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FULL LENGTH ARTICLE

Behavior and strength of beams cast with ultra high strength concrete containing different types of fibers

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Abstract Ultra-high performance concrete (UHPC) is a special type of concrete with extraordinary potentials in terms of strength and durability performance. Its production and application implement the most up-to-date knowledge and technology of concrete manufacturing. Sophisticated structural designs in bridges and high-rise buildings, repair works and special structures like nuclear facilities are currently the main fields of applications of UHPC. This paper aimed to evaluate the behavior of ultra-high strength concrete beams. This paper also aimed to determine the effect of adding fibers and explore their effect upon the behavior and strength of the reinforced concrete beams. A total of twelve simple concrete beams with and without shear reinforcements were tested in flexure. The main variables taken into consideration in this research were the type of fibers and the percentage of longitudinal reinforcement as well as the existence or absence of the web reinforcement. Two types of fibers were used including steel and polypropylene fibers. The behavior of the tested beams was investigated with special attention to the deflection under different stages of loading, initial cracking, cracking pattern, and ultimate load. Increased number of cracks was observed at the end of loading due to the use of fibers, which led to the reduced width of cracks. This led to increased stiffness and higher values of maximum loads.

Introduction

Ultra-high performance concrete (UHPC) is a new class of concrete that has developed during recent decades. First research carried out on UHPC was originated in the mid 1990s. UHPC is a cementations material that contains a high quantity of cement, silica fume, low quantity of water, incorporates large amounts of fibers and high-range water reducing agent (HRWRA). UHPC exhibits remarkable ductility, durability and strength properties [1–4]. Dili and Santhanam [3] reported that the quartz powder was useful for its reactivity

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during heat treatment. Voo and foster [5] present an overview of the material characteristics of a Malaysia blend of ultra-high performance ductile concrete (UHPdC). A comparable study occurred between UHPdC structures and conventional reinforced concrete (RC). They provided the enhanced durability of UHPdC for significant improvements over the design life. The compressive strength more than 200 MPa was achieved by Richard and Cheyrezy [6]. According to Vivekanandam and Patnaikuni [7] HPC with small aggregates is similar to a strong rock. In the mid 1980s, HPC with compressive strength up to 110 MPa was considered for precast and prestressed structural members. Compressive strength of UHPC up to 145 MPa was demonstrated by Sobolev [8]. This value of compressive strength was achieved by using high-performance cement and eliminating the coarse aggregate. Graybeal [9] reported that UHPC tended to have very low water content and can achieve sufficient rheological properties through a combination of optimized granular packing and the addition of high-range water-reducing admixtures. The reduction of the water-cement ratio results in a decrease in porosity and refinement of capillary pores in the matrix. In HPC water to cement ratio ranges usually between 0.28 and 0.38. Allena and Newtson [10] reported that the water to cement ratio in ultra-high performance concrete can even be lower than 0.2. They made attempts to develop UHSC mixtures with locally available materials. Maroliya [11] illustrated that the greatest compressive strengths obtained were 165.6 MPa for UHSC with steel fibers and 161.9 MPa for UHSC without fibers. The behavior of RPC in direct tension was investigated. Although high-strength concrete is often considered a relatively new material, its development has been gradual over many years [12,13]. The possibility of achieving high strength, durability and improved ductility with the use of UHSC encourages researchers and engineers to use this modern material in many practical applications like nuclear waste containment structures, high rise structures, long span bridges and walkways. So UHSC lead to use in a wide range of applications [14–17]. Flexure members in reinforced concrete structures are designed to fail in a ductile manner. Upper limits in design codes set the amount of longitudinal reinforcements to ensure yielding of steel before concrete reaches crushing strains. Different design codes predicted the shear strength and flexural strengths for UHS reinforced concrete beams [18–21]. Common shear failure patterns are shear-tension, shear compression, diagonal tension and arch-rib failures. The details of various failure modes are illustrated in ACI-ASCE [22]. Charron et al. [23] studied the permeability of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC). UHPFRC presented outstanding hardened properties, and a highly low permeability was noticed. Their properties make it extremely attractive for the rehabilitation of existing structures and for new conceptions. UHPFRC is characterized by a significant tensile strain hardening that can be used to optimize the mechanical performance of composite structural elements. Dario Redaelli and Aurelio Muttoni [24] tested a series of large-scale unreinforced and reinforced UHPFC specimens. They studied the effect of the amount and type of reinforcement on the reinforced specimens. The specific response of reinforced UHPFC members at cracking is analyzed. Voo et. al. [25] studied the behavior of ultra high-performance steel fiber-reinforced concrete beams under shear load. Span-to-depth, ratio, the quantity and type of steel fibers were used throughout this investigation. They observed a good correlation with a mean model to the experimental strength ratio of 0.92 and coefficient of variation of 0.12. Muñoz et al. [26] explored the bond characteristics between UHPC and NSC under varying stress configurations and environmental conditions. The experimental program showed that the bond performance between UHPC and NSC is adequate for bridge overlay applications, regardless of the degree of roughness of the concrete substrate, the age of the composite specimens, the exposure to freeze-thaw cycles and the different loading configurations.

The world's first engineering structure designed with UHPC was the Sherbrooke footbridge in Sherbrooke, Quebec, built in 1997 [27]. The concrete had a compressive strength of 150 MPa and contained 2.5% steel micro fibers (by volume). UHPC has been used for more than 25 years as wear protection in hydraulic and pneumatic transport and storage systems of abrasive materials like coal, fly ash, cement, steel, silica sand and chemicals [28]. In 2002, contractor Bouygues built a footbridge over the Han River running across Seoul in South Korea. Jointly conceived by the City of Seoul and "France's Year 2000 Committee" to commemorate the new Millennium, the footbridge symbolizes the cooperation and friendship between South Korea and France. Furthermore, the design and construction of the third bridge in France, in 2007 located just to the west of Rouen, this small bridge has a single 27-m-long span and is 14-m wide [29].

The objectives of the experimental program described within this paper were (i) studying the behavior of concrete beams cast with UHPC under flexure loading. (ii) Studying the effect of the type of fibers and the percentage of longitudinal reinforcement as well as the existence or absence of the web reinforcement on the structural behavior of test beams.

Experimental program

To achieve the main aim of the current study, an experimental program, including the test of twelve beams with and without web reinforcement was conducted. The beams were designed to have adequate resistance against flexure failure. Simply supported beams ($100 \times 150 \times 1000$ mm) were cast and tested until failure. The beams under investigation were either reinforced with two bottom rebars of 10-mm diameter (reinforcement ratio $\rho = 1.2\%$) or 12-mm diameter (reinforcement ratio $\rho = 1.7\%$). The geometrical and reinforcement details of the tested beams are shown in Fig. 1.

Materials

Locally produced ordinary Portland cement (CEM I 52.5 N) conforming with the requirements of E.S.S. 4756-1/2007 with specific gravity of 3.16 and Blain fineness of 4850 cm^2/gm was used. Locally produced silica fume (SF) was delivered in 15-kg sacks. According to the manufacturer, the powder had a specific gravity of 2.2 and specific surface area of 17 m^2/gm. Natural siliceous sand having a fineness modulus of 2.72 and a specific gravity of 2.58 was used. A modified polycarboxylate Admixture was used as a high range water reducer conforming to ASTM C 494 (types A and F) [30]. The admixture is a brown liquid with a specific gravity of 1.2 at 20 °C. Two types of fibers were used to improve the mechanical properties of