Architectural Use of Precast Ultra High Performance Concrete

Engineering

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M. Vijai Kishore	Dept. of Civil Engineering, University of Petroleum and Energy Studies, Dehradun
Harinder Yadav	Dept. of Civil Engineering, University of Petroleum and Energy Studies, Dehradun
Achal Garg	Structural Engineer, Keppel Offshore & Marine Engineering, Mumbai

ABSTRACT

As a material on the leading edge of concrete innovation, ultra-high performance concrete (UHPC) provides a new technology to expand a pre-caster's business with new products and solutions. The material's combination of superior properties facilitates the ability to design thin, multiplex shapes, curvatures and highly customized textures – applications which are difficult or impossible to achieve with traditional reinforced concrete elements. Due to UHPC's plastic and hardened properties, plus the elimination of rebar, pre-casters can achieve complex shapes that are extremely durable and cost effective, and require little preservation. The material re-produces textures, form and shape with high precision and can be produced in a range of enduring colors. With UHPC, pre-casters can offer new, innovative building envelope solutions for creative architects; for example: structural, decorative perforated facades in mesh or lattice-style designs; ultra-thin, lightweight panels with large surface areas and perforation rates that exceed 50%; and full facades with composite shapes, curvatures and textures.

INTRODUCTION

In the 1960s, concrete with a compressive strength of up to 116,000 psi (800 MPa) has been developed and produced under specific laboratory conditions. It was compacted under high pressure and thermally treated. In the early 1980s the idea was born to develop fine grained concretes with a very dense and homogeneous cement matrix preventing the development of micro-cracks within the structure when being loaded. Because of the restricted grain size of less than 1 mm and of the high packing density due to the use of different inert or reactive mineral additions they were called Reactive Powder Concretes (RPC). Meanwhile there existed a wider range of formulations and the term Ultra-High-Performance Concrete (UHPC) was established worldwide for concretes with a minimum compressive strength of 21750 psi (150 MPa). The main principle of this technology is based on systematic elimination of inherent weaknesses associated with conventional concrete. The ductile behavior of this material is a first for concrete, with the capacity to deform and support flexural and tensile loads, even after initial cracking. These superior performance characteristics are the result of improved micro-structural properties of the mineral matrix and control of the bond between the matrix and the fiber. With UHPC, pre-casters can offer new, innovative building envelope solutions for creative architects; for example: structural, decorative perforated facades in mesh or lattice-style designs; ultra-thin, lightweight panels with large surface areas and perforation rates that exceed 50%; and full facades with complex shapes, curvatures and textures.

RAW MATERIALS AND MATERIAL STRUCTURE

The optimization of granulars, fibers and admixtures provide a very low porosity in a cement-based mineral granulometric matrix. The premix components consist of granular material with a diameter less than 1 mm, and a highly reduced water-cement ratio (0.10-0.25, depending on the type of UHPC formulation required). Elimination of coarse aggregates, along with the granular gradation and fiber aspect ratio, facilitates a high fiber content and isotropic dispersion. Due to UHPC's plastic and hardened properties, plus the elimination of steel reinforcing bars, pre-casters can achieve complex shapes that are extremely durable and cost effective, and require little maintenance. The material replicates textures, form and shape with high precision and can be produced in a range of long-lasting colors. It works well for new, innovative concrete applications and supports new trends in architecture: purity of line, delicacy, enhancement of texture and mineral bias. The improved durability of UHPC is based upon four principles which are described in the below points.

2.1 A very low water-cement-ratio of about 0.10 to 0.25 resulting in a very dense and strong structure of the hydration products and minimizing the capillary pores, which are ductile to prevent brittle failure and to be able to use more or less traditional design approaches against the transport of harmful gases and liquids into and through the concrete.

2.2 A high packing density especially of the fine grains in the binder matrix reducing the water demand of the fresh mix and increasing the compressive strength – as well as the brittleness of the concrete.

2.3 The use of higher amounts of effective super-plasticizers to adjust the workability and – if needed.

2.4 The use of steel or other fibers to increase the tension, the bending tension and the shear strength and to make the concrete sufficiently ductile.

MANUFACTURING OF UHPC PRECAST ELEMENTS FOR ARCHITECTURAL WORK

The manufacture of precast UHPC elements presents the industry with additional challenges and opportunities. For instance, pre-casters are required to review their current batching methods, casting techniques, molding expertise and handling techniques.

3.1 Batching: The mixing efficiency and mixing performance depends on: the type and speed of the mixer; requested mixing time by the precaster; and the required UHPC volume for precast production. When setting up the batch plant for UHPC at a precast facility, the introduction of raw materials into the mixer must be considered. The key to producing high-quality UHPC products is very precise proportion control of raw materials, temperature control and optimization of the mixer's performance requirements.

3.2 Forming: Successful execution of a precast UHPC project depends on the design of the molds and the procedures developed to use them. Traditional hand screeding and finishing of UHPC is not normally used due to its high flow and fiber content of the plastic matrix. For accurate mold design, any potential deflections and initial UHPC shrinkage must be considered.

3.3 Placing: When placing the self-leveling UHPC material into formworks, it is important to take advantage of its fluid characteristics. When discharged from a concrete bucket onto flat-surface molds, UHPC will create a mass of material that will spread itself throughout the form. By moving the discharge point at a rate such that it always stays behind the leading edge of the flow, the mold can be filled in one continuous motion. This is important, because if UHPC flows meet each other, there will be minimal fibers bridging the junction, resulting in a weak plane. After placement, any exposed surfaces must be covered in order to prevent dehydration.

3.4 Curing: Architectural precast UHPC elements are typically removed from the mold after final set has been reached (11,000 psi or 75 MPa). If the elements have structural requirements, they can be thermally treated after setting and de-molding. This process requires the UHPC precast element to be exposed to 60 C at 95% relative humidity for 3 days. This allows the hardened architectural UHPC element to reach its ultimate strength and durability characteristics by hydrating all of the free water within the matrix.

3.5 Surface Treatment: Different sealers can be used with architectural UHPC products. The type of sealer depends on the application. For instance, vertical elements do not typically require much abrasion resistance but could be exposed to substantial heat, UV light and staining. Horizontal precast applications could be exposed to the same conditions as vertical applications as well as abrasion. Topical sealers generally repel staining but perform poorly with respect to abrasion.

APPLICATIONS OF PRECAST UHPC AND INDUSTRIAL OPPORTUNITIES

UHPC's superior mechanical performances can result in a reduced number of sections, eliminate the need for passive reinforcing, and allow for the design of cantilevered structures that are not possible with conventional concrete. Furthermore, UHPC enables the design and production of ultra-thin elements that are highly durable and sustainable. Examples of architectural UHPC precast elements with complex curves, textures and shapes are illustrated within the following sections.

4.1 Curves: Curved UHPC panels allow for the development of tighter radii that would not be efficient with a flat panel system.

4.2 Texture: The material's (UHPC) fluidity enables it to reproduce the texture of the molds with extreme precision. UHPC is the key element in the projects, providing the envelope, skin and ground wall connection.

4.3 Perforated and Lattice Panel Systems: Traditional perforated panels are made of metal, painted steel, cast iron, stainless steel or cast aluminum. UHPC offers an alternative for creating original precast decorative elements that are durable, and require less energy consumption to create and less maintenance over time.

4.4 Artisan: UHPC is well-suited for modern and contemporary interior decors including benches, tables, decorative panels, kitchens, bathrooms, floor tiles, fireplaces and planters. A good fit for current, modern trends in décor, it provides a bare, natural material for homes and businesses.

4.5 Interior Design: With UHPC, designers can create complex, organic interior design elements that are sleek and lightweight. UHPC can be molded to imitate stone or contemporary looks with a wide variety of attractive surface finishes or textures for surround fireplaces and planters.

4.6 Urban Furnishing: UHPC can be used for the production of practical, unique street furnishing in urban settings. Its combination of properties provides functionality, durability, aesthetics and a wide range of colored or textured options. Its impact- and weather-resistant qualities durability and low maintenance make it an excellent alternative to traditional materials such as steel, cast iron, aluminum, plastic or wood.

4.7 Mega Architectural Projects: Mega Architectural projects take advantage of the superior properties of UHPC with architectural and structural properties such as ease of curvature and texture, as well as high compressive and flexural strengths.

4.8 Marine and Offshore Projects: The structural capacity of braces and joints can be increased by injecting UHPC grouts or deploying UHPC grouted clamps and sleeves is arguably the most cost effective and technically efficient option available. The injection of UHPC grouts, which in compression reach strengths that are similar to steel, is a swift operation with comparatively little offshore work involved. The application of UHPC grouts significantly increases the structural capacity of both tubular braces and fatigue exposed joints.

CONCLUSION

In this paper, the authors have summarized the current activities across the world for UHPC in new construction in the areas of market transformation. To encourage greater implementation of precast architectural UHPC in advancing infrastructure there are some activities and documents required such as Market Research showing the cost effectiveness of UHPC in various applications, specific guidelines for design and construction of structures made with UHPC, research and development to address some of the missing information needed in the structural design guidelines, National and International Standard test methods and material specifications for UHPC. While the current LEED rating system lacks credits for ranking the numerous green benefits of precast concrete. In addition, UHPC presents the advancement for potentially lower embodied energy due to significant material reduction (up to 40 percent less weight) in optimized members. Long-term service life and expected very less maintenance cost are material characteristics that lend themselves to reduced life cycle costs for structures.

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