



UHPC

Ultra High Performance Concrete



Pathway to Commercialization



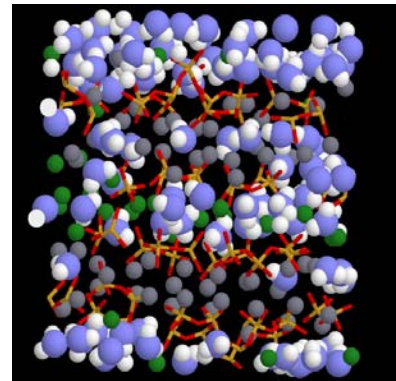
**Homeland
Security**

Science and Technology

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Introduction

The Ultra High Performance Concrete (UHPC) Workshop was held on January 11 – 12, 2011 at Columbia University in New York City. The workshop was sponsored by the U.S. Department of Homeland Security (DHS), Science and Technology (S&T) Directorate, and the National Transportation Security Center of Excellence (NTSCOE) at the University of Connecticut. The purpose of the workshop was to identify impediments to UHPC acceptance and usage in the U.S., and to identify actions needed to promote UHPC acceptance and use in U.S. construction. The workshop was attended by over 80 participants from 8 countries representing federal and state agencies, laboratories, universities, industry associations and organizations, and the private sector.



C-S-H model (MIT)

The federal and state agencies included the U.S. Department of Homeland Security, British Foreign and Commonwealth Office, Federal Highway Administration, National Research Council Canada, Michigan Department of Transportation, New York State Department of Transportation, and Virginia Department of Transportation. The federal laboratories included the Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux Laboratoire (previously Laboratoire Central des Ponts et Chaussées), National Institute of Standards and Technology, and U.S. Army Engineer Research and Development Center.

The universities included Columbia University, Georgia Institute of Technology, Massachusetts Institute of Technology, Michigan Technological University, New York University, Northwestern University, Ohio University, Technische Universität Graz, United States Military Academy, University of Arkansas, University of Connecticut, University of Florida, University of Kassel, University of Michigan, and University of Sherbrooke.

The industry associations and organizations included the American Society of Civil Engineers, Concrete Industry Board, Portland Cement Association, Precast/Prestressed Concrete Institute, and The Cement League. Representatives from the private sector came from BAE Systems Land & Armaments, Composite Technologies, Densit, Future Strategy Solutions, Karagozian & Case, Lafarge Centre de Recherche and Lafarge North America, Norchem, RFR Engineers, VSL Australia, Walter P. Moore, Weidlinger Associates, Wiss-Jannek-Elstner Associates, and WSP Cantor Seinuk.

This diverse group of international experts was given the challenge to formulate a roadmap of critical activities and research efforts required to enable the use of affordable, available, and reliable UHPC in the U.S. construction market. Their collective insight and advice as outlined in this document will help the nation to take full advantage of the performance benefits that UHPC can provide for our critical infrastructure.

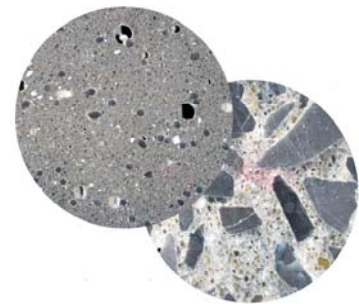
Detail of the Footbridge of Peace (Lafarge)



The Potential of UHPC

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 repair and enhance the performance of existing structures. These materials are required to be increasingly more energy-efficient, environmentally friendly, sustainable, affordable, and resilient. They need to meet multi-hazard/-performance design criteria and be easily produced and incorporated into construction methods and practice. Furthermore, these materials must be cost effective through a structure's life cycle

Concrete is the most widely used material in building construction. Within the last few decades, research has been conducted on what is known as Ultra High Performance Concrete (UHPC). The term includes a broad range of materials such as defect-free, dense particle, engineered composite, multi-scale particle, and fiber-reinforced cementitious materials with enhanced properties and characteristics. Commercial brands are available and many research mixtures have been developed to include local and "green" constituents.



Examples of a UHPC and a conventional concrete (ERDC)

For purposes of this workshop, a definition of UHPC is a class of "concrete" materials with an unconfined compressive strength over 20,000 psi (140 MPa) that usually has high binder content and special fine aggregates. For comparison, the unconfined compressive strength of conventional concrete is from 3,000 to 6,000 psi (20 – 40 MPa). Steam curing may be employed to attain strengths approaching 30,000 psi (210 MPa) and higher UHPC may contain fibers to achieve non-brittle behavior and, if possible, to dispense with passive (non-prestressed) steel reinforcement. The UHPC materials of interest have very small pores, low porosity, and disconnected pore spaces.

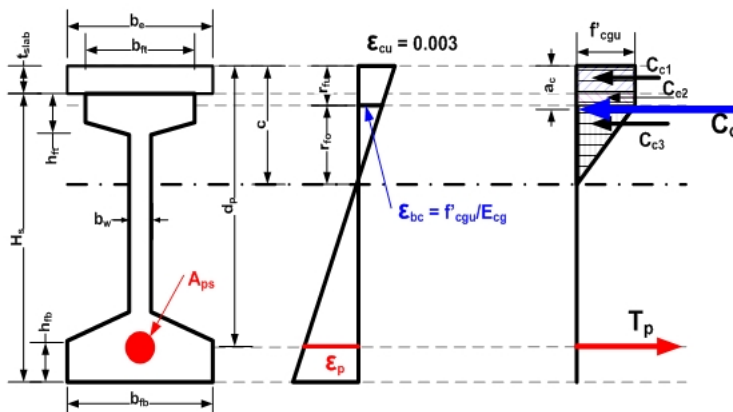
If viewed solely on the cost per cubic yard of material, the cost of UHPC materials can be over ten times greater than the cost of conventional strength concrete. However, UHPC materials may offer unique advantages and higher performance levels that justify the increased "first cost". Such factors include: 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.

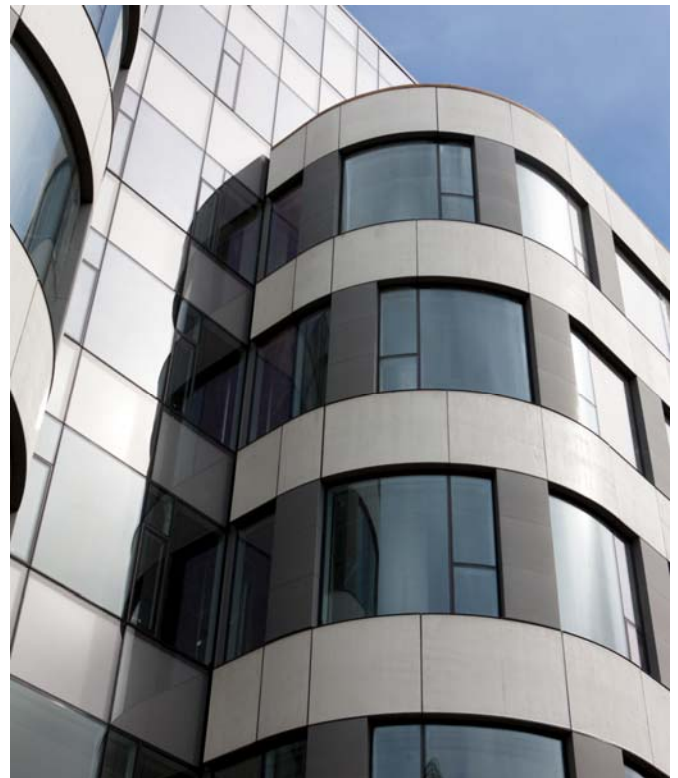
From an aesthetic viewpoint and also for security purposes (such as disguising the appearance of the material), some UHPC mixtures may have color and texture options, surfaces can be sanded or polished and can even be made to look similar to materials such as stone or marble.

In summary, advanced materials known as UHPC have a strong potential to help the revitalization of our nation's infrastructure, and in the building of new infrastructure that is sustainable, resilient and long-lasting. However, adoption of UHPC in the U.S. has been slow in comparison to Europe and Asia, notably Australia, China, France, Germany, Iran, and Japan. A concerted effort will be required to accelerate its usage in the U.S. construction industry.



Design Approach for Prestressed UHPFRC Girders (NRC-Canada)

UHPC building façade panels (Lafarge)



Addressing the Challenge of UHPC Commercialization

Conventional concrete has widespread usage in construction although it is a commodity that does not necessarily perform well in the long-term or when subjected to man-made or natural hazards. Advanced materials, such as UHPC, show exceptional potential to improve infrastructure performance, and need to be transitioned from the research and development phase to common construction use. They must, at the same time, compete with already established construction materials such as conventional concrete.

Currently, there are no set procedures that can guarantee transition of an advanced material into widespread construction usage. Acceptance for use in construction is dependent on developing economic incentives to use the material; overcoming resistance due to increased initial costs; and required changes in codes, standards, and current practices.

The UHPC workshop participants addressed these transition issues and provided input for a UHPC commercialization roadmap for the U.S. The six topic areas at the workshop were:

1. **Manufacturing and processing in the USA**
2. **Codes, guidelines, standards and other technical documents**
3. **Basic and applied research needs**
4. **International experiences and cooperation**
5. **Costs, benefits, and liabilities**
6. **Construction, QA/QC, maintenance, inspection and performance verification**

The following sections include key discussion points resulting from the workshop presentations and breakout sessions followed by goals and actions for each of the six topic areas. Finally, a list of suggested activities to help in the commercialization of UHPC in the U.S. construction industry is presented for consideration.



Large UHPC structural components (Lafarge)



*Pilot Project
Wildbridge Völkermarkt (Graz
University of Technology)*

1. Manufacturing and processing in the USA: Current and future status

Discussions were held on issues concerning the manufacturing and processing of UHPC in the U.S. construction industry. Topics included additional material and manufacturing capabilities (raw materials, production, transportation); availability of facilities and equipment and their required modifications to process UHPC; safety and environmental concerns; and liability to manufacturers, fabricators and contractors. It was observed that there must be a market demand for the product to justify major facility conversions. Specifications for materials and end-products; standards for processing; new standard operational procedures; and new testing methods to verify end product properties and quality may also be needed. Costs to implement changes would vary depending on the method of construction, e.g., prefabrication or field construction and curing requirements. It was stated that precasting of UHPC members can provide quality control over production, quicker construction (e.g., mobility), and possibly lower overall construction costs. Usage of UHPC needs to be based on lifecycle versus firstcosts, and sustainability benefits. Finally, steps need to be taken to justify and mitigate costs and risks to transition to UHPC production.



Batching facility for UHPC (Université de Sherbrooke).

It was stated that manufacturing, design, and construction issues that have already been addressed to some extent include batch sizes and mixing; pumping; curing of large segments; rapid curing; material property data for design for some UHPC types, performance of UHPC/HPC/conventional concrete hybrids; thin bonded UHPC overlays; and joints, connections and end conditions

General concerns were (1) it may be necessary to have a full-range of dedicated equipment to obtain required tight quality control of the material production and construction efforts, and (2) it would be beneficial if there were a forum for sharing knowledge of manufacturing and processing methods and procedures.



UHPC mixer (Kassel University)

Goals:

- **Generate a UHPC manufacturing and production capability in the U.S.**
- **Educate and gain acceptance of UHPC and generate a market for material**

Actions:

- **For UHPC production, perform a survey of U.S. material suppliers and a survey of manufacturing facilities to determine:**
 - **Existing capabilities that could produce or be modified to produce UHPC**
 - **Required equipment modifications and acquisitions and their costs**

- Needed technical guidelines, specifications, operating procedures, and testing methods
- Provide incentives to build facilities or change production facilities use
- Provide methods to reduce risks and liabilities



*Pilot Project Wildbridge Völkermarkt
(Graz University of Technology)*



2. Codes, guidelines and standards

Professional codes, guidelines, standards, specifications, and best practices are required for the use of a material in construction to ensure material performance, structure integrity, and environmental safety. Specifics may vary depending on the application, i.e., type of structure (bridges, buildings) and performance requirements (service loads, hazards).

For conventional concrete, these authoritative documents exist, but requirements usually do not typically address critical infrastructure criteria of sustainability, resiliency, and life-cycle design. For UHPC, there are design guidelines and recommendations in France, Japan, and Australia, but these documents need to be generated for U.S. construction purposes. This will require a definition of the material, a basic understanding of the material structure, properties, and behavior under loads and generation of processing-structure-property-performance relationships. Most importantly, these documents must also include critical key parameters for sustainability and resilience, and methods for measuring them.

As examples, the following were suggested at the workshop:

- **Material standards (including terminology; definition of UHPC and constituents and composition; material properties (statistically significant for design); tolerances, batching, packaging, marking, and storage; QA/QC and safety issues – MSDS)**
- **Laboratory and Field Testing Standards (including test methods; specimen details and preparation; procedure, precision, reporting, etc.; and lab qualification)**
- **Structural design codes (including minimum ductility requirement; bending with or without axial force, shear, torsion, punching, creep and shrinkages; impact strength and fire resistance/parameters for fire design; phi factors for flexure and shear; dosage of fibers; and dispersion of fibers)**
- **Construction procedures and practices (mixing, placement, consolidation, curing)**
- **Operation and maintenance guidelines**
- **Inspection and monitoring methods to verify properties of material, as-processed material characteristics, structural competency, and performance**
- **Rehabilitation methods and repair guidelines**
- **Security guidelines**
- **Durability and sustainability requirements (including cover provisions; chloride transfer characteristics; DEF provision and specification of key performance indicators for sustainable infrastructure such as service design life; minimal embodied energy; self-sufficiency for energy over usage life; self-sufficiency for water over usage life; minimal usage disruption or “out-of-use”; near zero maintenance and operations; and net zero impact on flora and fauna)**
- **Resiliency criteria (such as durable and exchangeable, and ability to inspect and retrofit)**
- **Service life prediction methods and recordkeeping requirements**

Lack of knowledge and experience with UHPC may also require different and more extensive engineering efforts and material considerations; different design approaches (such as performance based design); prototype testing; new material property and structural response testing methods; appropriate numerical



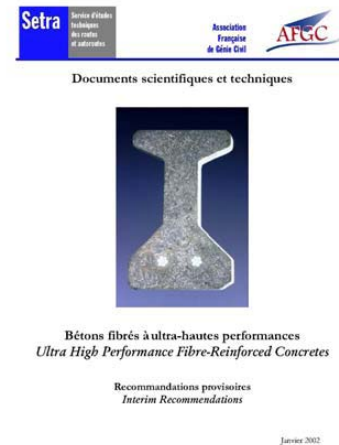
UHPC Pi-Girder design, Buchanan County Bridge (Lafarge)



UHPC - FHWA project (MIT)

models for design and analysis and solution verification methods; QA/QC guidelines to ensure material and structural performance including control of environmental conditions during production, and maintenance, inspection, repair and monitoring requirements. If this is the case, there will be a need to develop material testing requirements and procedures; lab certification procedures; and certification and training of personnel in manufacturing, construction and inspection.

Other comments included the need for education and support for code development; need to acquire acceptance of these documents by all interested parties; and the formation of national and international forums to share knowledge on all aspects of UHPC.



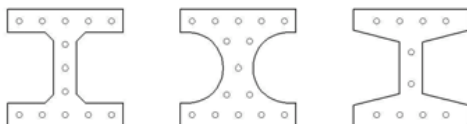
AFGC-Setra UHPFRC Interim Recommendations.

Goals:

- Provide the necessary technical, operating, and construction guidance to enable the design and construction of infrastructure using UHPC

Actions:

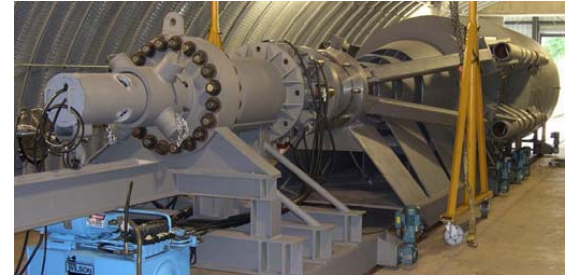
- Assemble and authorize an international team of experts to evaluate current codes, practices, test methods, and standards and make recommendations on needed changes for UHPC for the U.S.
- Develop resiliency criteria and risk assessment tools
- Develop, specify and mandate life cycle design and resiliency and sustainability requirements in materials, products, and structures
- Promote performance based design attitude, guidelines and specifications
- Generate multi-performance and sequenced performance design
- Form an ACI committee on UHPC



UHPC pile designs (Iowa State University).

3. Basic and applied research needs

Research necessary to introduce UHPC into the U.S. construction industry includes obtaining: fundamental data on UHPC materials; uncertainties in properties; correlation of properties to structural performance; and characteristic curves based on multiple testing of the same material (constituents and processing) to describe behavior. It would also be necessary to determine if traditional testing methods and procedures and interpretation of results for conventional/high strength concrete could be used, or if new ones would need to be developed for UHPC materials.

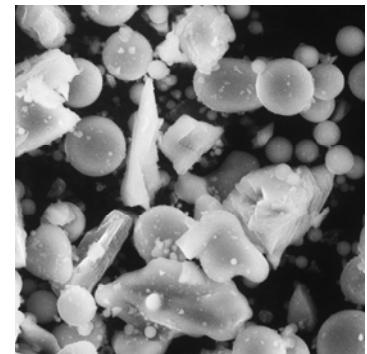


Blast load simulator (ERDC)

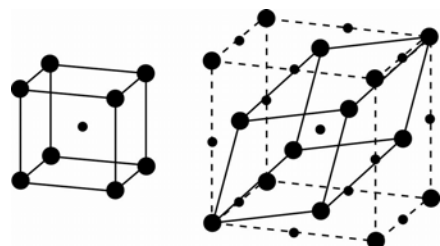
It was suggested that research should be conducted to:

- **Establish manufacturing ranges for constituents and processing**
- **Set tolerances for material production and construction**
- **Obtain data and information for QA/QC guidelines, material testing requirements and lab certification procedures, non-destructive testing techniques, inspection requirements, and performance based design criteria.**
- **Establish simple design methodologies for bridge/building designers**
- **Perform required testing and obtain data for code and specification purposes including simplified design equations, test data for material reduction factors (limit state) and reliability indices**
- **Develop models for performance optimization**
- **Develop material models and computational tools that can evaluate material from the processing stage through sequenced performance events**
- **Generate models for durability of damaged material**
- **Investigate stability of slender UHPC members**
- **Obtain better understanding of cementitious materials, compositions, phases and hydration mechanisms**
- **Perform research to develop more economical and “green” UHPC versions**

Specific research issues cited included early age stress-strain behavior; creep and relaxation; multiaxial strengths; fiber dosage, distribution, and orientation; fatigue under uni- and multiaxial compressive, tensile and bending tensile loads; bond development; pull-out capability; freeze/thaw resistance; resistance to deicing agents, acids and sulfate; corrosion of fibers in cracks; durability of glued connections; interaction between reinforcing bars/tension strands and fibered matrix; thin overlays and pavement layers; long term behavior, behavior of joints and connections; behavior during abnormal events (blast, earthquake, impact); and compatibility with other advanced materials.



Microspheres (ERDC)



Crystallographic structures

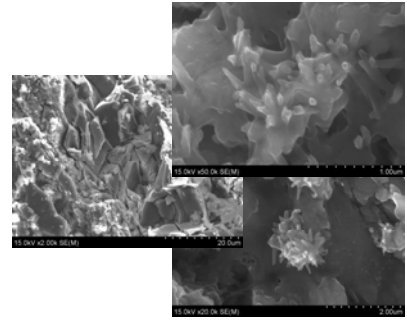
It was suggested that before any research can be done, there needs to be a definition of material (mix), application focus, and specification of performance criteria. Also, it would be beneficial to have an international forum for sharing information and knowledge.

Goals:

- Conduct research to obtain the necessary data and knowledge required to produce, construct, and use UHPC for infrastructure applications

Actions:

- Generate a current state of the art summary of UHPC materials to identify the knowledge gaps on UHPC needed for construction usage and provide direction for future focused research efforts
- Determine priority research issues for commercialization
- Build team of researchers to develop and execute a concerted and efficient research plan
- Form new and strengthen existing vehicles for sharing information and knowledge of UHPC
- Form funding hub of government agencies and associations to champion the effort

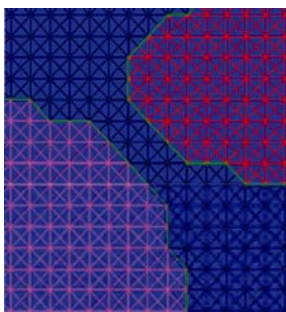


UHPC tested material structures (ORNL/SNL)

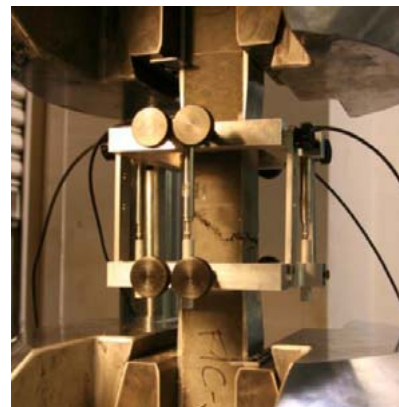


UHPC structural component testing (FHWA)

UHPC testing (FHWA)



Multiscale modeling of UHPC (GeorgiaTech)



4. International experiences and cooperation

Many of the advantages of UHPC materials have been recognized around the world with respect to new construction and retrofit of aging infrastructure.

Adoption of UHPC in Europe and Asia has been relatively fast in comparison to the U.S. UHPC projects have been based on structure performance problem solving, creative design opportunities, or advancement of technology. Successful projects are characterized by a high degree of coordination, cooperation, and commitment of a project team consisting of owners, designers (engineers and architects), material suppliers, manufacturers, fabricators, contractors, researchers, and people from technical societies and government agencies who have a strong interest in the success of the effort. These teams have been willing to work together and share the risks on this advanced material challenge.



Footbridge of Peace, Seoul (Lafarge)

It was stated that dissemination of information and education is extremely important to help commercialize UHPC in the U.S. Opportunities exist with respect to international conferences, workshops, tradeshow, meetings, publications, and published articles. Demonstration projects were also suggested as they would give the U.S. experience in design and construction with UHPC and specific applications could be chosen to show the benefits and versatility of the material.

Goals:

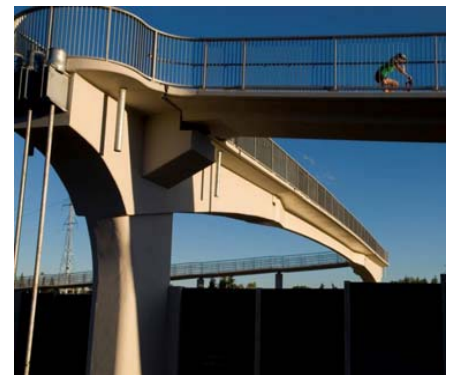
- **Build on foreign efforts and establish collaboration with foreign governments, agencies and researchers to bring UHPC and its benefits to the attention of the general public in the U.S. and introduce UHPC into the U.S. construction industry**



Gärtnerplatzbrücke, Kassel

Actions:

- **Enable international collaboration through exchange agreements, workshops, conferences and meetings and even international co-operative projects**
- **Sponsor or participate in international UHPC conferences on all aspects of the materials and its use in construction**
- **Form a UHPC task group to study UHPC activities and projects in foreign countries and provide recommendations for U.S. construction usage, including equivalency of national and harmonized standards**



Pedestrian bridge (Lafarge)

5. Costs, benefits and legal liabilities

UHPC offers many benefits to performance and design (see the Potential of UHPC section), but as with other advanced materials, the issues of initial cost and liability are currently of concern and usually provide impediments to the use of these materials in construction. For UHPC, material costs may be high due to mix requirements and raw material availability; but research could be conducted to modify the material mixtures, use regional raw materials, and develop more economic, efficient, and green UHPC versions. There will be initial costs of modification, conversion, or purchase of equipment and facility costs. New methods and procedures, training of workforce, and familiarization with the material may be necessary and may result in high manufacturing, processing and construction costs. It was suggested that some of these costs may decrease as the technology matures, experience is gained, competition develops, and the market demands mass production.

The cost of concrete is usually given in terms of a cost of material per unit volume basis, e.g., \$/cubic yard or initial construction cost and therefore, current UHPC costs are much higher than those of conventional concrete. However, in many cases, the volume of UHPC required to meet strength criteria will be less than that of conventional concrete thereby reducing these costs. Furthermore, if sustainability and resiliency requirements are to be mandated for infrastructure, costs need to be viewed on a lifecycle basis. Both conventional concrete and UHPC would be subject to long-term performance evaluation and this would include maintenance, inspection, and monitoring and repair and replacement. On this basis, UHPC has cost advantages over conventional concrete.

Legal liability issues are also a major concern when using a “new” material in construction. Some form of suspension of or limited liability may be required to provide incentives for project participants.

Goals:

- **Inform and educate owners, developers, design community, and society of performance and life-cycle benefits of UHPC**
- **Minimize or remove risks and liabilities for collaborators**

Actions:

- **Establish a database of conventional construction and UHPC construction life-cycle cost and performance issues**
- **Mandate life-cycle cost basis**



Examples of old and new bridges (Lafarge)

- For the benefit of all infrastructure materials efforts, suggestions were made to generate:
 - Field performance database from applications
 - Reasonable and safe acceptance limits/performance criteria
 - Long-term performance monitoring methods
 - Life-cycle performance analysis
 - Life-cycle cost evaluation and estimating tools
 - Economic optimization tools
- Form a council consisting of federal government departments to help expedite development and implementation of advanced materials into federal programs
- Provide financial incentives to the building industry to:
 - Upgrade manufacturing facilities and capabilities
 - Compete in the international arena
- Promote solutions to reduce risks and for liability protection problems
- Provide financial incentives/subsidies to infrastructure owners to use UHPC materials



Old bridge in Wapello County, Iowa (Lafarge)

Buchanan County Bridge, Iowa (Lafarge)



6. Construction, QA/QC, maintenance, inspection and performance verification

Since UHPC is a relatively new and little understood material in the U.S. construction practice, there is a need to review existing and possibly generate new methods of construction, QA/QC procedures, non-destructive testing methods, certification requirements for laboratory, plants, and field testing, training for contractors, suppliers, engineers, architects, inspectors and owners, and maintenance, and performance verification requirements. All modified and new procedures, methods, and technique should incorporate sustainability and resiliency requirements.

Some impediments to the use of UHPC include: concern for short-term construction costs and profits, competition for jobs vs. sharing experience, patent protection, and liability issues vs. sharing designs. Revised bidding processes may be needed to incorporate additional requirements on material quality, workforce training, and inspection techniques. Demonstration projects and initial ventures using UHPC may be restricted to select owners and large engineering/construction firms that are willing to work with advanced materials and assume the risks and liabilities that may result.

Specific QA/QC procedures mentioned in discussions were the evaluation of fiber orientation and distribution and correlation of cylinders tests to full scale components.



Structural component testing (Iowa State University)

Goals:

- **Generate a UHPC construction capability in the U.S.**
- **Educate and gain acceptance of UHPC to generate a market for material**

Actions:

- **Produce a summary of the variety of materials available on the market and their proper selection for UHPC**
- **For the U.S. construction industry, perform a survey of U.S. contractors and testing laboratories to determine:**
 - **Existing capabilities that could be used in UHPC construction projects**
 - **Required equipment modifications and acquisitions and their costs**
 - **Needed technical guidelines, specifications, operating procedures, and testing methods for construction**
 - **Interest to use UHPC as a construction material**
- **Review existing QA/QC procedures, testing, and operation and propose modifications required for UHPC structures**



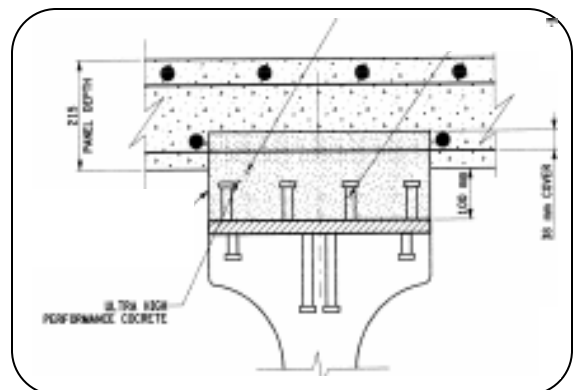
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- Determine training requirements and certifications for UHPC use in construction
- Provide incentives to contractors to develop and incorporate construction methods for UHPC
- Provide methods to reduce risks and liabilities



Performance testing of lap splice connection (FHWA)

Connection details (FHWA)



Suggested Activities for UHPC commercialization in the U.S. Construction

1. Form and support a UHPC group or committee that that would do the following tasks:

- Produce state of the art reports on UHPC in the areas of:
 - Research and development of UHPC materials
 - Design issues and code/guideline status
 - Foreign and U.S. construction projects, research, and modeling efforts
 - Required manufacturing, design and construction documents for U.S. construction
 - Bibliography
- Define UHPC for U.S. construction
- Provide recommendations for vision, focus, objectives and goals for UHPC commercialization - short-term and long-term
- Recommend UHPC demonstration projects – high profile and critical performance issues



UHPC building façade panels (Lafarge)

The group would consist of:

- US engineers and researchers to generate design codes, specifications, test methods, and practices
- Contractors to help with construction methods and practices
- Group of technical and business people to provide help with general project concerns
- Researchers to perform basic and applied research required to ensure performance

2. Promote and support the development and acceptance of UHPC codes, guidelines, standards, specifications and best practices

3. Sponsor or participate in:

- International UHPC conferences on all aspects of the materials and its use in construction
- Design competition - Inspire architects and owners with design advantages
- Sessions on UHPC at conferences such as ACI, ASCE, or PCI
- Student competition on UHPC applications with winners presenting at a conference such as ACI or ASCE

4. Conduct Construction Demonstration projects involving teams of owners, architects, engineers, researchers, construction experts, etc. in the following applications:

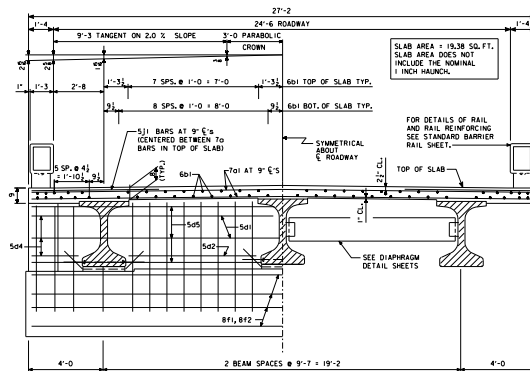
- High profile - Special government-specific monument, museum, etc. structure/façade
- Conventional highway bridge, building component or another type of structure requiring environmental and structural durability and generate and use a revised bid/award system to ensure proper design, QA/QC, adequate training of workforce, and other requirements for construction using UHPC material.

5. Provide financial incentives to building industry to:

- Upgrade manufacturing facilities and capabilities

- **Compete in the international arena**

6. Provide financial incentives/subsidies to infrastructure owners to use UHPC materials
7. Form a committee to document and address legal liability issues concerning UHPC
8. Mandate life cycle and resiliency/sustainability requirements in construction
9. Promote international collaboration through exchange agreements, workshops, and meetings



UHPC I-girders (Iowa State University)



*Pilot Project WildbridgeVölkermarkt
(Graz University of Technology)*

Closure

Ultimately, there is no single material solution to all our current and future infrastructure problems, but advanced materials can help. It is essential to our economy and environment that we research and develop these materials and effectively transition them into practice so their benefits can be fully realized. UHPC has a significant potential to improve our infrastructure, but to establish it as a construction material, there must be demand and guidance. To move UHPC into the U.S. construction industry, we must work together, capitalize on experience, and share the risks. With this commitment we have an opportunity to improve quality of life, the environment, and future prospects for U.S. citizens and our infrastructure.

UHPC example (Lafarge)



*La Galerie Enrico Navarra
(Lafarge)*



Abbreviations

AASHTO - American Association of State Highway and Transportation Officials
ACI - American Concrete Institute
AIA - American Institute of Architects
ANSI - American National Standards Institute
ASCE - American Society of Civil Engineers
ASNT - American Society for Nondestructive Testing
DHS - U.S. Department of Homeland Security
DOC - U.S. Department of Commerce
DOD - U.S. Department of Defense
DOE - U.S. Department of Energy
DOT - U.S. Department of Transportation
EISA - U.S. Energy Independence and Security Act
EPA - Environmental Protection Agency
FHWA - Federal Highway Association
IBC - International Building Code
ICC - International Code Council
NIBS - National Institute of Building Sciences
NIST - National Institute of Standards and Technology, U.S. Department of Commerce
NRC - National Research Council
PCA - Portland Cement Association
PCI - Precast/Prestressed concrete Institute
QA/QC - quality assurance/quality control
UHPC - Ultra-high performance concrete
USGBC - U.S. Green Building Council

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