga, Toronto, Canada

FUNCTIONALITY
Residential

COMPLETION
2012

OWNER
Fernbrook Homes; Cityzen Development Group

“The winner displayed remarkable creativity, as well as respect for the environment and a connection with the place and the urban surroundings.”

RICHARD COOK, CTBUH awards committee Chairman and founding partner COOKFOX Architects

LOCATION
Mississauga, Toronto, Canada

FUNCTIONALITY
Residential

COMPLETION
2012

OWNER
Fernbrook Homes; Cityzen Development Group

“Named 2012 Best Tall Building in the Americas”

Height tower A
56 STORIES / 170 m

Height tower B
50 STORIES / 150 m

Building area tower A
45,000 m²

Building area tower B
40,000 m²

Site area
4,090 m²

DESIGN ARCHITECT/ PROJECT MANAGER:
MAD

ASSOCIATE ARCHITECT:
Burka Architects

STRUCTURAL ENGINEER:
Sigmund Soudack & Associates Inc.

MEP ENGINEER:
ECE Group Ltd.; Stantec

MAIN CONTRACTOR:
Dominus Construction Group

CONCRETE ENGINEER:
Coffely Geotechnics

MATERIAL SUPPLIERS:
Innocon (Lafarge Joint Venture); Gilbert Steel Ltd.
OVERVIEW
Located at the intersection of two main thoroughfares in Mississauga, Toronto, Canada, the Absolute Towers are an integral part of a five-building development. Their uniqueness and flair have brought worldwide recognition to the city. The project chosen for the towers resulted from an international architecture and design competition in 2006. Their slender, undulating glass and steel shapes represent a breakthrough in conventional tower design—a fantastic example of creative thinking going beyond accepted limits. The project is recognized for making an extraordinary contribution to the advancement of tall buildings and urban environments and for achieving sustainability at the broadest level.

STRUCTURE
Behind the impressive torsional form of the towers lies an inexpensive and simple structural solution: a concrete grid of load-bearing walls that extends and contracts in response to the sectional fluctuation created by the 209° rotation of the floors. The latter have an elliptical form that rotates 2° every floor around a central vertical core made of concrete.

The lateral load-resisting system is composed of high-performance ductile core walls of reinforced concrete, shear wall panels, columns and reinforced concrete or composite link beams.

The formwork company, PERI, designed climbing formwork that used a revolving system, allowing the slab concrete reached the required strength. Moreover, to ensure safety and simplify heating requirements for the concrete slabs during winter pours, a special system was developed to enclose two floors below the deck under construction. The rotating floor plates imposed new challenges in terms of both horizontal and vertical thermal transfer. This was complicated by the unusual alignment of the window lines. To overcome this, a thermal break solution consisting of an internal bulkhead and an external insulated soffit was developed. The sections in the slab are up to 50 mm in width and have varying lengths of up to 1,200 mm. The resulting void was later finished with firestopping, a smoke seal and waterproofing. Thanks to efficient teamwork, a strong partnership and the integration of the latest in design and construction innovations, the Absolute Towers project pushed the boundaries of conventional industry norms and practices. The resulting sleek and iconic structures herald a distinct type of urbanism that is the mark of more attractive and sustainable future cities.

CHALLENGES AND OPPORTUNITIES FOR INNOVATION
Designing the unusual shape involved calculating the buildings’ reaction to more than 200 load combinations (dead and wind loads, seismic activity, etc.), leading to different wall and column designs for each floor. The unique column and wall designs meant the engineers had to find a solution that utilized sufficient rebar and concrete while still allowing for livable spaces.

The concrete was required to meet functionality considerations, ensure formability and the final finish of the flooring. The design team specified the concrete for the columns, walls and beams had to withstand 70 MPa and the slabs 50 MPa. As for the heavy reinforcement at the bottom of the tower, it had to have a strength of 35 M bars.

The main contractor, Dominius, approached Lafarge/Innocon for a product that could be supplied in high volumes, have accurate consistency, accommodate a tight construction schedule, be reliable in all seasons and have a functional workability on floor slabs. Based on these criteria, the decision was made to use the self-consolidating concrete Agilia®.

The use of Agilia® brought a wide range of benefits to the construction site. Combined with certain specific techniques, it contributed to the speed and efficiency of the construction cycle.

The construction schedule spanned a full cycle of seasons, thus requiring an optimal temperature in the summer and winter for proper concrete curing. As for the ultimate strength of 70 MPa—typically reached in 90 days—it was achieved in a mere 28 days, an advantage that allowed an accelerated schedule for the concrete finishers. This increased efficiency required less workers and minimized the risk of worker crowding. Dominius opted for the use of concrete pumps to alleviate unnecessary crane usage and also hoisted concrete with the traditional bucket method.

The forming system was also a challenge because it had to climb and move in relation to varying rotations (from 2° to 8° between each floor). This had to be done avoiding schedule delays and ensuring worker safety.

Efficient Building Systems:
- **FRAME:** High performance concrete
- **UNDERFLOOR HEATING:** Self-placing screed (Agilia Screed A&C)

The interior structural elements, are linear—resulting in unique floor plans for every residential unit.

The structural columns could not be hidden and the aesthetic finish of Agilia was incorporated into the modern design aesthetic of the condominium apartments.

Product: Agilia® was specifically chosen by the designers. It greatly contributed to the final result, meeting the architects’ contractors’ expectations for a concrete mix with a high degree of flow, which would not segregate when poured into high forms with high reinforcement density.

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The floor plates of the Absolute Towers are all the same shape but rotate a few degrees with every floor, creating the undulating exterior effect.
On the Calder River in Wakefield, near Leeds in the United Kingdom, stands the Hepworth Wakefield, an art gallery resembling a floating fortress. The gallery extends over a total surface area of 5,000 m² and is the largest gallery built in the UK in the last 50 years.
This is a moment to savor for so many people who have worked together over the last decade to see the dream of the Hepworth Wakefield become reality. We are proud to present the work of Barbara Hepworth, a daughter of this city, in this superbly designed gallery and to develop an international center for the visual arts, which will attract artists and visitors from all over the world.

SIMON WALLIS, Director
The Hepworth Wakefield

“The gallery is built out of a pigmented in-situ concrete. The intention is to create a smooth, continuous finish that allows the natural qualities of the materials to give character to the overall appearance.”

“Concrete is an inherently strong, robust material that for us has positive associations with solidity and performance. Casting it on site means we are able to create large monolithic walls and roofs that emphasize the geometric quality of the building. Adding pigment creates an unfamiliar appearance, which we hope will be as interesting to look at up close as it will be from a distance.”

DAVID CHIPPERFIELD, Architect
The Finished Building

The largest purpose-built art space in the UK

> 1,900 m³ of pigmented Agilia concrete
> 3,100 m³ of conventional concrete

ARCHITECT: David Chipperfield Architects
STRUCTURAL AND SERVICES ENGINEER: Ramboll UK
MAIN CONTRACTOR: Laing O’Rourke
BRIDGE ENGINEER: Ramboll UK
LANDSCAPE ARCHITECT: Max Gross
MATERIAL SUPPLIERS: Lafarge
THE HEPWORTH WAKEFIELD

OVERVIEW

The Hepworth Wakefield Art Gallery is located on the south side of the Calder River in Wakefield, West Yorkshire, England. It is named after local artist and sculptor Barbara Hepworth (1903-1975). The gallery site was developed at a cost of £35 million as part of the regeneration of the Wakefield Waterfront. This consisted of the restoration of a former mill and warehouse buildings, the development of new residential, office and leisure facilities, outdoor landscaping and a new footbridge across the Calder River, which helps access the gallery. The Hepworth Wakefield gallery is the largest purpose-built exhibition space outside London, with 5,000 square meters of gallery space divided into ten trapezoidal blocks. Each one will display over 40 works by sculptor Barbara Hepworth, alongside the works of other prominent artists. The two-story building houses a learning suite, café, lecture theater and ancillary facilities on the ground floor, with ten gallery spaces above. The various skew roofs of the airy gallery spaces (up to 13 m high) enable generous clerestory glazing as part of the natural lighting strategy. Below the building, river water is directed through the line of an old mill race at basement level to the line of an old mill race at basement level to

structure

The structure is built on a 400 mm raft slab on more than 100 CFA piles sunk across the site, with their caps connected by a continuous ring beam. The walls were cast in situ on this beam in Lafarge’s self-compacting concrete (Agilia®). The 300 mm-thick monolithic walls were constructed to reservoir standards, with a dense mesh of 20 mm rebars at 150 mm centers, laid in both directions across both faces. The floor spans were built in either flat slabs, T-beam slabs or post-tensioned concrete, depending on column spacing. The gallery floors are topped with a monolithic 20 mm screed, with two-way movement joints at the perimeters. Steel roof trusses support precast concrete planks.

Inspired by its environment, the building was conceived of as a group of ten linked blocks of varying sizes. Pigmented self-compacting concrete was chosen to make it as expressive as possible. As this was unprecedented in the UK, it required the development of dedicated pour techniques to achieve the meticulous mirror finish that was specified. In the end, this proved highly cost-effective when compared to precast options. It also advanced UK industry knowledge in the use of aesthetic concrete techniques. Lafarge was initially asked to supply Artevia® as a pigmented concrete for the facades. But after analyzing the request and the product specifications, the Lafarge construction specialist advised changing the expensive precast concrete design to cast-in-place technology by using the product Agilia® and integral pigment. Agilia® gave the architect the option of achieving precast quality with the benefit of in-situ methodology, a decision that saved £2 million on construction costs. The pigment – christened ‘Hepworth brown’ – was tested on a number of mock-up walls. The concrete color was finalized following construction of several block samples, small T-piece trial panels and three larger trial panels.

Given the industrial setting of the gallery and the fact that surface textures were one of the architect’s main concerns, he chose this material because of its structural and aesthetic qualities, its fluidity and its ability to produce colored concrete.

efficient building systems

- FRAME: Aesthetic finish concrete walls (Agilia Vertical and Agilia Architectural)
- Insulated sandwich wall cast in-situ (Agilia Vertical and Agilia Architectural)
- Matrixed concrete (Agilia Architectural)
- UPPER FLOOR: Vaulted ceiling (Agilia Horizontal)
- Underfloor heating with self-placing screed (Agilia Screed A&C)

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NOTES:
1). Under no circumstances should dimensions be scaled from the plane containing Twist.

2). Up to and including 1.2mtrs
Length of shorter sides
Straightness or Bow (from Intended Line)
250mm    +/- 1mm
Cross Section
6mts   +/- 1mm
Additional deviation for every subsequent Up to 3 mtrs              +1 / -1.5mm

3). All dimensions on this drawing are in IN DOUBT ASK”.

Fabrication Details for PURPLE shutters

PATTERNS & MOULDS LTD

Infill blocks
25-6-08
The new 10-lane Port Mann Bridge across the Fraser river in Canada was inaugurated in December 2012. It is the largest infrastructure project in British Columbia history.
The world's widest bridge

LOCATION
Vancouver, British Columbia, Canada (spans the Fraser River connecting Coquitlam and Surrey)

FUNCTIONALITY
Bridge

COMPLETION
2012

OWNER
Ministry of Transportation, British Columbia, Canada

ARCHITECT/PROJECT MANAGEMENT & MAIN CONTRACTOR:
Peter Kiewit Sons Co./Flatiron Constructors

CONSULTANTS:
T.Y. Lin International in collaboration with IBT

MAINTAINED BY:
Transportation Investment Corporation (TI Corp)

MATERIAL SUPPLIERS:
Lafarge; Harris Rebar

1,158 precast segments in the approach spans

25,000 metric tons of asphalt used for new bridge deck

116 steel composite segments in the cable-stayed span

45 km of cable

157,000 m³ precast segments in the approach spans

16 km of pile and 5 km of drilled shafts

28,000 metric tons of rebar and 13,000 metric tons of structural steel
OVERVIEW
The new 10-lane Port Mann Bridge across the Fraser River connects the communities of Surrey and Coquitlam, British Columbia, Canada. With a capacity of five lanes of traffic in each direction and the ability to accommodate rapid light rail transit, the bridge is part of the Port Mann/Highway 1 Improvement Project: the largest transportation infrastructure project in British Columbia history. Besides doubling the capacity of the bridge, the Improvement Project included widening Highway 1, upgrading interchanges and improving highway access and safety. The project spans a distance of approximately 37 kilometers from the McGill Street Interchange in Vancouver to 216 Street in Langley.

Not only is the new bridge the widest and longest main span river crossing in Western Canada, the Guinness Book of World Records has designated it the widest bridge in the world, further boosting its status as an iconic structure. It is just over 65 meters wide for most of its 470-meter span, reaching 65.23 meters at its widest points and beating the previous record by more than 16 meters. Its width includes 50 meters of roadway (with shoulders), a five-meter wide multi-use path, with three meters of clearance for pedestrians and cyclists, and a 10-meter median gap where pylons support the two bridge decks. Its 2,020-meter length makes the Port Mann Bridge the second longest in North America and the 29th longest in the world.

The new bridge has three main components:
- a cable-stayed main bridge across the Fraser river, 850 meters long (470 meters between the two towers), with 288 cables,
- a south approach (Surrey side), 360 m long,
- a north approach (Coquitlam side), 820 m long.

Using 251 large-capacity piles (up to 5,000-metric ton capacity) as foundations, the bridge’s main span is supported by 288 cables, which would cover about 45 kilometers if laid out end to end. The navigational clearance above the high water level is 42 meters.

MATERIAL
Lafarge was one of the leading players in the construction of this vast structure. We brought all our experience in major civil engineering structures to this ambitious project. Thanks to our network of concrete plants located along the 37 kilometers of the construction site, we were able to supply the 180,000 m³ of concrete needed to construct the 2,300 precast parts of the deck in Chronolia® and the 300 structures that make up the piers and the abutment footings in Agilia®, plus the two vertical 70-meter pylons supporting the main cables.

Agilia® facilitated the quick placement of concrete in heavily reinforced structures by ensuring minimal voids, maximizing contact with reinforcing steel and using labour resources effectively. Chronolia® was used to achieve a quick turnaround time of 1 day per piece between pouring and stripping the forms in the yard used to cast the bridge precast parts.

The two 158-meter pylon towers stand approximately 75 meters above the deck, with a total height of about 163 m from the top of their footing.
Chronolia® was used to accelerate the construction process. Its capacity to develop a high level of strength quickly speeded up the formwork rotation and reduced the number of molds and saved space, heating and eventually money. Agilia®’s fluidity and stability made it the perfect choice for the high surface quality and easy placement of the abutment footings needed, providing the worksite with valuable flexibility.

EFFICIENT BUILDING SYSTEMS

- FRAME: High performance concrete columns p.49
- CIVIL WORKS – BRIDGES: UHPC beams for bridges p.62
- CIVIL WORKS – BRIDGES: UHPC joint fill p.63
Built in the heart of the economic center of Chongqing, this is the largest exhibition center in Western China. Located in a region with a humid subtropical climate, the site of the complex faces multiple flooding risks which have been reduced with the use of the pervious concrete Hydromedia®.
“This is the first time Hydromedia® permeable concrete has been used in Chongqing on such a large scale. And as it was our first time designing a building, Lafarge worked closely with us to iron out problems we encountered in the design process. This experience has convinced me that Lafarge’s products are top quality and its staff is highly professional.”

MR. WEIMING LI, Design Director of China Coal Technology & Engineering Group, Chongqing Design & Research Institute

“The construction of 30,000 m² of permeable pavement concrete in 20 days illustrates Lafarge’s efficiency and professionalism. Its teams successfully controlled the concrete mixture design and the quality of construction. In my opinion, their permeable concrete technology is the best among the local players.”

MR. SHIPING JIANG, Project Manager, Chongqing Jiangong 9th Construction Co., Ltd.

DEVELOPER: Chongqing Yuelai Investment and Development Co., Ltd.
STRUCTURAL DESIGN: China Coal Technology & Engineering Group, Chongqing Design & Research Institute
AESTHETIC DESIGN: TDP and BIAD work group
MAIN CONTRACTORS: CQ Jiangong 9th Construction Co., Ltd.

> 30,000 m² of Hydromedia concrete pavement
Chongqing International Expo Center

Project Description
Located in the heart of the New Liangjiang area of Chongqing, the Chongqing International Expo Center (CQEXPO) is a modern facility built to hold exhibitions, conventions, and events. With a full catering service and accommodation, it is currently the largest venue in western China. CQEXPO was inaugurated in July 2010 and opened its doors on March 28, 2013. The center consists of 429,000 m² of exposition space, a 77,000 m² conference center, 43,000 m² of commercial facilities, and an outdoor area of 200,000 m². It is the second largest conference center in China and the eighth largest in the world. CQEXPO is a milestone for the Chongqing government. It was built using the latest green technology, with a total investment of CNY7.2 billion. The beautiful butterfly design by TDP adds to the brilliance of CQEXPO and has made it a familiar city landmark in Chongqing.

Application of Lafarge Hydromedia – Customer’s Critical Requirements
The customer required the outdoor exhibition pavement, which covers about 30,000 m², to have a 22 cm reinforced concrete base (underneath is 42 cm of cement-stabilized macadam). The pervious concrete had to be dark and light gray, with a thickness of 8 cm.
In addition to this, the pavement had to allow water to penetrate quickly. The concrete strength is C20 grade and is able to withstand a 30-metric ton load, meaning trucks can be exhibited on it. The color of the product also needed to be consistent with the design. Moreover, not only did Lafarge have to supply the product, but the contractor required Lafarge to place it as well. This had to be completed within 20 days.
When the contractor approached Lafarge for a solution to meet all these requirements, the prescriptive sales team proposed the Hydromedia® product. It represents a pervious concrete system well-suited to customers who require high quality, permeability, strength and aesthetics all in one. In this particular case, it represented a better option than the water-permeable bricks formerly in the design.
The advantages of Hydromedia® pervious concrete for CQEXPO are threefold:
- Its C20 strength
- Its permeable rate of ≥0.5 mm/s
- The tailor-designed concrete pavement and drainage structure

Thanks to the efficient organization of construction, the project was completed in 20 days. A good supply of materials and careful construction plans were key in keeping to the schedule. But just as important was a well-trained workforce, with more than 10 million square meters of construction experience. All of these factors, not to mention a concrete batching plant from Lafarge, contributed to reassuring the customers and providing them with the confidence they needed to move forward with this ambitious project.
Yet again, Lafarge has shown through its work on CQEXPO that it has the skills and products necessary to build landmark structures that require world-class materials and workmanship. This success story in China is proof that its innovative concrete products are indeed paving the way for the next generation of buildings.
OLEMBE LOW-COST HOUSING

CAMEROON

A NEW TECHNOLOGY TO REDUCE THE COST OF CONSTRUCTION

Olembe is a housing program led by the Public Real Estate Company of Cameroon in the capital Yaoundé, which required constructive solutions allowing to build fast, well and inexpensively. The technique of lost casing was the solution adopted to answer these needs.
"The partnership with experienced international groups such as COFFOR and Lafarge has allowed us to start using a new technology. This must not only contribute to improve construction quality and keep to our construction schedules, but also ensure an affordable price for the people of Cameroon."

Minister of Housing and Social Development in Cameroon
OVERVIEW
With urban population growth of more than 10% per year, social housing remains a major priority in Cameroon. Around one million homes are needed just to cope with the urgent needs of urban populations. It is therefore of paramount importance to come up with and put in place solutions for building top-quality structures as quickly and inexpensively as possible.
As a solution to this pressing problem, the Cameroon government launched a program that aims to build 10,000 housing units on 50,000 building plots throughout the country. The program is being carried out under the supervision of the Prime Minister’s office, with the involvement of various ministerial departments and public and private firms.
Within this context, the Public Real Estate Company (Société Immobilière du Cameroun, SIC) chose Olembe as the site on which to build this low-cost housing. It is located in the northern region of the capital city, Yaoundé, and has a surface area of about 18 hectares. The dense equatorial forest that previously covered the land has been partially turned into farmland, and the once sprawling habitat of villagers has been transformed into high-rise buildings, which dot the rocky terrain. The Cameroonian authorities have contracted the joint venture COFFOR Cemac – made up of Coffor Holding and local partners – to build 3,000 houses.
The Olembe low-cost housing project includes 65 buildings, with 20 apartments each. Each unit is built on an area of about 120 m², slightly over the global average for this type of construction. The housing consists of T4 and T5 apartments. They have a 32-34 m² living room, three 12 m² bedrooms for T4s and four for T5s, a shower, a toilet, a bathroom, a kitchen, a laundry room and a balcony.
The work is being completed in phases. The first phase consists of the construction of 640 houses, which require about 40,000 m³ of concrete over a period of 24 months, starting in mid-2013. The project uses a technique known as lost casing solutions. It is a quick and easy process, and it is very affordable. The project is being carried out by a partnership between the following entities:
• Lafarge Group for ready-mix concrete
• COFFOR Cemac and Coffor Holding for concrete structure
• ITALIA CERAMICA for secondary work

Working in together with the construction company, Lafarge will deliver the concretes C16/20, C20/25, C25/30, C30/37 for stay-in-place formwork, which is required for specific applications on the job site. The Lafarge value-added products Ultra Series® Retarded, Ultra Series® Fluid and Ultra Series® Pervious will also be used. Standard mortars and pigmented mortars will be used for plastering. Apart from the concrete production delivery and pumping, Lafarge provides technical assistance 24 hours a day by way of a dedicated team on site.

As a partner in this project, Lafarge has drawn on its extensive knowledge of construction solutions to provide building materials that are well suited to social housing in Cameroon. Indeed, fulfills housing needs in Olembe dovetails with Lafarge’s larger ambition to meet the extraordinary challenges posed by the increasing urbanization of the planet. Its strong presence in emerging countries in general and Africa in particular – it has close to 20,000 employees on the continent, more than on any other – means it can partner with local actors to develop building solutions adapted to local problems. This is exactly what it has done in Olembe.
Lafarge is developing new building systems in partnership with players all along the construction chain, to create solutions and services that will help to meet the enormous challenges of cities. As a global player in the construction world, Lafarge has the opportunity to study construction methods from around the world as well as to develop new approaches to construction. The Efficient Building Systems detailed in the following section are a selection of various solutions for different building and construction elements that contribute to an innovative approach to construction.
Foundations

Energy pile foundations P44

Frame

Insulated concrete formwork walls P45
Structural thermal concrete walls P46
Metallic integrated form walls P47
Tilt-up walls P48
High performance concrete columns P49
Hollow columns with air circulation P50
Aesthetic finish concrete walls P51
Double skin concrete insulated walls P52
Autoclaved Aerated Concrete P53
Matrixed concrete facades P54

Upper floor

Floors with void formers P55
Vaulted ceilings P56

Roofs

Light aesthetic UHPC roof P57

Non structural walls

UHPC lightweight insulated facades P58

Windows and doors

UHPC sunshades P59

Floor finishes

Aesthetic interior concrete finishes P60

Roads, paths & pavings

Aesthetic exterior concrete surfaces P61

Civil works - bridges

UHPC beams for bridges P62
UHPC joint fill P63
Energy Piles are thermo-active deep foundations, representing an integrated solution that combines the load-bearing function of structural piles and the geothermal energy source function. Absorber tubes are embedded within the piles and connected to the building's cooling or heating system, allowing for heat exchanges between the soil and the building.

**MAIN ADVANTAGES**

- **Integrated design**
  / Combining structural and energy performances
- **Very high energy efficiency**
  / Reducing up to 80% of electricity consumption for heating and cooling
- **Appealing payback period**

**MAIN DOMAINS OF APPLICATIONS**

- **BUILDING SECTORS**
  All types of buildings and infrastructures where there is a possibility to use deep foundations like piles or diaphragm walls.
- **SPECIFIC RECOMMENDATIONS**
  The system efficiency is optimized if it is used in both hot and cold seasons in order to maintain the soil temperature over the years.

**THE LAFARGE ADDED VALUE FOR THE SYSTEM**

Lafarge innovative concrete Agilia® Deep Foundation is dedicated to pile applications and brings with it the following added values for the Energy Piles solution:

1. Simplified and accelerated onsite implementation due to its longer workability period and high fluidity with a self-leveling quality.
2. Enhanced structural performance and durability due to the improved compaction of concrete.
3. Optimized energy performance also due to the improved compaction of concrete as it allows for a better heat exchange between the soil and the tubes.

**REFERENCE PROJECT**

**COLUMBUS CENTER**
Vienna, Austria

- **Project description**
  / Shopping mall (45,000 m²)
- **System description**
  / 300 Energy Piles + 12,400 m² of thermoactive diaphragm walls
  / Heating capacity: 1,200 kW
  / Cooling capacity: 1,400 kW
  / Annual heating energy: 660 MWh
  / Annual cooling energy: 1,670 MWh
**FRAME**

**INSULATED CONCRETE FORMWORK WALLS**

The Insulated concrete formwork walls system consists of large, hollow, lightweight polystyrene blocks or panels which are dry-stacked without mortar and filled with in-situ concrete. This advanced construction system does not require any intermediate bedding materials and provides the formwork for the poured ready-mixed concrete. The insulating formwork remains in place adding a high thermal insulation property to the constructed load-bearing wall.

**MAIN ADVANTAGES**

- High energy efficiency performance
- Performs the structural function of a load-bearing concrete wall
- Quick and easy on-site implementation

**MAIN DOMAINS OF APPLICATIONS**

- **BUILDING SECTORS**
  All types of buildings
- **SPECIFIC RECOMMENDATIONS**
  The structural design should take the load-bearing capacity of the poured concrete wall into account, thereby avoiding the need for columns.

**REFERENCE PROJECT**

LES 3 FORÊTS
2011, Val-d’Oise, France (120 m²)
- Project description
  / Individual housing

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**THE LAFARGE ADDED VALUE FOR THE SYSTEM**

*Agilia® Blockfill* is a Lafarge innovative concrete dedicated to filling masonry structures. The highly fluid mix facilitates the elimination of vibration during placement. The filling of all void spaces ensures no segregation, reduces labor costs, accelerates the pour and improves security and safety. This ready-made product is delivered to the site by a ready mix truck and boasts a compressive strength ranging from 20 to 55 MPa and also has a stronger bond to masonry than conventional grout.

The use of Lafarge Agilia® Blockfill concrete with the ICF innovative system brings additional jobsite simplification and quality optimisation to this solution.

*Agilia® Blockfill*  p.74
The Lafarge structural thermal concrete walls are load-bearing reinforced walls using a concrete having the strength and the structural performance of conventional concrete – compressive strength greater than 25 MPa (3,625 psi) – along with thermal properties of lightweight concrete that improve the building’s energy efficiency. The system does not require any changes in traditional on-site implementation of reinforced concrete walls.

**MAIN ADVANTAGES**
- Combines the structural performance of conventional concrete with the enhanced energy efficiency of lightweight concrete.
- Reduces thermal bridging effects by up to 50% and replaces thermal breakers.
- Uses traditional construction methods for reinforced concrete walls.

**REFERENCE PROJECTS**

**CITE ALLENDE**
2011, Villetaneuse, France
- Building description / Social collective housing, 42 apartments and 8 individual houses, 4,857 m²
- Certification and Labels / BBC-Effinergie label / Habitat & Environnement, Profile A

**COLLECTIVE DWELLING**
2011, Saint-Denis, France
- Building description / Collective residential, 60 apartments
- Certification and Labels / BBC-Effinergie label

The use of Lafarge Thermedia® for the proposed system guarantees the structural and thermal performances of the wall thanks to the Lafarge quality control procedures and to the robust and innovative concrete mix design. Thermedia® structural concrete has a range of thermal conductivity (λ) going from 0.35 W/mK (Thermedia® 0.3) to 0.54 W/mK (Thermedia® 0.6). Thermedia® 0.6 has a structural performance equivalent to conventional concrete.
FRAME

METALLIC INTEGRATED FORM WALLS

Integrated steel formwork (such as Coffor) is a structural stay-in-place formwork system for the implementation of reinforced concrete structures. It is made up of two expanded galvanized steel grids, reinforced by vertical stiffeners and horizontal connectors. The connectors fold up, significantly reducing the volume for transport and storage. The standard panel of the formwork has the dimensions of 1.1 m x 2.70 m and weighs 33 kg (an approximate weight of 11 kg/m²). The system is filled with ready-mix concrete providing load-bearing properties. The formworks remain in place after the concrete has been poured and act as part of the needed reinforcement. For low-rise buildings, additional reinforcement is usually not necessary.

THE LAFARGE ADDED VALUE FOR THE SYSTEM

Lafarge can provide adapted and robust mixed designs based on local raw materials with an optimized level of fluidity, resulting in the optimization of both quality and on-site implementation. The system can also be used with Lafarge Thermedia® 0.3 or 0.6 to benefit from a minimum of thermal insulation.

MAIN DOMAINS OF APPLICATIONS

- BUILDING SECTORS
  All types of buildings for both internal and external walls and for slabs and foundations.

- OTHER SECTORS
  Civil works (water tanks, retaining walls...)

- SPECIFIC RECOMMENDATIONS
  The structural design can be optimized to take into account the load bearing property of the system; avoiding the use of columns.

MAIN ADVANTAGES

- Structural performance and durability
- Cost reduction
  / Reduces implementation times
  / Avoids heavy equipment
  / No specific skills required

REFERENCE PROJECT

INDIVIDUAL HOUSING COMPLEX
2006, Dalian, China

- Project description
  / 50 2-story housing units (180 m² each, total of 9,000 m²)

- System information
  / The system has been used for all building elements including walls slabs. The concrete shell of each house was built in 2 weeks.
A tilt-up construction system consists of concrete walls that are initially cast on site in a horizontal position using the slab-on-grade as the formwork. After the wall panel has reached the necessary strength to be lifted, it is tilted upright by a crane into its final vertical position.

**REFERENCE PROJECT**

O’REILLY AUTO PARTS WAREHOUSE
2009, Kansas City, MO, USA

- **Project description**
  / Auto parts shop

- **System information**
  / Tilt-up walls with 218 m³ of Chronolia® poured at ambient temperatures as low as -12 °C.

**MAIN DOMAINS OF APPLICATIONS**

- **BUILDING SECTORS**
  All types of buildings, but mainly industrial, commercial, offices...

- **SPECIFIC RECOMMENDATIONS**
  The system is adapted to buildings lower than 4 floors to simplify the wall tilting phase without over dimensioning the wall structure or the lifting equipment.

**MAIN ADVANTAGES**

- Faster construction with time and money savings
- Quality and durability related to concrete walls
- Reduced jobsite risks

**THE LAFARGE ADDED VALUE FOR THE SYSTEM**

To speed up the construction process further when using this system, Lafarge proposes **Chronolia®**, an innovative and robust concrete. Chronolia® offers the same flexibility as conventional ready-mixed concrete with the advantage of developing very early high mechanical resistance even at ambient temperatures. Compressive strengths achieved (depending on intended use) range from 25 MPa - 35 MPa (3,625 psi - 5,076 psi) within 24 hours.

Chronolia®  p.76
The High Performance Concrete columns solution is based on structural design using a dedicated concrete with compressive strength higher than 60 MPa (8,700 psi), higher tensile strength and better durability, including resistance to wear and tear. These high strength properties provide economic benefits through thinner construction elements (increasing the floor space), reduced construction time and lower embodied energy due to reduced quantities of materials.

**MAIN ADVANTAGES**
- Reduces the column section
- Increases available floor surface
- Smaller building footprint
- Decreases the volume of concrete
- Decreases the number of required reinforcements
- Lessens the environmental impact
- Cost optimization by reducing the quantities of materials
- Higher durability
- Lower corrosion of rebar
- Lower degradation of concrete

**MAIN DOMAINS OF APPLICATIONS**
- **BUILDING SECTORS**
  - Mainly residential and office buildings with at least five floors, high axial design loads or long spans between columns.
- **SPECIFIC RECOMMENDATIONS**
  - Deciding to use high performance concrete columns during the early stages of the design phase allows optimization of the design and utilizes the advantages of the system.

**REFERENCE PROJECT**

**T1 TOWER**
2008, Courbevoie, La Défense, France
- **Project description**
  - Commercial Offices, 185 m high (37 floors),
- **System information**
  - Structure designed with High Performance Concrete Columns:
    - C80/95: 2,250 m³
    - C60/75: 12,300 m³
    - C40/50: 8,000 m³

Lafarge recommends the **Ultra Series**® High Strength concrete for High Performance Concrete columns projects, which is suitable for internal and external applications. The enhanced concrete properties make this product easy to pump and semi or fully self-compacting. For columns requiring a compressive strength higher than 150 MPa (29,010 psi), Lafarge can provide Ultra-High Performance Concrete such as **Ductal**®.

Ductal®  p.82
HOLLOW COLUMNS WITH AIR CIRCULATION

The Hollow Columns with Built-In Air Circulation system is a good example of an integrated design solution combining building services and structural functions in a single building element. The system is associated with a displacement or floor ventilation solution that uses the hollow core of the concrete columns to funnel air through the floors, allowing air stratification to take place. Floor ventilation also optimizes the use of the thermal mass available in the slab, thus allowing for better energy efficiency and thermal comfort.

MAIN DOMAINS OF APPLICATIONS

- BUILDING SECTORS
  The system is mainly adapted to public buildings with large surfaces and volumes; e.g. office buildings, theaters, libraries, etc.

- SPECIFIC RECOMMENDATIONS
  The system is tailored to spaces with a ceiling height of 3 m or more to allow for air stratification.

MAIN ADVANTAGES

- Optimized indoor air quality
  / Due to displacement ventilation

- Space design flexibility
  / The fresh air inlets can be easily repositioned allowing for space repartitioning.

- Optimized energy efficiency
  / Reduced power and energy consumption of HVAC systems due to displacement ventilation and thermal mass activation

- Reduced construction cost and life cycle costs
  / Substitution of most of air ducting network and false ceiling surfaces, reduction of needed power for HVAC, simplification of repartitioning works, etc.

REFERENCE PROJECT

THE LEAN OFFICE
2006, 160 Tooleystreet, London, UK

- Project description
  / Commercial building, £42M in construction costs

- Awards
  / BCO Innovation Award Shortlist 2009
  / British Precast Concrete Awards: SupremeProject 2008
  / BREEAM Rating - “Very Good”

- Design team
  / Allford Hall Monaghan and Morris (Architects), Arup (Engineers)

- Main contractor
  / Laing O’Rourke

THE LAFARGE ADDED VALUE FOR THE SYSTEM

The Lafarge Agilia® Vertical concrete allows for high quality finishing of the column surfaces even when cast in-situ, thus avoiding additional construction phases and materials for rendering.

The high fluidity of the Agilia® concrete also allows for jobsite time and noise reduction by avoiding vibration while achieving very good compactness and a compressive strength up to 60 MPa (8,700 psi).
AESTHETIC FINISH CONCRETE WALLS

The aesthetic and high quality finish concrete walls can be obtained by combining dedicated high quality fluid concrete, dedicated formworks with desired shapes and textures, and master on-site implementation. The optimized finishing quality of this solution can be applied to structural and nonstructural walls and columns including complex shapes.

MAIN ADVANTAGES

- Supports architectural creativity, by allowing for:
  / Complex shapes of walls, columns and openings
  / Extremely detailed textures
- Enhanced indoor air quality
  / The high-quality surface finish of interior walls eliminates the need to paint the wall and with it, the associated volatile organic compound (VOC) emissions.

MAIN DOMAINS OF APPLICATIONS

- BUILDING SECTORS
  All types of buildings.
- SPECIFIC RECOMMENDATIONS
  On-site preparation including that of the formwork is key for achieving high-quality results.

REFERENCE PROJECTS

ST. JOSEPH SEMINARY
2009, Edmonton, Alberta, Canada
- Project description
  / Religious Building
- Architect
  / DIALOG
- Main Contractor
  / Dawson Wallace Construction Ltd.
- Owner
  / Archdiocese of Edmonton
- Forming Supplier
  / DOKA Canada Ltd.

DEPARTMENT OF ISLAMIC ART,
LOUVRE MUSEUM
2012, Paris, France
- Project Type
  / Louvre Museum, Department of Islamic Arts
- Architects
  / Mario Bellini, Rudy Ricciotti
- Client
  / Department of Culture

THE LAFARGE ADDED VALUE FOR THE SYSTEM

For optimal results with this construction solution, Lafarge recommends the Agilia® concrete line of products. Agilia® technology offers a range of ready-mix, self-compacting concretes specifically designed to provide maximum mechanical performance, quality and durability.

By using Agilia® Vertical or Agilia® Architectural the following additional advantages of the system can be guaranteed:

- Faster and simplified on-site implementation:
  - No vibration
  - Time-saving for complex shapes and finishes (30-50% faster wall case than a conventional wall)
- Optimized durability: due to the high compaction of concrete
- Optimized aesthetics: very high quality of finished surfaces, replicating the most detailed textures.
**DOUBLE SKIN CONCRETE INSULATED WALLS**

This construction system consists of a thermal insulating panel placed between two layers of concrete, resulting in a structural load-bearing wall on the interior side and a thin concrete layer on the external face with an integrated external insulation. This system uses ready-mix concrete and is cast on site. Connectors ensure the joining of the two concrete layers and stabilize the insulation panel during pouring. Thermal bridges can be avoided by using plastic connectors.

The Double Skin Insulated Concrete Walls system is an efficient construction solution which responds to the increasing need for high thermal envelope resistance, while providing concrete aesthetic and robust surfaces on both internal and external surfaces.

**MAIN DOMAINS OF APPLICATIONS**

- **BUILDING SECTORS**
  Mainly residential and office buildings

- **SPECIFIC RECOMMENDATIONS**
  The system is tailored to buildings of at least 2 stories which have high thermal insulation requirements.

**MAIN ADVANTAGES**

- High energy efficiency
- High thermal insulation, reduced thermal bridges, high thermal mass
- High acoustic performance
- Optimized durability
  Robust finishing and insulation protection

**REFERENCE PROJECT**

**INDIVIDUAL HOUSING PROJECT**
2011, Lyon, France

- **Main Contractor**
  Entreprise Bertrand Duron
- **System information**
  The system used is based on White Agilia® Architectural concrete and GBE patented connectors.

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**THE LAFARGE ADDED VALUE FOR THE SYSTEM**

Lafarge developed a dedicated Agilia® concrete specifically for this system, resulting in simplified on-site implementation in addition to other advantages of Agilia in terms of durability and finishing quality.

Lafarge also tested different existing methods and connectors for this application, and selected the most performing solution based on GBE patented connectors.

Agilia® p.74
Autoclaved Aerated Concrete (AAC) is a precast concrete product that is lightweight and thermally insulating, easily shaped, highly workable, fire resistant, acoustically insulating, mold and water resistant, and can be used in both structural and non-structural applications. Autoclaved Aerated Concrete (AAC) is available in many standardized sizes and shapes (blocks, panels). Custom pieces can be commissioned for both pre and post-production. Autoclaved Aerated Concrete (AAC) is easily shaped into curved profiles (e.g., for moldings), surface textures, and complex topological forms.

**Main Advantages**

- High energy efficiency
  / Walls high thermal resistance
  / Avoids thermal bridging
- Simplified design
  / Reduces the thermal insulation installation phase
  / Reduces structural loads, thus reducing structural sections and reinforcement
- Simplified on-site implementation
  / Large size panels and lightweight masonry elements
  / Precise dimensioning avoiding masonry mortars
  /High workability

**Main Domains of Applications**

- **Building Sectors**
  All types of buildings. Structural and nonstructural elements. Insulating cladding panels. Masonry blocks and wall panels.
- **Other Sectors**
  Structural acoustical sound barriers.

**Reference Project**

**Miller Zero**

The Pinnacle, United Kingdom, 2009, Chisenham, Basingstoke, UK

- **Project description**
  / Zero-carbon single-family homes
- **Architect**
  / Fraser Brown McKenna
- **Developer**
  / Miller Homes, Midlands & South region
- **System supplier**
  / H+H Celcon
- **System information**
  / UK Code level 6 construction was met in part due to the thermal insulation provided by the 200 mm wall panels.

Lafarge can provide adapted mortars for plastering and rendering AAC walls.
MATRIXED CONCRETE FACADES

High-quality matrixed surfaces are obtained for cast-in-place and precast concrete walls by applying form liners to the internal face of the formworks and by using adapted concrete mix design. Today, concrete form liners can offer unlimited variety of patterns including a replication of the detailed textures of materials such as wood and natural stones, or any other geometric shapes and forms imagined by architects and designers.

The Matrixed Concrete solution allows for the combination of unlimited architectural creativity with the structural performance and durability of reinforced concrete walls.

**REFERENCE PROJECT**

**DOJO DE MOUGINS**

2012, France

- **Project description**
  / Center for martial arts

- **Architect**
  / A. Hannouz and M. Janneau

- **System information**
  / The project used 400 m³ of Agilia® Architectural concrete. This product was the ideal solution for the architectural constraints posed by a 12 m high exposed concrete wall and by the detailed texture desired.

**MAIN ADVANTAGES**

- Architectural creativity
  / Unlimited variety of patterns

- Simplified on-site implementation
  / Robust surface finishing is obtained with no additional steps

- Other advantages of concrete walls
  / High performing in structure, acoustic, thermal mass, fire rating, durability, etc.

**THE LAFARGEadded VALUE FOR THE SYSTEM**

For optimal performance of this construction solution, Lafarge recommends the use of Agilia® Architectural concrete. Agilia® technology offers a range of ready-mix, self-compacting concretes specifically designed to provide maximum mechanical performance, quality and durability. By using Agilia® Architectural the following additional advantages of the system can be guaranteed:

- Faster and simplified on-site implementation:
  - No vibration
  - Time-saving for complex shapes and finish (30-50% faster wall case than a conventional wall)

- Optimized durability: due to the high compaction of concrete

- Optimized aesthetics: very high quality of finished surfaces, replicating the most detailed textures.

Agilia® Architectural   p.74
UPPER FLOOR

FLOORS WITH VOID FORMERS

Light hollow bodies replace heavier concrete in places where it is structurally not needed. The visual appearance of a slab and the rigidity of the section remain the same. The reduction of weight increases the bearing capacity of the concrete slab itself. The obvious side effect is a weight reduction in all the other load-bearing elements, receiving loads from the floors, down to the foundation system. These savings in terms of concrete volumes do not only result in lower costs, they also increase the efficiency of the entire building and decrease its environmental footprint. Void formers can be used for cast in situ applications as well as for precast or semi-precast objects. They are usually placed in floor slabs. Void formers are also used in concrete bridges in some exceptional cases. It is also possible to use void formers in pre-stressed or post-tensioned structures.

The possible key performance parameters for concrete floors using void formers are listed below:

- Self-weight reduction: up to 35%
- Ability to take advantage of continuity above support lines or points (tension face can be on top or bottom)
- Cantilevered systems (e.g.: balcony) are possible and the weight reduction positively influences the span

The floor thickness ranges from 20 cm to 70 cm and the span can reach 16 m.

THE LAFARGE ADDED VALUE FOR THE SYSTEM

For this system Lafarge recommends the Agilia® concrete range:

- **Agilia® Horizontal** for the structural application
- **Agilia® Screed C** or **Agilia® Screed A** for the topping application

Agilia® technology encompasses a range of ready-mix, self-compacting concretes offering a full range of products adapted to individual applications. The highly fluid mix facilitates the placement of the concrete and the filling of all void spaces. It is specifically designed to provide maximum mechanical performance, quality and durability. The highly fluid material Agilia® Architectural concrete offers the highest quality surface finish to achieve aesthetically pleasing results without remedial work.

REFERENCES PROJECTS

SIEMENS CITY
2010, Vienna, Austria

- **Project description**
  / Siemens head office building + production & research facilities

- **Awards / Labels**
  / LEED Gold

- **System supplier**
  / Cobiax

- **System information**
  / Concrete savings: 167 m³
  / Max span: 8 m
  / Floor thickness: 30 cm

NARODOWY STADIUM
2011, Warsaw, Poland

- **Project description**
  / Capacity of 58,000 seats

The Narodowy Stadium hosted the opening games of the UEFA Euro 2012 football championship.
Vaulted ceilings are concrete wave-shaped ceilings designed as a component of the structural floor system. A vaulted ceiling is usually 10 cm to 15 cm thick, with a total height varying between 40 and 80 cm. The prefabricated elements are supported by transversal beams and columns. Their surface remains unfinished to optimize the concrete's thermal mass performance. Their design also optimizes the surface area of the ceiling, and increases the floor-to-ceiling height.

The energy efficient design elements of the system include passive design techniques (thermal mass of concrete vaulted ceilings) as well as more effective systems (displacement ventilation).

**Main Domains of Applications**

- **Building Sectors**
  Office and commercial buildings, schools, universities, convention centers and public facilities.

- **Specific Recommendations**
  Floor-to-ceiling height > 3 m (for effective operation)

**Main Advantages**

- Energy-efficiency resulting from the concrete thermal mass
- Effective ventilation if a displacement system is implemented
- Space savings and flexibility gained by the absence of drop ceilings
- Structural performance, leading to a reduction of the thickness of the slab (materials savings of up to 50%)
- Cost savings over the life cycle of the building (reduction of energy costs and higher flexibility)

**Reference Project**

**Council House 2**
2006, Melbourne, Australia

- **Project description**
  Office building

- **Awards / Labels**
  6 Stars (Green star label)

- **Design team**
  City of Melbourne and Design Inc Pty. Ltd.

- **System Information**
  Energy efficiency thanks to passive cooling (exposed thermal mass of the ceiling and nighttime ventilation).

- **Visual comfort**
  Because the ceiling heights are maximized, enabling light to penetrate deep into the office space.

**The Lafarge Added Value for the System**

For this system Lafarge recommends the Agilia® concrete range:
- Agilia® Horizontal for the structural application
- Agilia® Screed C or Agilia® Screed A for the topping application

Agilia® technology is a ready-mix, self-compacting concrete offering a full range of products adapted to individual applications. The highly fluid mix facilitates the placement of the concrete and the filling of all void spaces. It is specifically designed to provide maximum mechanical performance, quality and durability.

The highly fluid material Agilia® Architectural concrete offers the highest quality surface finish to achieve aesthetically pleasing results without remedial work.
ROOFS

LIGHT AESTHETIC UHPC ROOF

The light aesthetic Ultra-High Performance Concrete (UHPC) roofs system provides solutions for specific structural and aesthetic designs. The UHPC allows the construction of concrete roofs with almost no reinforcement, blending slim elements and complex profiles, offering design versatility with nearly endless arrays of colors and textures. Watertight seals and exceptional durability make it ideal for roof applications. There are many design applications for light aesthetic UHPC roofs which include thin shell canopy structures, cantilevers, and one-way precast slab construction with perforations for skylights. The material’s closed microstructure makes it nearly impermeable to water. It is totally waterproof when designed with a thickness of over 10 mm (according to tests performed by official certification bodies), making it possible to design shell roof structures which are untreated. All systems are precast and thus are quickly and easily installed on site.

MAIN ADVANTAGES

High performance material
/ Capable of extremely thin and complex architectural forms

Architectural surfaces
/ Multiple colors, textures and superior surface finish
/ Incorporation of glass in perforation for light filtration

Durability and extended life span
/ Resistance to fire, corrosion and abrasion

MAIN DOMAINS OF APPLICATIONS

BUILDING SECTORS
Recreational, commercial, industrial, offices, public (health and education), residential (individual housing, collective housing, high-rise buildings) and transport infrastructure.

Both new construction and renovation work

SPECIFIC RECOMMENDATIONS
This system must be used for precast applications.

REFERENCE PROJECT
WELEDA PHARMACEUTICAL LABORATORY
2010, Huningue, Alsace, France

Building function
/ Headquarters of Weleda Laboratories

Architect
/ Maryam Ashford-Brown

Building owner/client
/ Weleda

Additional information on the project:
/ Nine slabs of Ductal® AF 2.5 m x 12.75 m x 6 cm thick (except ribbing) 285 m² total area

Ductal® roofs can be designed for specific projects with high demands for structure and aesthetic integrity. Below are three different projects demonstrating three different design applications:

• One-way precast slabs for long spans with irregular openings
• Thin shell precast slabs with glass inserts
• Cantilevered structure

Ductal® is a family of Ultra-High Performance Concretes with a unique combination of properties such as strength, durability, ductility and aesthetics. Its compressive strengths are up to 8 times stronger and flexural strengths are up to 10 times stronger than conventional concrete. Ductal® provides architects and designers with exceptional freedom to meet almost any design requirements, offering a wide range of innovative structural and architectural solutions.

The properties of Ductal® offer flexibility of design for building systems that combine slim elements with long spans, making it ideal for the construction of concrete roofs. With Ductal, there are numerous possibilities for the design of elements with different shapes, textures and surfaces:

• Flat plain surface roofs
• Perforated roof designs
• Perforated roofs with glass inserts

Ductal® concrete is specifically designed:

• Ductal® with metal fibers designed for structural applications;
• Ductal® Anti-fire designed for structural applications with specific resistance to fire requirements;
• Ductal® with organic fibers designed for elements that require aesthetically pleasant appearances.

THE LAFARGE ADDED VALUE FOR THE SYSTEM

/ Ductal® p.82

/ Mucem and Jean Bouin roof detail ©Rudy Ricciotti p.08 & p.14

Ductal® © p.82
This innovative and high-performance wall solution offers a robust and aesthetically pleasing finish with integrated thermal insulation. Optimized use of Lafarge’s Ultra-High Performance Concrete (UHPC) allows for an architectural, easy to install, lightweight facade, with reduced thickness, energy efficiency, and superior durability.

A mold of specific dimensions and shape is designed to form the UHPC panels. It is made of two parts: the first part is reusable and creates the external shape or texture of the panel; the second is permanent and made of an EPS element that shapes the internal side of the UHPC layer while adding the desired thermal resistance. For complex shapes, computerized 3D modeling techniques are used to create the mold. The mounting technique and fixtures are also designed to optimize building performances with respect to fire ratings, water and air tightness, reduction of thermal bridges, etc.

The facade can be designed to be self-supporting or slab mounted (curtain wall) with great flexibility to produce these elements in a variety of shapes, colors and textures.

**Main Advantages**

- Architectural creativity / Unlimited variety of shapes and patterns
- Thermal performance / Exceptional insulation / wall thickness ratio
- Simplified on-site implementation / Easy-to-install large size panels

**Main Domains of Applications**

- Building sectors
  All types of buildings

- Specific recommendations
  This UHPC facade system is a non-structural wall solution. The panel design and installation technique (self-supporting or slab-mounted) should take into consideration the building height and the required thermal performance. The production of the panels should be done by a highly qualified precast facility.

**Reference Project**

**Pierre Budin Daycare Center**

2012, France

- Project description / Daycare Center
- Architect / ECDM
- Engineering firms / Saunier & associates, C&E Ingénierie
- Labels & certification
  Low energy consumption building (BBC Effinergie: 50 kWh/m² per year)
- System information
  520 m² of white precast Ductal® with organic fibers facade. Large size and wavy shaped panels were precasted with the integrated Expanded Polystyrene insulation.

**The Lafarge Added Value for the System**

This innovative building facade solution has been developed by Lafarge and specialized partners based on the exceptional performances of Ductal®. Ductal is an Ultra-High Performance Concrete (UHPC) with a unique combination of superior properties such as strength, durability, ductility and aesthetics. Its compressive strengths are up to 8 times stronger and flexural strengths are up to 10 times stronger than conventional concrete.

Ductal® provides architects and designers with an exceptional freedom to meet any design requirements, offering structural and architectural functions. Lafarge dedicated engineers can support architects to develop and design customized solutions for any architectonic facades. Lafarge can also select qualified and trained precast facilities for a high quality execution.
The main objective of solar shading systems is to reduce summer solar gains and related overheating or cooling energy consumption. When optimized, they take advantage of passive solar gains in the winter and block solar radiation in the summer. Compared to other commonly-used materials for solar shadings (aluminum, wood, textile, standard concrete, etc.), Ultra-High Performance Concrete (UHPC) offers a durable, aesthetic, mineral and robust alternative solution.

OVERHANG
The term overhang is used there to describe a horizontal or slightly inclined shading element placed over a window opening.

BRISE-SOLEIL
The term brise-soleil is used there to describe fixed horizontal or slightly inclined louveres placed in front of a window opening.

Lafarge innovative concrete Ductal® is an ideal product for architectural and robust sunshade solutions. Ductal is an Ultra-High Performance Concrete (UHPC) with a unique combination of superior properties such as strength, durability, ductility and aesthetics. Its compressive strengths are up to 8 times stronger and flexural strengths are up to 10 times stronger than conventional concrete. Ductal® provides architects and designers with an exceptional freedom to meet any design requirements, offering structural and architectural functions. Lafarge dedicated engineers can support architects to develop and design customized solutions for any type of projects. Lafarge can also select qualified and trained precast facilities for a high quality execution.

REFERENCE PROJECT
RESIDENTIAL BUILDING
Avignon, France

- Project description
  / Three-floor public housing unit
- Architect
  / De-So defrain-souquet architects
- Contractor
  / Citadis
- System information
  / Ductal® UHPC was used to make 51 perforated sunshades 50 cm wide and only 3 cm thick. Due to the strength of the material, no additional reinforcement was necessary. The light weight of the sunshades was also an important factor that reduced installation time on site.
Aesthetic concrete is an ideal interior flooring solution. There are different finishing types to choose from: polished, waxed and stamped concrete. An extremely wide range of aggregates and colors can be chosen to fit everyone’s needs. These solutions also offer the possibility to obtain very complex floor shapes and designs. These concretes not only provide a very beautiful finished surface, but also an affordable alternative to expensive floor treatment, for example marble. They also combine the well-known advantages of visible concrete in terms of thermal mass and related energy savings.

**Main Domains of Applications**

- **Building Sectors**
  - Housing, supermarkets, garages, museums, exhibition halls, restaurants, bars, meeting rooms.

**Main Advantages**

- Infinite variety of colors, shapes, textures & patterns
- Durability, high strength & low maintenance
- Energy efficiency due to the concrete’s thermal mass
- Improved daylight availability
- Dust and allergen-free
- The smooth and dense surface of polished concrete floors do not retain allergens
- Cost reduction over the life cycle of the building

**Reference Project**

**Yamaha Dealership**

- **2011, Johannesburg, South Africa**
- **Architect**
  - Empowered Space Architects
- **Applicator**
  - QS Concrete Grinding & Polishing
- **Area**
  - 504 m²
- **System information**
  - Artevia Polish was used for indoor applications, 120 mm thick of 30 MPa Artevia Polish with dark stone aggregates polished up to stage 7 and no pigment.
  - Artevia Polish was used for outdoor applications, 120 mm thick of 30 MPa Artevia polish with charcoal pigment, polished to stage 4.
  - Both used 13 mm aggregates.

**The Lafarge Added Value for the System**

Three Artevia® products are available:
- **Artevia® Polish** - the polished concrete solution, an alternative to marble, granite, tile, linoleum or coated concrete.
- **Artevia® Print** is the stamped concrete solution developed by Lafarge. It provides an inexpensive replica of more expensive materials and still maintains a very natural, authentic look.
- **Artevia® Ciré** - the waxed concrete solution has been developed to produce a coating that combines robustness with aesthetic qualities created by the light nuances of colors in the concrete.
Aesthetic concrete can be used as an exterior surfaces solution because it combines design and performance, offering a rich color palette, incomparable textured effects and infinite freedom of design. The use of a broad range of aggregates offers many complex colorful shapes and forms. Along with the beautiful finished surface, these concretes bring to the construction site high durability and strength and low maintenance.

**Main Domains of Applications**
- **Building Sectors**
  Residential, leisure, office, retail.

**Main Advantages**
- Infinite variety of colors, shapes, textures & patterns
- Durability, high strength & low maintenance
- Very quick installation, even for complex and curved shapes

**Reference Project**
**Houses in Serengeti Golf Estate**
Johannesburg, South Africa

- **System information**
  / Artevia® Exposed used with sandstone pigment for the top house. The concrete was cast in boxes and loose white stones were used as expansion joints. The picture is used in many of our adverts!
  / Artevia® Color with mocha pigment was used in the second house. Slate blocks were used as expansion joints as well as to divert run off water to the garden on the side of the driveway.

**The Lafarge Added Value for the System**

**Artevia®** is a range of ready-to-use concrete with a compressive strength of 23 MPa to 50 MPa after a minimum of 28 days, depending on the specifications. Lafarge recommends periodic refreshing with a replacement sealer to preserve the high quality finish of the product and therefore protect and keep the surface in good condition. Compared with other aesthetic materials used for paving (mainly tiled finishes), Artevia® is 3 to 5 times quicker to install.

Artevia’s extensive product line includes:
- **Artevia® Exposed** is a robust and slightly rough concrete with visible aggregates.
- **Artevia® Saharo** is a concrete where the retarding effect is lighter than with Artevia® Exposed.
- **Artevia® Sand** reproduces the effect of a compacted sand. It remains stable and dust-free in all weather conditions.
- **Artevia® Stone** looks and feels like natural cut stone.
- **Artevia® Color** is a collection of concretes with a broad palette of tones.
- **Artevia® Print** is a versatile and attractive product suited to prints simulating the appearance of other building materials, for example bricks, wood and stone.
- **Artevia® Polish** has a smooth texture like polished marble; it is soft to the touch and elegant.
- **Artevia® Ciré** is a waxed concrete with aesthetic qualities.
Bridge beams, generally referred to as girders, provide the main load-bearing support in a bridge system. The span between bridge supports and deck panels are placed on them for continuity. Thanks to its exceptional durability, high strengths, and enhanced formability, Ultra-High Performance Concrete (UHPC) presents exciting opportunities to rethink the construction, reconstruction, and maintenance of roads and bridges. For new bridges, large UHPC precast elements can be easily transported to the jobsite, allowing faster construction and reduced impact to the environment.

UHPC beams for bridges can be created in different sizes, shapes, and strengths in order to meet the specific needs of a certain project. They have high compressive and flexural strengths that allows for heavy traffic loads with lightweight structural members. The high compressive and flexural strengths allows a UHPC beam to outperform steel and traditional concrete elements to transfer loads to the bearing elements.

Among the road bridges that have been constructed around the world with UHPC girders (France, US, Japan, Malaysia), two main types of UHPC cross sections can be distinguished:

- Composite structure made of UHPC beams and an ordinary concrete deck,
- “Double T” or “PI” girder cross section.

**Main Domains of Applications**

- **Building sectors and applications**
  - Precast Sections for Bridges
  - Precast Decks for Bridges

**Main Advantages**

- Heavy loading and high strength
  / Exceptional compressive and flexural strength
- Improved durability
- Superior resistance to abrasion, chemicals, freeze-thaw, carbonation and chloride ion penetration.
- Quick installation

**Reference Project**

**Wapello/Mars Hill Bridge**

2006, Wapello County, IA, USA

- Project description
  / Highway Bridge
- Awards / Labels
  / PCA Concrete Bridge Award (2006)
- Design team
  / Architect, engineering firm
- Owner
  / Wapello County
- System information
  / First North American highway bridge to use UHPC girders
  / Simple span covered by 3 • 33.5 m UHPC Girders without rebar for (shear) stirrups
  / Product implemented : UHPC CS1000.

**The Lafarge Added Value for the System**

Lafarge’s product for this system is **Ductal®**. Ductal is an Ultra-High Performance Concrete (UHPC) with a unique combination of superior properties such as strength, durability, ductility and aesthetics. Its compressive strengths are up to 8 times stronger and flexural strengths are up to 10 times stronger than conventional concrete. **Ductal®** provides architects and designers with an exceptional freedom to meet any design requirements, offering impressive structural and architectural functionality.
Ductal® Joint Fill is an Ultra-High Performance Concrete field-cast connection solution that provides superior strength, durability, fluidity and increased bond capacity for precast bridge systems. Its fiber matrix is significantly stronger than conventional concrete and performs better in terms of fatigue, abrasion and chemical resistance, freeze-thaw, carbonation and chloride ion penetration. When used with precast deck panels, precast box girders or bulb-tee girder joints, fabrication and installation processes are simplified, full deck continuity is achieved and the bridge deck joint is no longer the weakest link.

**REFERENCE PROJECT**

RAMAPO RIVER BRIDGE
2011, NY, USA

- Project description
  / Accelerated construction to replace a previous structure lost during a hurricane.
- Owner
  / New York State Department of Transportation.
- System information
  / UHPC Product used to connect the precast concrete deck panels: JS1100RS.

**MAIN ADVANTAGES**

- High compressive and flexural strengths
- Improved durability
- Superior resistance to abrasion, chemicals, freeze-thaw, carbonation and chloride ion penetration
- Suitable for Accelerated Bridge Construction (ABC) projects
- Remote area construction

**MAIN DOMAINS OF APPLICATIONS**

- BUILDING SECTORS
  Precast bridge projects
- APPLICATIONS
  Connection of precast concrete bridge elements

**THE LAFARGE ADDED VALUE FOR THE SYSTEM**

The solution proposed by Lafarge is an Ultra-High Performance Concrete (UHPC) which is reinforced with steel fibers. Its mechanical properties exceed those of conventional concrete and present an opportunity to significantly enhance the performance of normal concrete joint connections.

Ductal® is an Ultra-High Performance Concrete (UHPC) with a unique combination of superior properties such as strength, durability, ductility and aesthetics. Its compressive strengths are up to 8 times stronger and flexural strengths are up to 10 times stronger than conventional concrete. Ductal® provides architects and designers with an exceptional freedom to meet any design requirements, offering impressive structural and architectural functionality.
Buildings and structures must be designed to be resistant, stable and sustainable to their surrounding environment as well to the occupants or uses that they were intended for. These conditions can be ensured through the appropriate selection and use of the construction materials. The proper functioning of a construction depends not only on design, but also on the right utilization of the materials and their quality. The innovative properties of Lafarge's range of products stimulate architectural creativity, engineering performance and guarantee quality over time.
Worldwide presence

Cement

Concrete
  Artevia P71
  Agilia P74
  Agilia Screed P75
  Chronolia P76
  Extensia P77
  Hydromedia P78
  Thermedia P79
  Ultra Series P80
  Morpla Series P81

Ultra-High Performance Concrete
  Ductal P82

Aggregates P84
WORLDWIDE PRESENCE

- CANADA
- USA
- MEXICO
- FRENCH WEST INDIES
- ECUADOR
- BRAZIL

CEMENT
AGGREGATES
CONCRETE

GYPSUM: USA, Morocco, Algeria, Egypt, Saudi Arabia, South Africa
ASPHALT/PAVING: Canada, USA, United Kingdom
Cement is a hydraulic binder, a finely ground inorganic material which, when mixed with water, forms a paste which sets and hardens by means of hydration reactions and processes and which, after hardening, retains for centuries its strength and stability even under water (EN-197).

**Lafarge**

Cement production historically represents Lafarge’s core business. Cement is the principal hydraulic binder. It is the principal strength-giving and property-controlling component of concrete. It is a high-quality, cost-effective building material that is a key component of construction projects throughout the world. Based on both internal and external research, Lafarge is a world-leading producer of cement, taking into account sales, production capacity, geographical positions, technological development and quality of service.

Lafarge has designed a diversified product range intended for construction professionals. Lafarge cements are designed to respond to the requirements of all of the Group’s customers. Its broad range of products is suitable for industrial players, individual customers and architects:

- **Portland cements**: high-quality basic building materials that are both efficient and versatile;
- **Cements for different types of environments**: products suitable for exposure to sea water, sulfates and other aggressive environments;
- **Special cements for specific applications**: including white cements for architectural projects, cements for well drilling operations, and cements for road surfacing;
- **Cements for masonry and mortars** for concrete blocks, tiles, rendering, stucco, etc.

These different cements can all be used for construction with a variety of characteristics and properties.

**Lafarge Innovation**

All cements are NOT the same! The Lafarge brand is the mark of confidence in:

- **Quality**: all-around quality assurance
- **Consistent product performance**: the investment and technology to ensure that the cement will perform consistently according to customer requirements
- **Related services**: technical support; order and delivery logistics, documentation, demonstrations and training related to the characteristics and proper use of cement.
- **Strength**: while buyers may have some protection under a country’s law, the Lafarge name is your assurance of achieving the strength performance stated on the bag
- **Quantity**: buyers receive the quantity of cement stated on the bag
- **Packaging**: bags of suitable quality to minimize handling losses

Most of the ongoing R&D work at Lafarge today focuses on designing products with a reduced environmental footprint. We have developed new ranges of products and services and it is our ambition that by 2020 they represent a 33% reduction in CO₂ emissions compared to 1990 levels.

**CEMENT IMPORTANT CHARACTERISTICS**

**Initial setting time.** The time needed for the cement water paste to attain a certain degree of hardness is known as the initial setting time of cement. This is the time between mixing (cement hydration) and when the cement water paste mixture attains a certain degree of hardness.

**Soundness.** This is the property of hardened cement paste undergoing large change in volume after setting (pure paste, mortar or concrete), generally less than 0.8 mm/m. This change in volume can be linked to drying i.e. the earlier evaporation or to the hardening phenomenon itself.

**Hardening.** It corresponds to the gradual gain of compressive strength of a set cement paste due to the progress of hydration. This resistance is expressed in MPa (psi). The standard strength of cement is the compressive strength measured at 28 days. Three classes of standard strength are included: class 32.5, class 42.5 and class 52.5. The compressive strength measured at either 2 days or 7 days represents the early strength of cement. Two classes of early strength are included for each class of standard strength, a class with ordinary early strength, indicated by N, and a class with high early strength, indicated by R.

**Fineness.** Can be defined as the measure of size of particles of cement or as a specific surface of cement. The fineness of cement has an important bearing on the rate of hydration, on the rate of gain of strength and also on the rate of evolution of heat. Finer cement offers a greater surface area for hydration and hence accelerates the development of strength.

**Its main constituents**: limestone fillers, blast furnace slag, fly ash and pozzolanas optimize the quality of the mixture.
## REFERENCE STANDARDS SPECIFICATION VS. PERFORMANCE

<table>
<thead>
<tr>
<th>DURATION OF USE (YEARS)</th>
<th>10</th>
<th>25</th>
<th>25</th>
<th>50</th>
<th>100</th>
<th>100 ++</th>
</tr>
</thead>
<tbody>
<tr>
<td>CATEGORY</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temporary structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Replaceable structural elements</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Agricultural and similar structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings and other current structures</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Monumental buildings</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bridges and other civil engineering structures</td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

### NON-STRUCTURAL

Specially designed Masonry cements with high levels of limestone & Cementitious addition & air entraining agent. Blended cements, with high C/K ratio: class 22.5* or 32.5 (CEMI, III, IV, V...)

- Blended cements with fine clinker for high early strength; Blended cements 32.5 class R

- Rendering, plastering, repairing mortars (bags)

- Precast products (block, tiles, edges)

### STRUCTURAL

- OPC, CEM I; CEM II to CEM V; Class 42.5 or 32.5 A/B depending on applications III 52.5R or N

- OPC or blended cements, class R; Blended cements with very fine clinker for high early strength

- Reinforced concrete

- Pre-stressed concretes

- Precast products

- High Performance concrete

- Ultra-High Performance Concrete (DUCTAL)

### SPECIAL

Specially designed products to reach moderate to low heat of hydration requirement depending on application requirement: OPC or blended cements II to V; 32.5 or 42.5.

- Blended cements II to V; 42.5 or 32.5

- Mass concrete works (for dams e.g.)

- Roads applications & soil stabilization

Specially designed products to reach sulfate resisting requirements

- OPC with low to very low alumina level

- Blended cements: high level of fly ash, Pozzolan (30% or more approxi) and or very high level of slag (60% or more approxi)

- Underground applications & Aggressive chemical environment (sulfates in soil, sea water...)

- Oil-well cementing

**Note:** The national standard of some countries allows production of blended cements equivalent to EN 20; 5 strength class as common cement improving the C/K ratio (Africa, Asia...,).

EN cement standard was used as a base to define the cement type for each application in the table above.
EUROPEAN STANDARD

The European standard EN 197 – 1 defines and gives the specifications and the composition of the following cements:

- 27 common cements (CEM I, II, III, IV and V)
- 7 common sulfate-resistant cements
- 3 low early strength blast furnace slag cements
- 2 sulfate-resistant low early strength blast furnace slag cements

The definition of each cement includes the proportions in which the constituents are to be combined to produce these products in a range of 9 strength classes: 3 early strength classes (L = Low, N = Ordinary, R = High) included for each standard strength class (32.5, 42.5 and 52.5) at 28 days.

EN 197.1 common cements cover the need for all concrete, mortar and grouts applications, except when special cements are required:

The right cement should be selected based on environmental conditions, the type of construction and durability requirements (for example low alkalis, steel corrosion, etc.). The adjacent table describes the main common cement families and their ability to improve concrete/mortar usage qualities:

<table>
<thead>
<tr>
<th>COMMON CEMENTS</th>
<th>DESIGNATION</th>
<th>ADDITION RATE</th>
<th>COMMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland Cement</td>
<td>CEM</td>
<td>0 - 5%</td>
<td>Sulfate-resistant cements could be developed by reducing the alumina level (C3A &lt; 5%) Many types of additions could be used (blast furnace slag, fly ash, Pozzolanic, Limestone...) giving more flexibility to cement producers to develop relevant products meeting customer requirements: The addition of Blast Furnace slag generally improves 28-day strength and sulfate resisting, and reduces heat of hydration Fly ash improves workability (when carbon level is low and fine particle), contributes to late strength development (Pozzolanic reaction), reduces heat of hydration &amp; improves sulfate-resisting properties Pozzolanic: contributes to late strength, reduces head of hydration &amp; improves sulfate-resisting properties Limestone improves workability.</td>
</tr>
<tr>
<td>Portland Composite Cement</td>
<td>CEM II A&amp;B</td>
<td>6 - 35%</td>
<td>Blast Furnace Cement CEM III A,B &amp; C 36 - 95% Slag cements, generally leads to high late strength and good concrete durability Pozzolanic Cement CEM IV A&amp;B 11 - 55% Pozzolanic cements, generally leads to high late strength and good concrete durability High levels of Pozzolanic material also assist in the reduction of the heat of hydration Composite Cement CEM V A&amp;B 36 - 80% Composite cements (Slag, Fly ash/Pozzolanic), generally leads to high late strength and good concrete durability</td>
</tr>
</tbody>
</table>

Today, road binders are standardized in different European countries. A project for a common EN standard for road binders (EN 13282) is under validation covering:

- Rapid hardening hydraulic road binders
- Normal hardening hydraulic road binders

In addition to all mineral additions allowed to be added to normal cement (EN 197.1), it is possible to use lime to develop rapid hardening road binders.

ASTM STANDARD

The type of pure cements (max addition = 5%) are described in the ASTM C150 standard according to the table below:

<table>
<thead>
<tr>
<th>COMMON CEMENTS</th>
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<th>COMMENTS</th>
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</tr>
</tbody>
</table>

According to ASTM C 595 & local regulations (CSA, AASHTO...), two types of Blended Hydraulic Cement can be developed:

- Slag cement (type IS, S, SM) with a maximum addition rate up to 70% except for masonry mortar, for which we can exceed this level,
- Pozzolanic cement (type IP, P, PM) with a maximum addition rate up to 40%

There are no strength classes specified in the ASTM standard, rather the following prescriptive specifications:

- Standard and optional Chemical requirements,
- Standard and optional Physical requirements (tested on mortar and paste).

Compared to the European standard, the ASTM standard or equivalent (CHA, AASHTO, and others which are applied in Canada and the USA) offers few possibilities to develop blended cements: only slag cement and Pozzolanic cement can be developed with the ability to use 4 mineral additions: Slag, Pozzolanic, fly ash and silica fume. Limestone can be added up to 5% only. Discussions are progressing to enlarge the type and level of additions allowed in the ASTM standard (composite cement, etc.). Limestone cement with the % addition up to 15% was recently introduced in the CSA Canadian standard.

Oil Well cements are standardized under API (American Petroleum Institute) and masonry cements & mortar under ASTM C91 & ASTM C 1329.

As shown above, there is a strong difference in terms of product specifications and composition between EN and ASTM standards. We therefore recommend selecting the cement according to the local national standard, taking into account the local applications and customer requirements.

ASTM C 1157 TYPES OF HYDRAULIC CEMENT

<table>
<thead>
<tr>
<th>PORTLAND CEMENT TYPE</th>
<th>DESCRIPTION / USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>GU</td>
<td>Hydraulic cement for general construction. Use when one or more of the special types are not required.</td>
</tr>
<tr>
<td>HE</td>
<td>High early strength</td>
</tr>
<tr>
<td>MS</td>
<td>Moderate sulfate resistance</td>
</tr>
<tr>
<td>HS</td>
<td>High sulfate resistance</td>
</tr>
<tr>
<td>MH</td>
<td>Moderate heat of hydration</td>
</tr>
<tr>
<td>LH</td>
<td>Low heat of hydration</td>
</tr>
</tbody>
</table>

ASTM C 595 BLENDED HYDRAULIC CEMENT TYPES

<table>
<thead>
<tr>
<th>PORTLAND CEMENT TYPE</th>
<th>DESCRIPTION / USE</th>
</tr>
</thead>
<tbody>
<tr>
<td>IS, IP &amp;P, IPM, ISM</td>
<td>For general construction</td>
</tr>
<tr>
<td>S</td>
<td>For masonry Mortar</td>
</tr>
</tbody>
</table>
Concrete is a building material made by mixing water, aggregates and sand with cement as a binding agent and, if necessary, additives. This mixture can be made on building sites or in batch plants located off site.

The characteristics of a concrete can vary greatly depending on the choice of cement and cement-aggregate ratio, the type of aggregate used, the inclusion of additives, etc.

**LAFAARGE**

As the world’s fourth largest producer of ready mix concrete, Lafarge is known for its innovation with sophisticated, high value-added concretes. In a highly competitive market, Lafarge works to set itself apart based on the quality and consistency of its products, the breadth of its product line and, especially, the innovative products by its research center.

**A consistent quality**

All Lafarge plants have their own laboratory for their daily testing: plasticity control, resistance control, slump cone, etc. The perfect mastery of the manufacturing process, complemented by thorough compliance controls, ensures our customers consistent quality from one revolving drum to another.

**A local industry**

Concrete stations are installed as close as possible to the markets in order to limit truck transportations and to guarantee a presence as close as possible to consumption locations.

---

**LAFAARGE INNOVATION**

Concretes are divided into two families

- **Standard concretes** (foundation, floor, wall, etc.)
  - Strength adapted to customer needs
- **Special concretes bringing innovation**
  - ARTEVIA
  - AGILIA
  - CHRONOLIA
  - EXTENSIA
  - THERMEDIA
  - HYDROMEDIA
  - ULTRA SERIES
  - MORPLA SERIES

The range availability of concrete through Lafarge will vary from country to country. Please check with your local contacts to determine what is available in your country.
**CONCRETE KEY FEATURES**

**AVAILABLE ANYWHERE AROUND THE WORLD**
- The only material that is available enough to meet all the construction needs around the world.
- With more than 10 billion m³ of concrete cast per year, i.e. the equivalent of 1.5 m³/year/inhabitant, concrete became vital in the construction field.

**A MATERIAL WITH NO BOUNDARIES**
- Growing innovation in the ready mix concrete field today makes it possible to satisfy all the designers’ expectations in terms of shapes, colors, design, materials effects, etc.
- The largest use range possible compared to all competing building materials.
- Not concrete, concretes. With more than 500 different formulations, concretes are used today in multiple applications, from the most simple to the most sophisticated, mainly in construction.

**STRONG, RESILIENT AND LONG-LASTING**
- Compressive strength up to 200 MPa (29,000 psi)
- Withstands external aggressions, weathering, pollution, saline environment, etc.
- Concrete structures can last for hundreds of years with limited maintenance.

**INEXPENSIVE**
- Concrete can be used to build at a reasonable cost, without compromising on quality and strength.
- Indispensable for humanity: has been and will be the ideal material for responding to huge human needs.

**UNRIVALLED VERSATILITY AND AESTHETICS**
- Enables many shapes
- Allows unlimited architectural creativity
- Colorful
- Multiple surface finishes

**CONTRIBUTES TO ENERGY EFFICIENCY IN BUILDINGS**
- Low embodied energy and low carbon footprint
- Material with a high thermal inertia

**CONCRETE FUNCTIONS**
- Structural function
- Slab
- Envelope
- Coverage

**QUALITIES OF CONCRETE**
- Intrinsic qualities
  / Concrete possesses intrinsically and simultaneously a number of qualities that are highly prized in the building industry: mechanical properties, price, resistance to fire, thermal and acoustic comfort, durability, availability, ease of use and versatility. Other complementary or rival materials may have one or another of these qualities, sometimes even to a greater extent, but only concrete brings together the unique combination of all these qualities.
- Extrinsic qualities
  / Factors independent of the material properties of concrete that make concrete an outstanding solution: excellent quality/price ratio, adaptability and consistency.

**AMERICAN AND EUROPEAN STANDARDS**

**AMERICAN STANDARDS**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATCM C150</td>
<td>Standard specifications for Portland cement</td>
</tr>
<tr>
<td>ATCM C595</td>
<td>Specifications for Blended Hydraulic Cements</td>
</tr>
<tr>
<td>ATCM C33</td>
<td>Standard Specifications for Concrete Aggregates</td>
</tr>
<tr>
<td>ATCM C618</td>
<td>Specifications for Coal Fly-ash and Raw or Calcined Natural Pozzolan for use as a mineral admixture in Concrete</td>
</tr>
<tr>
<td>ATCM C1240</td>
<td>Standard specification for Silica Fume used in Cementitious Mixtures</td>
</tr>
<tr>
<td>ACI 305R</td>
<td>Hot Weather Concreting</td>
</tr>
<tr>
<td>ACI 306R</td>
<td>Cold Weather Concreting</td>
</tr>
<tr>
<td>ACI 308</td>
<td>Standard practice for Curing Compounds</td>
</tr>
<tr>
<td>ATCM C171</td>
<td>Standard specifications for Sheet materials for Curing Concrete</td>
</tr>
<tr>
<td>ASTM C260</td>
<td>Standard specifications for Air-entraining Admixtures for Concrete</td>
</tr>
<tr>
<td>ATCM C309</td>
<td>Standard Specification for Liquid Membrane Forming Compounds and for Curing Concrete</td>
</tr>
<tr>
<td>ATCM C494</td>
<td>Standard Specification for Chemical Admixtures for Concrete</td>
</tr>
<tr>
<td>ACI 301</td>
<td>Specifications for Structural Concrete for Buildings</td>
</tr>
<tr>
<td>ACI 318</td>
<td>Building Code Requirements for Structural Concrete</td>
</tr>
<tr>
<td>ASCC</td>
<td>Guide for Surface Finish of Formed Concrete</td>
</tr>
</tbody>
</table>

**EUROPEAN STANDARDS**

<table>
<thead>
<tr>
<th>Standard</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 197-1</td>
<td>Cement - Part 1: Composition, Specifications and Conformity Criteria for common cements</td>
</tr>
<tr>
<td>EN 12620</td>
<td>Aggregates for Concrete</td>
</tr>
<tr>
<td>EN 450</td>
<td>Fly-ash for Concrete</td>
</tr>
<tr>
<td>EN 13263</td>
<td>Silica Fume for Concrete</td>
</tr>
<tr>
<td>EN 206-1</td>
<td>Concrete - Part 1: Specification, Performance, Production and Conformity</td>
</tr>
<tr>
<td>EN 934-2</td>
<td>Admixtures for Concrete, Mortar and Grout - Part 2: Concrete Admixtures - Definitions and Requirements</td>
</tr>
<tr>
<td>EN 13670</td>
<td>Execution of Concrete Structures</td>
</tr>
</tbody>
</table>

The table above should not be considered all-inclusive.
Artevia® by Lafarge is a range of decorative concretes for indoor and outdoor applications that combines freedom of design with low maintenance and durability, offering a rich color palette, incomparable textured effects and infinite freedom of design. Fully customizable, Artevia® concrete offers great aesthetics and outstanding performance.

**BENEFITS /APPLICATIONS**

Artevia can be molded in its fresh state providing more flexibility for its application. The use of a broad range of aggregates offers many complex colorful shapes and forms.

**BENEFITS**
- Decorative concretes for indoor and outdoor, horizontal & vertical use
- Freedom and ability to design aesthetic, economic and sustainable projects
- Variety of colors and textures which can be integrated into any kind of spaces and environments
- Potential for more innovative finishing especially in indoor and vertical applications.

**APPLICATIONS**

**Private market**
- Residential/housing
  /Large-scale new development
  /Renovations
  /Individual housing
- Non-residential market (commercial, industrial, agricultural)
  /Offices
  /Stores, shopping malls
  /Warehouses
  /Hotels, restaurants
  /Exhibition areas, showrooms
  /Hospitals
  /Schools, universities
  /Libraries
  /Prisons
  /Cultural centers
  /Health clinics, golf course hardscapes
  /Industrial buildings
  /Agricultural buildings
  /Drive-thrus
  /Entertainment, parks
  /Parking lots

**Public sector market**
- Town hardscapes
- Hospitals, health clinics
- Schools, universities
- Libraries, cultural centers
- Official buildings
- Monument refurbishment
- Industrial buildings
- Agricultural buildings
- Bus stops, light rail stops
- Railway stations
- Airports
- Parks

---

**MARKETS**

**Market segments**
/Individual housing, collective building, industrial and commercial areas, landscaping and urban development, roads

**Type of applications**
/Indoor and outdoor horizontal and vertical decorative applications. Due to its workability Artevia can be used for very complex shapes

---

**ARTEVIA FOR STRUCTURAL ENGINEER**

- Freedom and ability to design aesthetic, economic and sustainable projects

**ARTEVIA FOR ARCHITECT**

- Freedom and ability to design aesthetic, economic and sustainable projects
- Can be used for very complex shapes
- Variety of colors and textures
- Potential for more innovative finishing

**ARTEVIA FOR CONTRACTOR**

- High workability
- Used for very complex shapes

---

**CONCRETE SPECIFICATIONS**

Artevia, decorative concrete with the following characteristics:

- Compressive Strength at 28 days: greater than 20 Mpa (2,900 psi) to 50 Mpa (7,250 psi), depending on the specifications.
- Consistency Class: S3
- Slump: 100 mm to 150 mm (4 in to 6 in)
- Workability Retention: 2h
- Maximum water cementious ratio: the maximum water cementious ratio is specified by the Designer Project Engineer.
- Air content: insert air entrainment if the concrete element is required

---

**EFFICIENT BUILDING SYSTEMS:**

- ROADS, PATH & PAVINGS: Aesthetic exterior concrete surfaces p.61
- FLOOR FINISHES: Aesthetic interior concrete finishes p.60
Agilia® is a self-compacting, self-leveling concrete that provides solutions and opportunities for design and placement. A fluid concrete that will flow freely around congested steel reinforcement and fully compact without any added placing energy.

**Range / Applications / Benefits**

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agilia®</td>
<td>• Columns, walls, beams&lt;br&gt;• Bridges, overpasses&lt;br&gt;• Decorative formworks&lt;br&gt;• and more</td>
<td>• No vibration&lt;br&gt;• Worksite flexibility&lt;br&gt;• Easy placement&lt;br&gt;• Faster-working concrete&lt;br&gt;• High surface quality&lt;br&gt;• Speed and ease of placement&lt;br&gt;• Greatly reduces placing time&lt;br&gt;• Pumping and crane time significantly reduced&lt;br&gt;• No vibration needed&lt;br&gt;• Frees up labor for other valuable tasks&lt;br&gt;• Less finishing required&lt;br&gt;• Ideal for direct placement of carpet, tile and wood without the need for power trowelling&lt;br&gt;• Reduced bugholes&lt;br&gt;• Reduced time-consuming and costly rubbing or patching repairs&lt;br&gt;• Reduce space consumption&lt;br&gt;• The flowability of Agilia allows it to flow through congested rebar that would otherwise be too restrictive.&lt;br&gt;• Denser rebar arrangement allows for designs using thinner walls and columns&lt;br&gt;• Improved work environment&lt;br&gt;• Reduced noise on site promotes better local relations&lt;br&gt;• No requirement for finishing crews into late evening hours&lt;br&gt;• Reduced construction time&lt;br&gt;• More efficient use of labor means quicker completion of jobs&lt;br&gt;• Agilia maintains its integrity rain or shine&lt;br&gt;• Quicker completion mean targets hit and bonuses achieved</td>
</tr>
<tr>
<td>Agilia® Vertical</td>
<td>• Slab-on-grade&lt;br&gt;• Overlaying existing slabs for leveling&lt;br&gt;• Elevated slabs</td>
<td>- Reduced labour for placing and costs&lt;br&gt;- Reduced costs for finishing labour&lt;br&gt;- Reduced repair and surface rubbing required</td>
</tr>
<tr>
<td>Agilia® Horizontal</td>
<td>• Horizontal basement floor&lt;br&gt;• Garage Pad&lt;br&gt;• Horizontal basement floor</td>
<td>- Cement wood block walls&lt;br&gt;- UPPER FLOOR: Floor with void former (p.55&lt;br&gt;- FRAME: Matrrixed concrete facade (p.54&lt;br&gt;- FRAME: Aesthetic finish concrete walls (p.51&lt;br&gt;- FRAME: Double skin concrete insulated wall (p.52&lt;br&gt;- FRAME: Hollow column with air circulation (p.50&lt;br&gt;- Underfloor heating with self-placing screed (Agilia screed A &amp; C)&lt;br&gt;- Cement earth block walls&lt;br&gt;- FUNDATIONS: Energy pile foundation (p.44&lt;br&gt;- FRAME: Insulated concrete formwork walls (p.45&lt;br&gt;- Insulated semiprecast double walls</td>
</tr>
<tr>
<td>Agilia® Horizontal housing</td>
<td>• Pile foundations</td>
<td>- Cement wood block walls&lt;br&gt;- UPPER FLOOR: Floor with void former (p.55&lt;br&gt;- FRAME: Matrinxed concrete facade (p.54&lt;br&gt;- FRAME: Aesthetic finish concrete walls (p.51&lt;br&gt;- FRAME: Double skin concrete insulated wall (p.52&lt;br&gt;- FRAME: Hollow column with air circulation (p.50&lt;br&gt;- Underfloor heating with self-placing screed (Agilia screed A &amp; C)&lt;br&gt;- Cement earth block walls&lt;br&gt;- FUNDATIONS: Energy pile foundation (p.44&lt;br&gt;- FRAME: Insulated concrete formwork walls (p.45&lt;br&gt;- Insulated semiprecast double walls</td>
</tr>
<tr>
<td>Agilia® Blockfill</td>
<td>• Masonry cavity walls</td>
<td>- Cement wood block walls&lt;br&gt;- UPPER FLOOR: Floor with void former (p.55&lt;br&gt;- FRAME: Matrinxed concrete facade (p.54&lt;br&gt;- FRAME: Aesthetic finish concrete walls (p.51&lt;br&gt;- FRAME: Double skin concrete insulated wall (p.52&lt;br&gt;- FRAME: Hollow column with air circulation (p.50&lt;br&gt;- Underfloor heating with self-placing screed (Agilia screed A &amp; C)&lt;br&gt;- Cement earth block walls&lt;br&gt;- FUNDATIONS: Energy pile foundation (p.44&lt;br&gt;- FRAME: Insulated concrete formwork walls (p.45&lt;br&gt;- Insulated semiprecast double walls</td>
</tr>
</tbody>
</table>

**Agilia for Structural Engineer**
- Ability to design with higher reinforcement density
- Higher percentage of the steel surface bonded
- Improved structural integrity

**Agilia for Architect**
- Improved aesthetics
- Design creativity enhancements
- Consistency of finished appearance
- Sharp lines

**Agilia for Contractor**
- Reduced labour for placing and costs
- Reduced costs for finishing labour
- Reduced repair and surface rubbing required

**Concrete Specifications**
Agilia ready-mix concrete with the following characteristics:
- Compressive Strength at 28 days: 25 MPa to 70 MPa (3,625 psi to 10,150 psi)
- Flow: 550 mm to 750 mm (20 in to 30 in)
- Maximum water cementitious ratio: the maximum water cementitious ratio is specified by the Design Project Engineer
- Air content: Insert air entrainment if the concrete element is required to comply with severe exposure conditions.

**Markets**
- Market segments<br>  / Residential<br>  / Buildings<br>  / Civil applications
- Applications: heavily reinforced elements, decks and slabs, foundations, walls and columns, block fill, precast elements, civil applications, tunnels.

**Efficient Building Systems**
- Cement wood block walls
- UPPER FLOOR: Floor with void former (p.55
- FRAME: Matrinxed concrete facade (p.54
- FRAME: Aesthetic finish concrete walls (p.51
- FRAME: Double skin concrete insulated wall (p.52
- FRAME: Hollow column with air circulation (p.50
- Underfloor heating with self-placing screed (Agilia screed A & C)
- Cement earth block walls
- FUNDATIONS: Energy pile foundation (p.44
- FRAME: Insulated concrete formwork walls (p.45
- Insulated semiprecast double walls
Agilia® Screed is a self-placing, self-compacting product that can easily be placed providing a leveled, high-quality surface without cracking. Agilia® Screed is well suited for underfloor heating applications as it is laid much thinner compared to traditional screed. The free-flowing Agilia® floor screed ensures a good compaction around the heating pipes, due to the flowing nature of the product, which eliminates voids and air-pockets common with traditional screeds.

**RANGE / APPLICATIONS / BENEFITS**

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
</table>
| Agilia® Screed A | • All building applications where non-structural toppings are used.  
• Heat conduction systems and can be used for underfloor (not recommended in wet environments such as kitchens and bathrooms) | • Quick and easy to use, attractive and ergonomic, offering higher quality results  
• Exceptional fluidity, to easily fill in all spaces, thus avoiding some of the more physical and noisy steps such as vibration  
• Generating value for our customers, by reducing overall construction and placement costs through productivity gains  
• Better coating for heating floors |
| Agilia® Screed C | • All building applications where non-structural toppings are used  
• Ideal for heating floor systems, maximizing the heat transfer. Also reduces drying time compared to gypsum-based screeds.  
• Good medium for underfloor heating systems  
• Can be used in wet areas (bathroom, etc.) | |

Agilia screeds provide a higher and more homogeneous surface temperature due to their better homogeneity and higher conductivity. The following photos, taken after 80 minutes of heating, represent the distribution of the surface temperatures of two floor heating systems. The first is a conventional concrete screed, the second is an Agilia screed A.

![Floors.png](Floors.png)

**CONCRETE SPECIFICATIONS**

**SELF-CONSOLIDATING SYNTHETIC ANHYDRITE FLOOR SCREED:**

**AGILIA SCREED A**

- Anhydrite-based “self-leveling” screed for non-structural toppings, and placed by pumping.  
  - Flow: 200 mm to 280 mm (8 in to 11 in)  
  - Compressive Strength at 28 days: 12 MPa to 60 MPa (1,740 psi to 8,700 psi)  
  - Flexural Strength at 28 days: 3 MPa to 12 MPa (435 psi to 1,740 psi)  
  - Thermal conductivity: 2.2 W/m/K  
  - Thermal expansion: 0.012 mm/m/K  
  - Drying shrinkage < 0.015%  
  - Dry-density: 2,000 kg/m³ to 2,200 kg/m³ (125 lbs/ft³ to 137 lbs/ft³)  
  - Maximum Aggregate size: 5 mm (0.2 in)  
  - Maintenance of fluidity: 4h

**AGILIA SCREED C**

- Self-leveling Cementitious-based screed for non structural topping and placed by pumping.  
  - Flow: 230 mm ± 30 mm (9 in ± 1.2 in)  
  - Compressive Strength at 28 days: greater than 12 MPa (1,740 psi)  
  - Flexural Strength at 28 days: greater than 2 MPa (290 psi)  
  - Thermal conductivity ≥ 1.4 W/m/K  
  - Dry-Density: 2,200 kg/m³ ± 200 kg/m³ (137 lbs/ft³ ± 12.5 lbs/ft³)  
  - Maximum Aggregate size: 5 mm (0.2in)  
  - Average shrinkage: 0.5 mm/m  
  - Air content: 0.5 – 2%

**SCREED TYPE**

<table>
<thead>
<tr>
<th>SCREED TYPE</th>
<th>THERMAL CONDUCTIVITY</th>
<th>HEAT FLUX</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agilia® Screed A</td>
<td>2.5 W/m.k</td>
<td>~120 W/m²</td>
</tr>
<tr>
<td>Agilia® Screed C</td>
<td>1.7 W/m.k</td>
<td>~100 W/m²</td>
</tr>
<tr>
<td>Conventional screed</td>
<td>1.2 W/m.k</td>
<td>~90 W/m²</td>
</tr>
</tbody>
</table>

**MARKETS**

- Market segments  
  / All buildings: commercial, administrative, individual and collective housing  
- Applications: screed: typically from 2.5 cm, up to 8 cm thick when used with some heating floor systems.

![Efficient.png](Efficient.png)
Chronolia® is the range of very high early strength concretes, defined by a rapid surface setting and rapid hardening properties with a very high early strength. Chronolia® uses advanced technology resulting in very early high strenth gain with the same comfort of use as any standard ready-mix concrete (2 hours slump retention).

### BENEFITS / APPLICATIONS / RANGE

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
</table>
| Chronolia® 4H | • Form release 4h after batching (walls, columns, etc)  
• Making walls that are bottleneck in the cycle in half a day  
• Dilatation joints (sandwich walls)  
• Pile heads | • Speed up cycles  
• Catching up delays; double rotation of forms  
• Speed up pouring of problematic walls  
• Speed up cycle: everything in one day  
• Speed up by rotation the formworks faster |
| Chronolia® 6H | • Allows demolding and lifting of elements 6h after batching  
• Driveways  
• Prefabrication on site (beams, walls, …), posts and retaining walls | • Back to service earlier  
• Speed up the rotation of the molds to save the number of molds, save space, save heating  
• Loading the post earlier  
• Safer earlier |
| Chronolia® 15H | • Prefab on site  
• Overhangings  
• Central shaft, lifts, etc  
• Lightweight roadwork | • Same as Chronolia 6H but less demanding in early strength  
• Remove shorings earlier (savings of rental cost, space)  
• Jumpform or Slip form  
• Back to service earlier (10 MPa required) |
| Chronolia® 24H | • Crane bases  
• Overhangings (balconies, etc)  
• Remove slab formworks earlier  
• Heavy load traffic | • Install the crane earlier  
• Same as Chronolia 15H with less stress on time  
• Savings on shores, rental cost of formworks, space  
• Open to service earlier (20 MPa required) |
| Chronolia® 48H | • Shore removal of floors | • Same as Chronolia 24H with less time constraint  
• Remove earlier the shore (earlier access) |

### CHRONOLIA FOR CONTRACTOR

- Catching up delays
- Double rotation of forms
- Speed up pouring of problematic walls
- Savings on shores, rental cost of formworks, space

### MARKETS

- Market segments  
  / Industrial, commercial, administrative, housing, repairs in civil engineering
- Type of applications  
  / Floors, walls, bridge deck repairs, roads, slabs  
  (PM training June)

### CONCRETE SPECIFICATIONS

Chronolia ready-mixed concrete with the following characteristics:
- Maximum water cementious ratio:  
The maximum water cementious ratio can be specified by the Design Project Engineer or the relevant standard.
- Air content: insert air entrainment if the concrete element is required to comply with severe exposure conditions.
- Slump Flow: greater than 300 mm (12 in)
- Workability retention: 2h
- Compressive Strength at 28 days: greater than 30 MPa (4,350 psi)
- Compressive strength values achieved at early age are presented in the following table:

<table>
<thead>
<tr>
<th>Chronolia Product range Compressive Strength</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Product</td>
<td>Strength (MPa) vs time after batching</td>
<td>Strength (psi)</td>
</tr>
<tr>
<td>Chronolia® 4H</td>
<td>1 / 4h</td>
<td>145</td>
</tr>
<tr>
<td>Chronolia® 6H</td>
<td>3 / 6h</td>
<td>435</td>
</tr>
<tr>
<td>Chronolia® 15H</td>
<td>15 / 15h</td>
<td>2,175</td>
</tr>
<tr>
<td>Chronolia® 24H</td>
<td>20 / 1 day</td>
<td>2,900</td>
</tr>
<tr>
<td>Chronolia® 48H</td>
<td>25 / 2 days</td>
<td>3,625</td>
</tr>
</tbody>
</table>

### EFFICIENT BUILDING SYSTEMS

- Tunnel formwork for buildings
- FRAME: Tilt-up wall  [p.45]
- Aluminium formwork for buildings
Extensia® is an innovative technology in high strength - low-shrinkage concrete for commercial and industrial floors. Process for the fabrication of wide industrial and commercial slabs on ground with higher performance and less joints, with or without steel reinforcement depending on design and needs.

**BENEFITS**

- Increased flexibility in floor design
  / the mechanical and shrinkage properties of Extensia allow design of thinner and unreinforced slabs, with increased joint spacing (up to 400 m²).
- Rapid execution of floor construction
  / the floor construction sequence can be shortened with Extensia, mainly due to the possibility of early power-trowelling of the surface and early cutting of joints.
- Early loading at 14 days: thanks to superior mechanical performance.
- Surface performance with and without surface hardeners: abrasion resistance, chemical resistance, impact,…
- Shorter drying delays enabling the toppings to be put one or two weeks earlier.
- Reduction in maintenance costs:
  / the drastic reduction of joints, the limited curling at remaining joints combined with the high surface durability of Extensia allow substantial savings in maintenance costs of the floor.
- Controlled placing process that guarantees excellent final quality
- Reduced job time compared to standard and steel fibered concretes slabs (faster setting + less joints)

**MARKETS**

- Market segments
  / Industrial, heavy industrial, retail, shops, warehouse
- Type of applications
  / Interior slabs (no exterior). Ground bearing slabs for use in industrial, warehousing and commercial floors, with or without mesh reinforcement or fiber depending on need and design option.

**EXTENSIA FOR STRUCTURAL ENGINEER**

- High flexibility in floor design with reduced thickness, reduced steel fibers, reduced steel bars and increased joint gracing

**EXTENSIA FOR ARCHITECT**

- Increased flexibility in floor design
- Meticulous placing process that guarantees excellent final quality

**EXTENSIA FOR CONTRACTOR**

- Reduced job time
- Less joints
- Rapid execution of floor construction
- Reduction in maintenance costs
- Earlier project completion (benefits the end-user)

**CONCRETE SPECIFICATIONS**

Extensia ready-mixed concrete with the following characteristics:

- Slump Flow: up to 550 mm (22 in)
- Compressive Strength at 1 day - 20N/mm²; at 7 days - 40N/mm²; at 28 days - around 60 MPa (8,703 psi)
- Flexural Strength at 28 days: greater than 5 MPa (725 psi)
- Dry-Density: 2,400 kg/m³ ± 200 kg/m³ (150 lbs/ft³ ± 12.5 lbs/ft³)
- Maximum Aggregate size: 20 to 22.4 mm (0.8 to 0.88 in)
- Average shrinkage: less than 450 μm/m
A technologically advanced product combining hydraulic and mechanical performance. Hydromedia® is an ideal solution for surface and storm water management. Typically containing at least 20% void space, it allows water to pass directly through it at a permeability of 150 - 1000 L/min/m.

The Hydromedia® mix design optimizes the porosity at 20 to 30% and achieves a compressive strength of between 10 and 25 MPa.

**BENEFITS/APPLICATIONS**

**BENEFITS**
- Range of simple concrete solutions adapted to different customer needs from residential to infrastructures (by mastering porosity and compressive strength)
- Assists in managing water drainage on highways, roads, walkways (safer environment)
- Buffer in water management systems that contributes to sustainable development
- Recharge of water table (avoiding droughts) and helps to limit the size of storm water systems (avoiding floods)

**In common with standard Pervious:**
- Can form part of a cost-effective Sustainable Urban Drainage System (SUDS)
- Eliminates need for detention ponds
- Offers space saving for more efficient land development
- Mitigates surface pollutants

**Additional advantages of Hydromedia:**
- Robust wearing surface
- Faster draining
- Smooth clean look
- Ease of placement
- Low compactability
- Easier maintenance and high durability

**APPLICATIONS**
- Commercial and residential parking lots
- Sidewalks, bike & pedestrian paths
- Driveways
- Patios, courtyards and terraces
- Swimming pool decks
- Sport grounds surfaces
- Infrastructure facilities
- Pavement edge drains and gutters
- Draining layers in roofing systems

**MARKETS**
- Market segments
  - Exterior residential, commercial, roads and transportation.
- Type of applications
  - Interior parking lot pavements, low-usage roads, recreation, pedestrian walkways, patios, decks, retaining walls and highways, roadway storm water management, roof systems, sport grounds surfaces.

**HYDROMEDIA FOR STRUCTURAL ENGINEER**
- Simple concrete solution customizable to different customer needs

**HYDROMEDIA FOR OWNER**
- A durable solution
- Alternative systems bringing comfort and safety
- Environmentally-friendly solution

**HYDROMEDIA FOR ARCHITECT**
- Excellent final quality

**HYDROMEDIA FOR DESIGNER**
- Increased flexibility of design options
- A performant alternative to existing solutions

**HYDROMEDIA FOR CONTRACTOR**
- Reduced job time
- Ease of placement

**CONCRETE SPECIFICATIONS**

Hydromedia ready-mix concrete with the following characteristics:
- Porosity: 20 to 35%
- Permeability: 150 to 1000 L/min/m²
- Compressive Strength at 28 days: 10 MPa to 25 MPa (1,450 psi to 3,626 psi)
- Flexural Strength at 28 days: 1.5 MPa to 3 MPa (217 psi to 435 psi)
- Maximum water/cement ratio to be specified by the Designer Project Engineer.
- Unit weight is up to 30% less than conventional concrete
- Workable for up to 90 minutes
- Slump approx 150 mm
- Void content: Minimum 20%
- Typical Nominal Maximum Aggregate size: 14 mm (May vary according to regional availability and depending on application).

**Note:** Hydromedia characteristics will depend on the aggregates and on local mix design and standards.

**DESIGN**

Depending on the application and the system considered, there are two factors that determine design thickness of Hydromedia:
- Hydraulic properties such as permeability (related to yearly average rain fall) and volume voids (related to water storage)
- Structural properties such as flexural strength offering better load-bearing properties

Selection of appropriate Hydromedia properties is dependent on the more dominant between:
- Hydraulic requirements
- Load-bearing requirements

The larger of these values governs design thickness.
Thermedia® is a new-generation concrete contributing to energy efficiency in buildings.

This range of ready mix concrete with both properties, mechanical strength and thermal performance, has been developed for facade walls in collective building to reduce heat loss at thermal bridges (internal insulation). Its physical characteristics (durability, shrinkage), acoustics and fire behavior were also successfully tested.

It is the only structural ready-mix concrete capable of combining strength and lightness which represents a technological breakthrough in insulating concrete.

### RANGE / APPLICATION / BENEFITS

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermedia® 0.3-0.6</td>
<td>Load-bearing and insulating concrete Mainly dedicated for external walls in collective and public housing with or without insulating product behind depending on local regulations / local climate. Thermal bridges decreasing by 35% • between external facades and floors (Intermediate Floor, Top Floor, ground slab) • between facades and internal wall Combine insulating properties and mechanical strength Uses: • Load bearing walls • Elevated slabs • Raw materials: Lightweight aggregates</td>
<td>• Full strength structural support • 35% reduction in heat losses through thermal bridges • Fluidity and excellent workability • No need to adapt building methods • Economically viable for a given thermal performance when compared to alternative solutions</td>
</tr>
<tr>
<td>Thermedia® &lt; 0.1</td>
<td>Not commercially available Non structural and high thermal performance Self-bearing and insulating concrete with 2 types of application: Horizontal: possibility to replace insulating product or system based on screed + insulating product; Could be used in collective / individual housing Vertical: possibility to replace both block/brick + existing insulating product or can respond future local thermal regulations.</td>
<td>Complete substitution of conventional insulating layers</td>
</tr>
</tbody>
</table>

### THERMEDIA FOR STRUCTURAL ENGINEER
- Reduced heat loss at thermal bridges
- Full strength structural support

### THERMEDIA FOR CONTRACTOR
- Fluidity and excellent workability

### EFFICIENCY OF THE SYSTEM WITHIN CLIMATIC REGIONS

The structural thermal concrete walls have a major added value related to the high thermal resistance it can bring to a building. This performance is more or less needed and therefore efficient in different climate zones depending on the heating and cooling needs in these zones.

### MARKETS
- Market segments
  / All buildings: individual/collective housing, public/administrative buildings, industrial
- Type of applications
  / External walls / facades (without shape constraints)

### CONCRETE SPECIFICATIONS

Thermedia 0.6, ready-mixed concrete with the following characteristics:
- Maximum water/cement ratio: 0.6
- Compressive Strength at 28 days: greater than 25 MPa (3,625 psi) on cylinders
  / Rc = 25 MPa LC 25/28
  / Compliance with european norms EN 206.1 and "règles de l'Art"
- Dry-Density: 1200 kg/m³ to 1,400 kg/m³ (75 lbs/ft³ ± 87 lbs/ft³)
- Maximum Aggregate size: 20 mm (0.8 in)
- Thermal conductivity:
  / \( \lambda_{\text{utile}} = 0.54 \text{W/m.K} = 0.329 \text{Btu/hr.ft.°F} \)
  / \( \lambda_{\text{utile}} \) certified in France
- Consistency Class: S5, fluid
- Modulus of Elasticity in Compression: 12,000 MPa ± 2,000 MPa (1,740 kpsi to 290 kpsi)

Thermedia 0.3-0.6, ready-mixed concrete with the following characteristics:
- Average Thermal Expansion Coefficient: 0.010 mm/m/K
- Workability Retention: 2h

Efficient Building Systems
- FRAME: Structural Thermal Concrete Walls – Thermedia

Efficient Building Systems
# Ultra Series®

**In India the Ultra Series range is referred to as Mega Series**

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## Performance Enhanced Concrete

### BENEFITS / APPLICATIONS / RANGE

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
</table>
| **Accelerated**        | • Concreting in cold weather  
• Requirements of high initial resistance  
• Concreting of pre and post-tightened elements  
   | • Setting delay not affected by cold weather  
• Quicker removal of formwork  
   |   |   |   |
| **Anti Abrasion**      | • Heavy traffic accesses in mines, commercial areas, gas stations  
   | • Allows early opening of roads  
• Faster construction  
• Labor reduction  
• Reduces the costs of maintenance and repair of mining pavements  
   |   |   |   |
| **Anti-washout/underwater** | Anti-Washout is recommended for any underwater application of concrete or in fully saturated conditions.  
• Piling in wet soil conditions  
• Bridge piers and pilings  
• Seawalls and shoring  
   | • Minimization of the environmental effects of cement washout into rivers, streams and ponds  
• Reduction of segregation when placing concrete through reinforcement  
• Maintaining water/cement ratio and therefore durability of the structure  
• Reduction of washing costs  
   |   |   |   |
| **Chemical/Sulfate**   | • Concrete for floors of bio-waste silos on farms  
• Sewage systems and collectors  
• Industrial waste collectors  
   | • Chemical resistance to chemical attack of most of the chemicals usually present in soil, subterranean waters and industrial plants  
• High final strength of concrete (strength class up to C40/50)  
• Low shrinkage (no penetration of chemicals)  
   |   |   |   |
| **Delayed**            | • Project site at a long haul from the concrete supply  
• Ambient temperature conditions affecting setting  
• High cement concrete that sets very rapidly  
• When a site delay is expected  
   | • Reduction of the risk of costly repairs  
• Reduction of the risk of error or injury of crew while fighting to place setting concrete  
• Reduction of the risk of site personnel demanding additional water (thus affecting quality)  
   |   |   |   |
| **Extrusion**          | • Highway safety barriers  
• Continuous concrete walls  
• Gutters  
• Borders  
   | • Economical solution  
• Usable right after removal of the mold  
• Reduction of the quantity of joints  
• Optional different surface finishes (colored, deactivated...)  
• Almost no need for maintenance or repair  
   |   |   |   |
| **Fill (and Trench)**  | • Closure of burrows, canals, pits and mines  
• Coverage of sewage, cables and water pipe canals enabling re-excavation  
   | • Easy to place (pumping or pouring) thanks to its fluidity  
• No forming of voids during placement and no need for spreading or compacting.  
• Compressive strength can be adapted upon need (from 1 MPa to 10 MPa after 28 days)  
• Can be excavable if necessary (for cable maintenance for example)  
   |   |   |   |
| **Flow Fill, Filling, Fluid** | • Underground conveyors, pipe bedding, tunnels, holes, abandoned tanks, trenches  
• Empty spaces between walls or floors  
• Leveling of surfaces  
• Replacement of contaminated soil  
   | • An alternative to use in compacted soil, providing a perfect filling of empty spaces and when access is difficult  
• No vibration  
• Re-excavable  
• High level of job productivity (500 m³/day) reducing labor needs with low equipment requirement  
   |   |   |   |
| **High Density**       | • Walls for X-ray rooms  
• Research Facilities  
   | • Enables reduction of wall thickness  
   |   |   |   |
| **High Early Strength**| • Fast-track concrete projects  
• Infrastructure / Roads  
   | • Rapid strength gain which allows the forms to be removed early  
• Good surface appearance and increased surface durability  
• Good workability, pumppability and placeability  
• Reduced time to complete projects and reduced labour costs  
   |   |   |   |
| **High strength (>50 MPa)** | • Columns  
• High performance areas  
   | • Ability to build columns with a high length to diameter ratio  
   |   |   |   |
| **Light Weight Concrete** | • Mortar screed (floor & roof)  
• Light weight precast blocks/panels  
• Backfill and void filling; Road sub base  
• Insulating Floors of Building Structure  
• Foundry structures  
• Compressive layer in all buildings  
   | • Density of the concrete is lower than the standard  
• Lighter weight mortar mix contributes to reduction of cost to overall structural design  
• Insulating, lightweight, sound isolation, withstands high heat  
• Better insulating capability vs standard concrete  
   |   |   |   |
| **Light weight foam**  | • Filling of trenches in roadways  
• Filling of disused tanks  
• Void filling  
• Backfill below underfloor heating  
• Lightweight topping and slopping layer  
• Insulation  
• Arrestor beds, particularly in airports  
   | • Quick setting  
• Low density  
• High workability  
• No compaction required  
• Super insulation properties, thermal conductivity (0.1-0.3)W/m.k  
• Flowable  
• Lower overall maintenance costs  
• Cost effective solution  
• Time saving with backfilling  
   |   |   |   |
Morpla Series® represents the range of stabilized mortars solutions.

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Low Heat (Mascrrete LH)</strong></td>
<td>• Mass pour and rough foundation • Pour by high temperature</td>
<td>• To minimize and prevent micro thermal cracking • Higher ultimate strength depending on the cement • Chloride and sulfate resistance, resistance to alkali silica reaction depending on the cement</td>
</tr>
<tr>
<td><strong>Pervious</strong></td>
<td>• Exterior hardscaping and walkways • Vehicle parking lots</td>
<td>• In place, pervious pavements reduce the amount of runoff water by allowing some water to seep through to the subgrade</td>
</tr>
<tr>
<td><strong>Piling</strong></td>
<td>• Bore pile</td>
<td>• No need to add water on site even after long waiting and transport time, thus no strength loss, scaling, bleeding, or cracking</td>
</tr>
<tr>
<td><strong>Polypropylene Fibers</strong></td>
<td>• Driveways, pathways, floors • Precast elements • Cold room floors • Very thin sections with large surface-to-thickness ratios</td>
<td>• Simplifies the construction process • Reduces labor required to place and handle plastic shrinkage control mesh • Reduces the overall bleed and consequential settlement cracking</td>
</tr>
<tr>
<td><strong>Projected Concrete/Shortcrete/Gunite</strong></td>
<td>• Repair/structural reinforcement/slope stabilization; tunnels and gallery coatings; monument coatings; pools</td>
<td>• No forms/molds needed • Direct application on inclined surface • Rapidity of application</td>
</tr>
<tr>
<td><strong>Ravoirage → Levelling Layer</strong></td>
<td>• Unlevel slab (before laying the screed, or the insulation layer) • Filling before laying the screed</td>
<td>• Easy placement • Enhanced productivity on the construction site • Excellent flatness for insulation and/or screed</td>
</tr>
<tr>
<td><strong>Reduced Shrinkage</strong></td>
<td>• Commercial and industrial warehouse floors • Commercial and retail interior floors • Concrete on wood and metal decks</td>
<td>• Reduction of costly call backs from visible cracking • Reduction of curling and therefore reduction of joint maintenance • Potential to increase joint spacing • Potential to reduce secondary reinforcement for crack control • Reduction of micro cracking</td>
</tr>
<tr>
<td><strong>Screed</strong></td>
<td>• Leveling screeds for slabs and floors • Foundation isolation jobs and protection</td>
<td>• Assured quality via automated production and quality raw materials • Enables higher application speeds compared to alternatives • Different pumping applications available for easy service • Clean jobsite • Reduction of labor requirements on site</td>
</tr>
<tr>
<td><strong>Self-compacting</strong></td>
<td>• Concrete barriers • Drainage channels • Security barriers • Flood barriers</td>
<td>• Reduced the need for steel mesh and rebars • Resistance to impact • Eliminates shrinkage which occurs when using wire mesh solution • High tensile and flexural strength</td>
</tr>
<tr>
<td><strong>Slip Form</strong></td>
<td>• Industrial floors, parking lots, commercial floors, heavy load accesses</td>
<td>• Increased productivity • High quality finish • Increased durability • Variety of colours and finishes available</td>
</tr>
<tr>
<td><strong>Steel Fiber</strong></td>
<td>• Swimming pools, retaining structures • Walls, water treatment plants • Basement carparks</td>
<td>• Faster and effortless fabrication of slabs and floors • High quality of surface finish • Eliminates power-floating on site</td>
</tr>
<tr>
<td><strong>Watertight</strong></td>
<td>• Pool, outdoor water features, hyperbaric chambers, marine environments, etc.</td>
<td>• Affordable • Durable</td>
</tr>
</tbody>
</table>

**BENEFITS/APPLICATIONS/RANGE**

<table>
<thead>
<tr>
<th>RANGE</th>
<th>APPLICATIONS</th>
<th>BENEFITS</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Bricklaying Mortar - Retarded / Stabilized</strong></td>
<td>• Bricklaying</td>
<td>• Uniform strength • Reduces labour cost • No power or water necessary on the jobsite</td>
</tr>
<tr>
<td><strong>Rendering Mortar/Coarse Plastering Mortar Retarded / Stabilized</strong></td>
<td>• Big commercial projects / Mass-housing projects • Small midsize housing • EPS panel building system contractors</td>
<td>• Clean jobsite • Pumping possible • Spraying application possible • Improved application speed • Reduces labor cost • Consistency</td>
</tr>
<tr>
<td><strong>Screed Mortar</strong></td>
<td>• Leveling screed applications • Foundation isolation jobs</td>
<td>• Enables higher application speeds • Different pumping applications available for easy service (appropriate for screed applications) • Better heat isolation than alternatives • Clean jobsite</td>
</tr>
</tbody>
</table>
The Ultra-High Performance Concrete or uhPC, is a class of concrete defined by its exceptionally high strength and durability. It was developed for specialized applications that demanded superior strength and resistance to aggressive environments.

LAFARGE

As a pioneer in Ultra-High Performance Concrete (UHPC), in the early 90’s Lafarge explored new possibilities in advanced concrete technologies. At the end of the 90’s, ten years of research produced a revolutionary innovative material offering a range of technological performances that had never been seen before.

At the forefront of the growth in UHPC use, Lafarge's UHPC/Ductal® has very specific properties, the foremost being ductility, one of the reasons that sets it apart from conventional concrete. Its unique combination of superior performance characteristics free people from the constraints of traditional solutions, in particular because steel rebars are generally superfluous.

Lafarge's engineering expertise and partnerships with architects, designers, design offices and precasters have enabled the development of a great many uses for UHPC. Today we can demonstrate the material's unequalled resistance and longevity properties.

UHPC/Ductal® has been deployed on a vast array of projects in the construction sector, yet also in industry, urban furniture, interior decor, etc. Over a decade of use with this material has enabled the Lafarge teams to develop unique levels of experience and know-how. Rigorous testing and field trials have given it the most experience of all materials of this kind. This expertise is also confirmed by several official documents in the United States, Canada, France and Japan that prescribe the use of UHPC/Ductal® for building, infrastructure, manufacturing, artistic and industrial designs.

LAFARGE INNOVATION

UHPC/Ductal advantages (compared to conventional materials):
- Superior durability, strength and ductility
- Compressive resistance: 120-200 MPa (6 to 8 times greater than conventional concrete)
- Flexural strength: 15-45 MPa (up to 10 times greater)
- Extremely low permeability & porosity & chloride ion diffusion
- Superior abrasion, impact & freeze/thaw resistance
- Aesthetic solutions combining colors, textures & shapes
- Extended life with reduced maintenance & environmental impact
- Faster construction through prefabrication
- Improved dimensional stability & seismic performance
- Thin lightweight structures requiring little or no passive reinforcement/shear reinforcements
- Optimal heights & longer, thinner spans

Depending on the application, UHPC/Ductal® elements can be precast in a plant and shipped to the site or, in some cases, may be cast on site.

UHPC/DUCTAL APPLICATIONS

ARCHITECTURAL
- Advantages
  - Thin and lightweight, complex shapes, longer spans, custom textures and colors, superior durability and waterproofness
- Types of projects
  - Lightweight building envelopes
  - Perforated or solid facades
  - Roofing/Canopies
  - Sunshades
  - Urban furniture
  - Façade Restoration

STRUCTURAL
- Advantages
  - It is also characterized by its strength, durability, ductility and improved resistance to abrasion, chemical resistance, freeze-thaw, carbonation and chloride ion penetration.
- Types of projects
  - Precast and field-cast bridge solutions
  - Columns
  - Blast Walls
  - Renovation and restoration (such as marine or bridge structures/wear elements exposed to harsh or extreme weather environments)

UHPC/DUCTAL PROPERTIES

DURABILITY PERFORMANCE

<table>
<thead>
<tr>
<th>Performances</th>
<th>Conventional Concrete</th>
<th>UHPC/Ductal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Penetration</td>
<td>2*10^-11 m²/s</td>
<td>2*10^-14 m²/s</td>
</tr>
<tr>
<td>Freeze-thaw durability</td>
<td>&gt;1000 g/m²</td>
<td>&lt;10 g/m²</td>
</tr>
<tr>
<td>Carbonation depth</td>
<td>10 mm</td>
<td>&lt;0.05 mm</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performance</th>
<th>Normal</th>
<th>HOC</th>
<th>Ductal*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water-accessible porosity (%)</td>
<td>12-16</td>
<td>9.16</td>
<td>1.5-6</td>
</tr>
<tr>
<td>Oxygen permeability (m²)</td>
<td>10^-15</td>
<td>10^-16</td>
<td>10^-17</td>
</tr>
<tr>
<td>Tritium (+) diffusion coefficient (m/s)</td>
<td>2.10^-11</td>
<td>2.10^-13</td>
<td>2.10^-14</td>
</tr>
<tr>
<td>Portlandite content (kg/m³)</td>
<td>76</td>
<td>86</td>
<td>0</td>
</tr>
</tbody>
</table>

* Mineral ions have less mobility than tritium, which means they have a lower diffusion coefficient.
MECHANICAL PERFORMANCE

The values below are for guidance only and cannot be used as technical design specifications. They depend on the product characteristics, experimentation method, raw materials, formulae, manufacturing procedures and equipment used; all of which may vary. This data provides no guarantee or commitment that the values will be achieved in any particular application of Ductal®.

<table>
<thead>
<tr>
<th>Density (kg/m³)</th>
<th>Ductal® with metal fibers</th>
<th>Ductal® with metal and polypropylene fibers</th>
<th>Ductal® with organic fibers</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength (MPa)</td>
<td>2,500</td>
<td>2,500</td>
<td>2,350</td>
</tr>
<tr>
<td>Elastic Limit in tension (MPa)</td>
<td>150-200</td>
<td>150-180</td>
<td>150-180</td>
</tr>
<tr>
<td>Post Cracking Direct Tensile Strength at w=0.3 mm (MPa)</td>
<td>9-10</td>
<td>7-9</td>
<td>8-9</td>
</tr>
<tr>
<td>Equivalent Flexural strength (MPa)</td>
<td>7-10</td>
<td>6-9</td>
<td>6-8</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>20-40</td>
<td>15-30</td>
<td>15-30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Performances</th>
<th>Conventional Concrete</th>
<th>UHPC/Ductal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive strength</td>
<td>25 MPa</td>
<td>&gt;150 MPa</td>
</tr>
<tr>
<td>Flexural strength</td>
<td>5 MPa</td>
<td>&gt;20 MPa</td>
</tr>
<tr>
<td>Young’s Modulus</td>
<td>25 GPa</td>
<td>&gt;50 GPa</td>
</tr>
</tbody>
</table>

COMPRESSION BEHAVIOR

Performance in compressions: It is 4 to 8 times higher than conventional concretes. Compression behaviour is almost linear elastic up to the maximum stress and exhibits no damage to the material during this phase.

BEHAVIOUR UNDER FIRE

Ductal® materials are classed as “M0” (non-flammable). ISO 834 fire-resistance tests on loaded and non-loaded columns and beams have been carried out at the Centre Scientifique et Technique du Bâtiment (CSTB - Marne-La-Vallée) and VTT Technical Research Centre of Finland. These tests have demonstrated the material’s excellent resistance and near total absence of spalling.

SHRINKAGE AND CREEP BEHAVIOR

For ordinary concrete, the creep coefficient can reach 3-4; for high-performance concrete, this is reduced but the recorded deformation remains higher than the elastic deformation. The creep coefficient of Ductal® is less than 0.8, and if a heat treatment is applied, the creep factor is less than 0.2, as shown in the figure above. As a rule, a value of 0.3 is considered for calculations.

Ductal® does not exhibit drying shrinkage. An endogenous shrinkage is observed (300 to 400 µm/m), but when heat treatment is applied, shrinkage is complete by the end of the treatment and there is no subsequent residual shrinkage, as shown in the figure above.

BENDING BEHAVIOR

Ductal® with metal fibers (with 2% by volume), or more than 50 million metal fibers per cubic meter. The fibers give the material a ductile behavior during bending; when loaded in flexure beyond the elastic limit, micro-cracks occur and the fibers hold the cracks tightly closed, providing a ductile performance rather than a sudden or brittle failure.

FATIGUE BEHAVIOR

The loading applied was between 10 and 90% of the elastic limit. The figure above shows a crack opening displacement curve in relation to the number of cycles. Note: There is no increase in the crack opening, i.e. no crack propagation, at 1.2 million cycles.
Aggregates are a granular material such as crushed rock, manufactured sand, natural sand and gravel, typically measuring from 0.08 to 80 mm in diameter, and are the most-used materials in the world, after water; 25 billion metric tons of aggregates are used per year, at an average of 4 metric tons per person. Aggregates are used as raw materials for ready-mixed concrete (made of 80% aggregates), masonry, asphalt (made of 95% aggregates), lime, cement, and other industrial processes, and as base materials for roads, landfills, and buildings.

Aggregates differ in terms of their physical characteristics such as hardness, geological nature (limestone, granite, etc.), their granularity (ranging from sand to riprap used in seawalls), their shape, their color and their granular distribution. These characteristics have a large impact on the quality of the applications in which they are used, especially for concrete. Some of those characteristics affecting performance are purely based on the quality of the deposit whereas other characteristics can be modified by the manufacturing process. The average consumption of aggregates varies depending on the type and use and the size of the work in question. Here are some ratios used in common applications.

THREE MAIN FUNCTIONS:
/ Support, due to their strength
/ Filling: aggregates make mixtures more compact
/ Embellishment, due to their aesthetic qualities

LAFARGE INNOVATION

Asphalt solutions: Duraclime® and Duracycle® (products in North America)
Decorative sands & aggregates: Sands or gravel whose colors or shapes are admired for their decorative properties.
Manufactured sand: To preserve the natural alluvial sand that is becoming an increasingly rare and difficult-to-access resource, Lafarge found an alternative solution - manufactured sands, produced by crushing rocks.
Aggneo®: Recycled aggregates: Lafarge diverts material away from landfills and enables us to save natural aggregate reserves.
Capillia®: Aggregates for urban drainage systems.
Stabilia®: Aggregates stabilized with a binder to provide superior stability.

There are many possible Life Cycles, depending on the intermediate and final use of aggregates, but in theory aggregates may be recycled indefinitely.
AGGREGATE APPLICATIONS

STRUCTURAL PRODUCT APPLICATIONS

- Portland cement concrete
  / All concrete applications
- Asphalt concrete
  / Hot mix asphalt
  / Surface treatments
- Base material
  Horizontal layer structural application:
  / Pavement construction:
    - highways, rail, airfield projects
    - parking lots, storage areas
  / Ballast/subtlety layers:
    - railroad track structures
  / Weak layers:
    - working platforms, pedestrian walkways, bicycle paths
Other building applications:
  / Drainage structures
  / Retaining wall structures
  / Erosion control structures and scour protection - riprap and gabions
  / Deep foundation-supported structures
  / Geotechnical structural applications:
    - stone columns;
    - reinforced soil construction (sand, gravel, open-graded stone)
    - Specification (high degree durability stone)

NON-CONSTRUCTION USE APPLICATIONS

- Agriculture
  / Aglime to correct soil acidity fertilizer filler or conditioner as an ingredient in mineral livestock feeds and poultry grit
- Chemical and industrial processing (fillers)
  / Portland cement manufacture
  / Paper and pulp
  / Manufacture (limestone & lime)
  / Flux stone - production of steel & non-ferrous metals (limestone)
- Environmental
  / Stack gas desulfurization
  / Acid mine drainage abatement
  / Treatment of coal refuse
  / Landfill construction
  / On-site residential sewage systems
- Various miscellaneous applications
  / ex. Coal mine dusting (limestone dust)
REFERENCE STANDARD SPECIFICATION VS. PERFORMANCE

Traditionally aggregate suitability has been determined by using a reference standard specification. In this methodology criteria are defined that have to be met for the material and processes. Whether used as a base material, or in concrete and asphalt, aggregate specifications traditionally test the aggregate properties in the table below. Some of the characteristics most frequently used are based on criteria such as gradation and resistance to gradation. The chosen criteria are selected in order to meet an acceptable level of performance on one or more of the relevant functions listed in the table below. One of the main advantages of a method specification is that it defines criteria easy to test and to keep under control in the aggregates manufacturing process.

AGGREGATES: PROPERTIES AND FUNCTIONS

<table>
<thead>
<tr>
<th>FUNCTION</th>
<th>AGGREGATE PROPERTY</th>
<th>Relative Importance of Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>1) ADEQUATE INTERNAL STRENGTH &amp; STABILITY TO DISTIBUTE SURFACE PRESSURES AND TO PREVENT EXTENSIVE SURFACE DEFLECTIONS</td>
<td>Mass stability</td>
<td>NA</td>
</tr>
<tr>
<td></td>
<td>Particle strength</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle stiffness</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle surface texture</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Grading</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maximum particle size</td>
<td>I</td>
</tr>
<tr>
<td>2) RESISTANCE TO DETERIORATING EFFECTS OF WEATHER AND CHEMICAL ACTIONS</td>
<td>Resistance to chemicals, such as salts</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Solubility</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Staking</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Resistance to wetting/drying</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>Resistance to freezing/thawing</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>Pore structure</td>
<td>I</td>
</tr>
<tr>
<td>3) RESISTANCE TO DETERIORATING EFFECTS PRODUCED BY APPLIED LOADS</td>
<td>Resistance to degradation</td>
<td>I</td>
</tr>
<tr>
<td>4) RESISTANCE TO THE EFFECTS OF INTERNAL FORCES, SUCH AS EXPANSION, CONTRACTION, WARPING AND CURLING</td>
<td>Volume change - thermal</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Volume change - wetting and drying</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Pore structure</td>
<td>I</td>
</tr>
<tr>
<td>5) AGGREGATE AND BINDER COMPATIBILITY</td>
<td>Chemical compound reactivity</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Organic material reactivity</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Coatings</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Thermal volume stability</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Base exchange</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Surface charges</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Pore structure</td>
<td>U</td>
</tr>
<tr>
<td>6) RETENTION OF A SURFACE THAT WILL ASSURE ACCEPTABLE STANDARDS OF PERFORMANCE, TO HAVE THIS CHARACTERISTIC, CONSIDER THE FOLLOWING SURFACE PROPERTIES</td>
<td>A) SKID RESISTANCE</td>
<td>Particle shape</td>
</tr>
<tr>
<td></td>
<td>Particle surface texture</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maximum particle size</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Particle strength</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Wear resistance</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle shape of abraded fragm</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Pore structure</td>
<td>I</td>
</tr>
<tr>
<td>B) SURFACE ROUGHNESS</td>
<td>Maximum particle size</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Grading</td>
<td>I</td>
</tr>
<tr>
<td>7) GLARE AND LIGHT REFLECTION</td>
<td>Reflection</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Glare</td>
<td>I</td>
</tr>
<tr>
<td>8) LOOSE MATERIAL</td>
<td>Resistance to degradation</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Specific gravity</td>
<td>N</td>
</tr>
<tr>
<td>E) TIRE WEAR</td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td>F) ROLLING RESISTANCE</td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle surface texture</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maximum particle size</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td>G) NOISE LEVEL</td>
<td>Maximum particle size</td>
<td>U</td>
</tr>
<tr>
<td>H) ELECTROSTATIC PROPERTIES</td>
<td>Electrical conductivity</td>
<td>U</td>
</tr>
<tr>
<td>I) APPEARANCE</td>
<td>Particle color</td>
<td>N</td>
</tr>
<tr>
<td>7) RETENTION OF PROP DURING THE CONSTRUCTION PROCESS THAT SUPPORTS ALL OTHER FUNCTIONS OF THE SYSTEM</td>
<td>Oxidation and hydration reactivity (stains and popouts)</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maximum particle size</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Grading</td>
<td>I</td>
</tr>
<tr>
<td>8) DRAINAGE CAPACITY AND VOID CONTENT</td>
<td>Particle surface texture</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Particle shape</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Grading</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Maximum particle size</td>
<td>I</td>
</tr>
</tbody>
</table>

Note: I=important; N=not important; U=importance unknown; NA=not applicable; PCC=portland cement concrete; Asph C.=bituminous or asphalt concrete; Base=unbound aggregates base

The main limitation is that there are so many parameters affecting function that it’s possible to have a wide variation in performance for different aggregates which all met the requirements of a method specification. In theory it is possible that this could result in a material, which met the specification requirements, having performance issues. However in nearly all cases the material performs as required. The major short coming of this process is that it eliminates the potential to tailor the material to the performance required which has the potential, particularly in aggregate intensive projects, to save significant costs or to lengthen the life cycle of the application.

Let’s consider an example of an application where both drainage and stability under pressure are important and where the specification calls for the following gradation.

<table>
<thead>
<tr>
<th>SIEVE SIZE</th>
<th>% PASSING</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 mm</td>
<td>100%</td>
</tr>
<tr>
<td>10 mm</td>
<td>100%</td>
</tr>
<tr>
<td>15 mm</td>
<td>40%</td>
</tr>
<tr>
<td>20 mm</td>
<td>0%</td>
</tr>
<tr>
<td>25 mm</td>
<td>0%</td>
</tr>
</tbody>
</table>

Let’s now look at an example with the two aggregates A. and B. below meeting that method specification

Intuitively, we can see that the Aggregates A will have a better drainage capacity but a lower stability under pressure than the Aggregates B.

Lafarge, with its technical expertise, is not only looking at meeting a set of standard specification but also understanding how our aggregates affect the performance in the different applications.

EXAMPLE OF PERFORMANCE PARAMETERS THAT CAN BE OPTIMIZED WITH LAFAIGE PRODUCT IN DIFFERENT APPLICATIONS

- Aggregates as base material
  / Stability as measured by the resilient modulus (MPa)
  / Drainage capacity as measured by the permeability (cm/s)

- Aggregates in concrete
  / Impact on the air void in the concrete (%)
  / Impact on the compressive strength (MPa)

- Aggregates in Asphalt
  / Impact on the air void in the asphalt (%)
  / Impact on the flexural strength (MPa)
Pavements are used in several applications, roads, runways, pedestrian walkways, parking lots, driveways, paved yards, etc. Pavements can be made of aggregates only in low-end applications but higher performance pavements are composed of asphalt or concrete as the surface course. The asphalt or concrete are built upon an aggregates base.

Pavements have been designed for many years with reference standard specifications developed through empirical learning. A pavement design that has been performing in a past project will be copied in a project with a similar environment.

For instance, based on soil and traffic conditions, a design might call for a certain thickness of aggregates base, with the aggregates meeting certain characteristics such as gradation, and a placement imposing a minimum compaction level.

One of the limitations of such a method is that it doesn’t take into account the wide variation of performance of different aggregates (or asphalt or concrete) meeting the same reference specification. As a result, pavements can be under-designed (resulting in early failure such as cracking, swelling or rutting) but also over-designed (not optimized from a cost perspective).

Some newer methods, that can be referred to as "mechanistic-empirical" aim at simulating the deformation of the pavement under load and anticipating the performance of the pavement based on that deformation. In such a method, physical parameters of the aggregates such as the resilient modulus are used as an input in the model and become more relevant than the actual gradation. Those methods open the door to innovation as Lafarge can now modify its manufacturing process, not to meet a particular gradation, but to optimize the performance/cost ratio of the aggregates.

Another trend in pavement projects is the increase use of Design-Build contracts as opposed to Design-Bid-Build contracts. Design-Bid-Build contracts are based on reference-standard specifications and allow comparing the prices that different contractors estimate for the same design and methods. Design build contracts focus instead on the performance over time of the pavement. For example, the road should perform for a period of 15 years, without any cracking larger than a certain dimension. The contractors then become responsible for any repair required to maintain the performance criteria. This type of contracts also open the door for innovation and Lafarge expertise can help optimize the design in term of performance vs. cost.