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# **Ultra High Performance Concrete Information and Literature Search - 2011 (UHPC I&LS-2011)**

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August 2011



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Final report

Approved for public release; distribution is unlimited.

Prepared for Headquarters, U.S. Army Corps of Engineers  
Washington, DC 20314-1000

Under DHS S&T Directorate Inter/Intra-Agency Agreements  
HSHQDC- 10-X-00194 and HSHQDC-09-X-00460  
Advanced Materials Effort and Counter IED Mitigation (Active Blast Protection)

**Abstract:** Ultra high performance concrete (UHPC) materials are advanced cementitious materials that display much higher levels of technical performance compared to conventional strength and high strength concretes. This category can include materials such as defect-free, dense particle, reactive powder, engineered composite, multi-scale particle, and fiber-reinforced concretes. UHPC materials can have unique advantages with respect to response capabilities, mechanical properties, environmental stability, construction methods and forms, and aesthetic qualities, and have the potential to help revitalize a deteriorating infrastructure. This report is the 2011 version of search results for open-source information and technical literature references on UHPC materials. References are provided on product information from engineering and scientific journals, conference proceedings, magazine articles, books, and patents. The scope extends from basic and applied research to construction projects.

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## Preface

The research for the Ultra High Performance Concrete Information and Literature Search-2011 reported herein was conducted by personnel of the U.S. Army Engineer Research and Development Center (ERDC). Funding for the work was provided by the Department of Homeland Security, Science and Technology Directorate, Infrastructure Protection and Disaster Management Division: Mila Kennett, Program Manager.

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The author gratefully acknowledges Deborah J. Carpenter, Jim A. Dolan, Susan D. Hicks, Helen Ingram, Nancy C. Liston, Mary E. McAlpin, and Ruthie G. McCoy of the ERDC Information and Technology Laboratory and George G. Tom of ACE-IT for their help and assistance in the database searches and procurement of information. The author also thanks Brian H. Green of the GSL Concrete and Materials Branch and Professors David L. McDowell and Min Zhou, Brett Ellis, Jennifer Gordon, Christopher Lammi, and Andrew Moore from the George W. Woodruff School of Mechanical Engineering, Georgia Institute of Technology, for their assistance in obtaining reference materials.

COL Kevin J. Wilson was Commander and Executive Director of ERDC. Dr. Jeffery P. Holland was Director.



# 1 UHPC Materials and UHPC I&LS-2011

Currently, there is a critical need for advanced building materials for the U.S. domestic infrastructure, not only for new high-performance construction, but also to enhance the performance of existing structures. These materials are required to be increasingly more energy-efficient, environmentally friendly, sustainable, and resilient. They need to meet multi-hazard and multi-performance design criteria and be easily produced and incorporated into construction. Furthermore, these materials must be cost effective through a structure's life cycle.

Concrete is the most widely used material in building construction. However, there are durability, security, and sustainability issues concerning current commercially available products. Within the last few decades, research has been conducted on advanced cementitious materials displaying ultra high performance characteristics. This includes a broad range of materials such as defect-free, dense particle, reactive powder, engineered composite, multi-scale particle, and fiber-reinforced concretes. Research and commercial brands are available and examples are BCV® - beton composite vicat, BSI - Beton Special Industriel, CARDIFRC®, Cemtec<sup>multiscale</sup>®, Ceracem®, CRC® - compact reinforced composites, Cor-Tuf®, DSP - densified small particles, Densit®, DFG UHPC, DORSICEM, Ducon®, Ductal®, MDF - macro-defect free, Microdur®, NIM - new inorganic materials, RPC - reactive powder concrete, SIFCON, and SIMCON.

For purposes of the current research effort, a definition of ultra high performance concrete (UHPC) is a class of “concrete” materials that display “ultra high” performance in at least one technical performance area and with an unconfined compressive strength approximately 20,000 psi (140 MPa) and higher. The materials can have high binder content and special fine aggregates. They may contain fibers to achieve non-brittle behavior and, if possible, to dispense with passive (non-prestressed) reinforcement. One type of UHPC material of interest has very small pores, low porosity, and disconnected pore spaces, and steam curing and pressure can be used to attain strengths approaching 30,000 psi (210 MPa) and higher. Example microstructures of a conventional strength concrete material and a reactive powder UHPC material are shown in Figure 1.

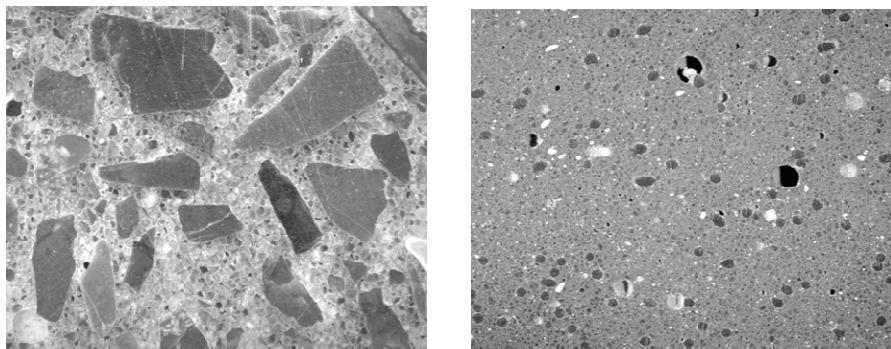


Figure 1. Microstructures of two concrete materials

If viewed on the basis of just a cubic yard of material, the cost of UHPC materials can be over ten times greater than the cost of conventional strength concrete. However, UHPC materials may offer unique advantages and higher performance levels that justify the increased cost. Such factors to be considered include strength, ductility, flexibility and toughness, impact resistance, dimensional stability, durability / increased useful life, impermeability /freeze/thaw resistance, corrosion resistance, abrasion resistance, aggressive environment resistance, and chemical resistance. Other advantages may include ability to construct thin sections and use complex structural forms, elimination of passive reinforcement (reinforcement bars), precise replication, use of conventional concrete equipment, ability to cast by pouring, injection or extrusion techniques, self-consolidation, off-site manufacturing, fast construction, and reduced maintenance. From an aesthetic viewpoint, but also for security purposes such as disguising the appearance of the material, some UHPC mixtures may have color and texture options, sanded or polished surfaces, and even are made to look similar to materials such as stone or marble. Laboratory and field testing have shown that some UHPC materials may be significantly better than conventional concrete for protective structure applications. Research efforts on UHPC are being conducted around the world to reduce costs and use local and “green” materials.

In summary, advanced cementitious materials known as UHPC have a strong potential to help in the revitalization of a deteriorating infrastructure and in the building of new infrastructure that is sustainable, resilient, and long-lasting. However, to date, application of this material has been limited in the U.S. construction industry.

This UHPC Information and Literature Search-2011 (UHPC I&LS-2011) is a “work in-progress” to provide a listing of information on and references for UHPC materials with respect to basic and applied research, technical data, and project information. It is an expansion and update of an unpublished, baseline UHPC I&LS that was generated by the author in 2008. In the UHPC I&LS-2011 report, information and reference items from the baseline UHPC I&LS are given in black and not preceded by a symbol. An item preceded by a plus sign (symbol “+”) is a reference obtained subsequent to the 2008 version. An item preceded by a negative sign (symbol “-”) and displayed in a light gray color was obtained from the reference section of a document referenced in the baseline UHPC I&LS, and the item content needs to be verified and its corresponding reference material needs to be obtained.

The UHPC I&LS-2011 is divided into three sections: Section 1 contains a listing of product information references; Section 2 is a bibliography of technical documents and articles from engineering and scientific journals, conference proceedings, magazines, and books; and Section 3 includes a list of U.S. and foreign patents on UHPC materials and their precursors. It is hoped that this report provides a helpful and efficient resource for anyone interested in UHPC materials and their potential to enhance infrastructure performance.

## **Section 1: UHPC Products and Information**

The following is a listing of information on UHPC products, technical data, and projects:

### **Bekaert**

Bekaert StrHiCsteel fibres 2003

+Ceracem. Sika Ceracem®: Brevet BSI®  
<http://www.sika.fr/construction/document/nt/nt275.pdf>

+CRC® – Compact Reinforced Composite [www.cr-tech.com](http://www.cr-tech.com)  
+CRC® – Intro web  
+CRC® – A description  
+CRC® – Compact Reinforced Composite  
+CRC® – Durability  
+CRC® – Safety Data Sheet  
+CRC® JointCast  
+CRC® JointCast – Handling instructions  
+CRC® JointCast – Examples of applications

- +CRC® Joints - High strength joints for precast bridge slabs – Summary report
- +Tech-Wise – Off-shore wind turbine towers in high-strength concrete

## Densit®

- Densit® advantages[1]
- +[Densit® – CtO's field of operations](#)
- Densit® pro-concrete-binder[1]
- Densit® pro-flexbinder-uk[1]
- Densit® pro-inducast-3000-uk[1]
- Densit® pro-inducast-4000-uk[1]
- Densit® pro-inducast-6000-uk[1]
- Densit® pro-inducast-tt5-uk[1]
- Densit® security barriers
- Densit®

## Ductal® – Lafarge, Bouygues & Rhodia

### Lafarge, Bouygues & Rhodia websites

- <http://www.lafargenorthamerica.com/wps/portal/>
- <http://www.imagineductal.com/imagineductal/history.asp?RND=3P4IS40EFCDYIXR>
- <http://www.bouygues.fr/us/index.asp>
- [http://www.rhodia.com/us/home\\_tunel.asp](http://www.rhodia.com/us/home_tunel.asp)
- <http://www.ductal-lafarge.com/cgi-bin/lafcom/jsp/homeDuctal.do?lang=en>

## Ductal® – Technical & Project Information

### Ductal® – Technical Information

- +CSTB Ductal® -FO Evaluation Technique, 28 pgs.
- Ductaloo FAQ
- Ductaloo Introduction Comm Kit
- Ductalo1 WhatIsDuctal
- Ductalo2 HowStrongIsDuctal
- Ductalo3 HowDurableIsDuctal
- Ductalo4 AestheticsOfDuctal
- Ductalo5 HowDuctileIsDuctal
- Ductal® – Products and Services
- +Ductal® A revolutionary new material for new solutions, 38 pgs.
- Ductal® Aesthetic qualities
- Ductal® At a glance
- +Ductal® BS1000 – Product Data Sheet
- Ductal® Characteristics
- Ductal® Durability data
- Ductal® Durability
- Ductal® History and Evolution
- Ductal® Mechanical performance
- +Ductal® Product Data Sheet AN1000
- +Ductal® Product Data Sheet AR1000
- +Ductal® Product Data Sheet BS1000
- +Ductal® Product Data Sheet CS1000
- +Ductal® Product Data Sheet JS1000
- Ductal® Spec-FM Gris 2GM2.0
- Ductal® Spec-FM Gris 3GM2.0
- Ductal® Spec-FM Gris Feu 2GM2.0F

Ductal® Spec-FM Gris Feu 3GM2.oF  
Ductal® Spec-FO Blanc 2Bo4.3  
Ductal® Spec-FO Blanc 3Bo4.3  
Ductal® Spec-FO Gris 2Go4.3  
Ductal® Spec-FO Gris 3Go4.3  
Ductal® Standard Operating Procedure  
Ductal® TechChar Metallic Fibres – Imperial  
Ductal® TechChar Metallic Fibres – Metric  
Ductal® TechChar Organic Fibres – Imperial  
Ductal® TechChar Organic Fibres – Metric  
Ductal® Trademark  
+Ductal® Ultra-High Performance Concrete - Building Envelope Solutions  
Ductal® What can Ductal do for you  
Ductal® What is ductal  
Lafarge cement manuf 1  
Lafarge cement manuf 2  
Lafarge cement manuf 3  
Lafarge cement manuf 4  
Lafarge Ductal® – Architectural Brochure  
Lafarge Ductal® MechPerf web 2006  
Lafarge Ductal® Passanti home 2007  
Lafarge Ductal® Premix MSDS  
Lafarge Ductal® R&D  
Lafarge Research – Nanomaterials  
Lafarge Research – Nanotechnologies – Monteiro  
Monteiro – Strength presentation  
RPC concrete  
+VSL Ductal® - Roof protection system against mortar threats. 2007, 2 pgs.  
+VSL, 2007. Ductal® solutions – from material to valuable, innovative solution.  
2007, 2 pgs.  
+VSL Ductal® protection solutions. 8 pgs.  
z Lafarge Ductal® docs

#### Ductal® Projects

CN de Arts&Metiere Ductal  
Ductal®-o-AESTHETICS  
Ductal®-o-DUCTILITY  
Ductal®-o-DURABILITY  
Ductal®-o-STRENGTH  
Ductal® – aalborgwhite wu\_01\_2007  
Ductal® Applications Bridges & Footbridges – words  
Ductal® Applications Bridges & Footbridges  
Ductal® Applications Building Envelope  
Ductal® Applications Urban Environment  
Ductal® Architect Ductal Qualities  
Ductal® Architect References  
Ductal® Architect Testimony  
Ductal® Discover Ductal Engineering Office  
Ductal® Engr Office Methods & Calculations  
Ductal® Engr Office References  
Ductal® Engr Office Testimony  
Ductal® Owner Durability and Maintenance  
Ductal® Owner References  
Ductal® Owner Standards and Certifications

Ductal® Owner Testimony  
Ductal® Potential Applications  
Ductal® Precaster Applications  
Ductal® Precaster References  
Ductal® Precaster Testimony  
Ductal® Renovation  
Ductal®- Structure  
Ductal®-Bus shelter  
Ductal®-Escaliers Decors – Staircase  
Ductal®-Joppa long span silo roofs  
Ductal®-Shawnessy LRTAwards PrRel  
Ductal®-Thias Bus Center 03122007-MIPIM-uk  
ETT Proposal FLA Ductal®  
Lafarge Ductal® Making headlines-Photos  
Lafarge – Ductal® – Correctional Facilities  
Lafarge – Ductal® – Projects – o List – website  
Lafarge – Ductal® – Projects – Alberta Construction  
Lafarge – Ductal® – Projects – Anchor Plates for Seawall Tie  
Lafarge – Ductal® – Projects – Anchor Plates  
Lafarge – Ductal® – Projects – Cottenham Cooling Towers Beam  
Lafarge – Ductal® – Projects – Detroit-Columns  
Lafarge – Ductal® – Projects – Joppa Long Span Silo Roof  
Lafarge – Ductal® – Projects – Martel Tree  
Lafarge – Ductal® – Projects – Monaco Train Station  
Lafarge – Ductal® – Projects – ratp thiais  
Lafarge – Ductal® – Projects – Salon du Meuble 2006  
Lafarge – Ductal® – Projects – Shawnessy LRT Station  
Lafarge – Ductal® – Projects – Sherbrooke Bridge  
Lafarge – Ductal® – Projects – The Footbridge of Peace  
Lafarge – Seonyu – Ductal® 09162004-press\_Skorea\_042602-uk  
Lafarge Discover Ductal® Owner  
Lafarge Ductal® A new dimension of concrete  
Lafarge Ductal® Aesthetic Qualities  
Lafarge Ductal® Concrete  
Lafarge Ductal® Making headlines – Photos  
Lafarge Ductal® Making Headlines  
Lafarge Ductal® New Applications  
Lafarge Ductal® Newsletter 2005 ANGnum2  
Lafarge Ductal® Precaster  
Lafarge Ductal® Sustainable Development  
Lafarge Ductal® Use  
Lafarge NA Ductal® projects  
Lafarge NA Project list  
Lafarge Research Hypergreen  
z Ductal® Projects – misc images 1  
z Ductal® Projects – misc images 2  
z Ductal® Projects – additional information

### **Lafarge, Bouygues & Rhodia & VSL**

Bouygues – SefiFrance  
Bouygues & Rhodia  
Lafarge 03222006-press\_themabook-Brochure\_Chair\_sustainable-uk  
Lafarge 03222006-press\_themabook-PressKit\_Chair\_sustainable-uk  
Lafarge 06202005-pub\_sus\_dev-Lafarge\_and\_wwf\_partnership-uk

Lafarge 06212006-press\_sus\_dev-Lafarge\_Award\_Renew\_Energy\_uk  
Lafarge 06222006-press\_group\_finance-Excellence\_2008\_analyst\_pres-uk  
Lafarge 22032006-press\_sus-academic\_chair-uk  
Lafarge – 05312006-press-arts\_et\_métiers\_exhibition-uk  
Lafarge – Batimat 09162004-press2003\_110303-uk  
Lafarge – Batimat 09152004-press\_2001\_110201-uk  
Lafarge – CNRS 09162004-press\_CNRS\_012202-uk  
Lafarge – Hypergreen 03092006-press\_sus\_products-MIPIM-uk  
Lafarge – Lafargeenviroev  
Lafarge – Thias Bus Center Ductal® 03122007-press-MIPIM\_mar07-uk  
Lafarge – WETC 09162004-press\_products-R&D\_100903-uk  
Lafarge Annual Report 2004  
Lafarge ANON CementAn2004  
Lafarge Group web 2006  
Lafarge Joppa Roofs Nova Award NomBook2003  
Lafarge Lafont Interview 2006  
Lafarge Overview web 2006  
Lafarge Sales web 2006  
Lafarge Technology Center  
Lafarge, Bouygues & Rhodia Co Symbols  
Lafarge Perry ecosmart  
Perry PressRelease2003 Shawnessy LRT Station  
Perry PressRelease Detroit Columns  
Rhodia\_dans\_le\_monde  
VSL Int website 2007

**Ducon® <http://www.excedinc.com>**

Ducon® rev  
Excend-DUCON®SecuriyProducts2007

**ERDC – VHSC, Cor-Tuf**

WES Treat Island

+Fondu Fyre – Anon, Wikipedia, 2010

**f-u-r web2007 <http://f-u-r.de/>****G crete web2007 [www.gtecz.com](http://www.gtecz.com)****Holcim [www.holcim.com](http://www.holcim.com) [www.hocim.de](http://www.hocim.de)**

Holcim web  
HolcimDeutschland\_Sulfo\_2006

**IntExtFab IslandInt web2007 [www.islandcompanies.com](http://www.islandcompanies.com)****Max Bogl**

Max Bogl Company Profile  
MaxB UHPC

**Schillaci architecture – uhpc web2007**

<http://architettura.supereva.com/architetture/20060715/index.htm>

**Smartec RocTest Gp web 2007**

**Taiheiyo Cement Corp**

Taiheiyo Cement annual report 2005  
Taiheiyo Cement Bldg Mat Website  
Taiheiyo Cement NL July 30 2007

+Takenaka – APC <http://www.takenaka.co.jp>

- +Architectural technology certification received from third-party organization for the “APC® concrete,” 2009
- +The world’s first practical use of 200 newtons per square millimeter-strong advanced performance concrete, 2008
- +Technology established for high fire-resistant and high-strength concrete able to withstand up to 200 newtons per square millimeter, 2006
- +Construction of a 56-story reinforced concrete condominium, the tallest in Japan, 2002
- +Preparing for an era of 50-floor-class superhigh-rise RC structures, 2002
- +New superhigh-strength concrete with advanced fire resistance that can expand floor space and reduce the costs and construction time of 50-story-class RC condominium high-rises, 2000

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- +Aarup, B., Jensen, L.R., Ellegaard, P., 2005. Slender CRC columns. Nordic Concrete Research 34(2), pp. 80-97. [www.crc-tech.com](http://www.crc-tech.com)
- +Aarup, B., 2008. CRC – Structural applications of ultra high performance fibre reinforced concrete. In: Ultra High Performance Concrete (UHPC), Proceedings of the Second International Symposium on Ultra High Performance Concrete, 5-7 March 2008, Kassel, Germany, Eds. E. Fehling, M. Schmidt, S. Stürwald (Kassel, Germany: Kassel University Press, 2008), pp. 831-837. (in book pdf)
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### **Section 3: U.S. and Foreign Patents on UHPC and Precursor Materials**

The following is a listing of patent websites and patents on UHPC and precursor materials:

#### **Patent websites**

European Patent Office

<http://www.epo.org/patents.html>

[http://gb.espacenet.com/search97cgi/s97\\_cgi.exe?Action=FormGen&Template=gb/EN/home.htm](http://gb.espacenet.com/search97cgi/s97_cgi.exe?Action=FormGen&Template=gb/EN/home.htm)

US Patent and Trademark Office, Department of Commerce

<http://www.uspto.gov/patents/index.jsp>

World Intellectual Property Organization

<http://www.wipo.int/portal/index.html.en>

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<b>1. REPORT DATE (DD-MM-YYYY)</b> August 2011			<b>2. REPORT TYPE</b> Final report		<b>3. DATES COVERED (From - To)</b>	
<b>4. TITLE AND SUBTITLE</b>  Ultra High Performance Concrete Information and Literature Search-2011 (UHPC I&LS-2011)			<b>5a. CONTRACT NUMBER</b>			
			<b>5b. GRANT NUMBER</b>			
			<b>5c. PROGRAM ELEMENT NUMBER</b>			
<b>6. AUTHOR(S)</b>  Beverly P. DiPaolo			<b>5d. PROJECT NUMBER</b>			
			<b>5e. TASK NUMBER</b>			
			<b>5f. WORK UNIT NUMBER</b>			
<b>7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)</b>  U.S. Army Engineer Research and Development Center Geotechnical and Structures Laboratory 3909 Halls Ferry Road Vicksburg, MS 39180-6199			<b>8. PERFORMING ORGANIZATION REPORT NUMBER</b>  ERDC/GSL SR-11-1			
<b>9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)</b>  Headquarters, U.S. Army Corps of Engineers Washington, DC 20314-1000			<b>10. SPONSOR/MONITOR'S ACRONYM(S)</b>			
			<b>11. SPONSOR/MONITOR'S REPORT NUMBER(S)</b>			
<b>12. DISTRIBUTION / AVAILABILITY STATEMENT</b> Approved for public release; distribution is unlimited.						
<b>13. SUPPLEMENTARY NOTES</b>						
<b>14. ABSTRACT</b> Ultra high performance concrete (UHPC) materials are advanced cementitious materials that display much higher levels of technical performance compared to conventional strength and high strength concretes. This category can include materials such as defect-free, dense particle, reactive powder, engineered composite, multi-scale particle, and fiber-reinforced concretes. UHPC materials can have unique advantages with respect to response capabilities, mechanical properties, environmental stability, construction methods and forms, and aesthetic qualities and have the potential to help revitalize a deteriorating infrastructure. This report is the 2011 version of search results for open-source information and technical literature references on UHPC materials. References are provided on product information from engineering and scientific journals, conference proceedings, magazine articles, books, and patents. The scope extends from basic and applied research to construction projects.						
<b>15. SUBJECT</b> Ultra high performance concrete UHPC		Defect free, Dense particle, Reactive powder, Engineered composite Multi-scale particle			Fiber -reinforced	
<b>16. SECURITY CLASSIFICATION OF:</b>			<b>17. LIMITATION OF ABSTRACT</b>	<b>18. NUMBER OF PAGES</b>	<b>19a. NAME OF RESPONSIBLE PERSON</b>	
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED			176	

