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BEHAVIORAL STUDY OF ULTRA HIGH PERFORMANCE CONCRETE GRIDERS

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Abstract

Ultra-high-performance concrete (UHPC) is a promising new class of concrete material that is likely to make a significant contribution to addressing the challenges associated with the load capacity, durability, sustainability, economy, and environmental impact of concrete bridge infrastructures. Ultra High Performance Concrete (UHPC) is one of the newer and superior classes of concrete that can be used to develop improved bridges capable of meeting the present and future traffic, environmental, maintenance and economical requirements. Developing on the superior material properties of UHPC, the research discussed herein studies the behavior of UHPC when used as a bridge girder material. Four optimized girders have been cast and studied for various early age as well as long term properties such as early age shrinkage, transfer length, creep behavior and shrinkage under steam treatment. This project focuses on the material modeling of UHPC and design of bridge girders made of UHPC. A two-phase model used for modeling the behavior of UHPC was briefly discussed, and the model was implemented in a preliminary design case study. Based on the implemented design and the reported use of UHPC in bridge applications, the advantages, limitations, and future prospects of UHPC bridges were discussed, highlighting the need for innovative research and design to make optimum use of the favorable properties of the material in bridge structures.

1.0 INTRODUCTION

Ultra High Performance Concrete (UHPC) is one of the newer and superior classes of concrete that can be used to develop improved bridges capable of meeting the present and future traffic, environmental, maintenance and economical requirements. Developing on the superior material properties of UHPC, the research discussed herein studies the behavior of UHPC when used as a bridge girder material Ultra-high performance concrete (UHPC) is a novel construction material exhibiting enhanced mechanical and durability properties, which can lead to economical construction through reducing the cross-sections of structural members with associated materials savings and lower installation and labor costs The relatively high initial cost of UHPC has restricted its wider use in the construction industry. However, ongoing research and investigations are filling knowledge gaps in order to commence innovative UHPC having reduced initial cost.

Furthermore, the development and wide acceptance of an UHPC design code provisions should encourage stakeholders in the construction industry to implement large scale applications. This becomes even more relevant with the more recent push by organizations such as the American Concrete Institute, which identified using high-strength steel reinforcement in concrete as a top research priority. Combining UHPC and high-strength steel is expected to yield unique structures in the near future. UHPC potential applications include tall structures, rehabilitation works, structural and non-structural elements, machine parts and military structures. Lighter weight structures owing to smaller cross-sections can be made using UHPC. Therefore, UHPC can be effectively utilized in the precast concrete industry. Furthermore, architecturally and aesthetically appealing structures can be made using UHPC the existing UHPC applications around the world. In the present study, an extensive review of literature on UHPC properties was conducted and summarized in tabular representation for a user friendly access to this scattered information

UHPC: Ultra-High Performance Concrete (UHPC) is a solution developed to address some of the main design, service life and life cycle costing issues associated with the use of concrete. Ductal by Lafarge is the Ultra High Performance Fiber Reinforced Concrete used in this research. It is a steel fiber reinforced concrete consisting of an optimized gradation of fine powders and a very low water to cementations materials ratio. It exhibits enhanced strength, durability and ductility properties when compared to normal concrete or high performance concrete. UHPC in general is steel fiber-reinforced reactive powder concrete that typically displays twice the compressive strength of any High Performance Concrete (HPC) used in United States bridge construction. The French firm Bouygues SA developed the reactive powder concrete originally, which is engineered to be a highly compacted concrete with a small, disconnected pore structure that helps to minimize many of the limitations of typical HPCs. These advancements are achieved through a combination of finely ground powders and the elimination of coarse aggregates. The addition of small steel fibers to the mix is responsible for much of the tensile strength and toughness of the material. These fibers eliminate the need for mild reinforcing steel in the girders and knit the material together after cracking has occurred. The placement and curing of UHPC can be performed using procedures similar to those already established for use with some HPCs. The fluid mix is virtually self-placing and requires no internal vibration. If required, external form vibration causes the mix to flow smoothly into place.

Objectives:

The objectives of this study were to evaluate the impact of different materials and design parameters on UHPC performance and to proportion a non-proprietary UHPC mix using local materials. A methodology to proportion the materials is presented, and key parameters, e.g., the w/b, the type of binder and its content, gradation of the aggregate, types of fibers, HRWR, and the type of mixer were evaluated

2.0 LITARATURE REVIEW

W. Sun, H. Qian, H. Chen,(2000). The fiber-fortified cement is a composite material basically comprising of regular cement strengthened by fine filaments. Concrete is solid in pressure yet exceptionally powerless in strain. This shortcoming in the solid makes it to break under little loads, at the tractable end. These splits continuously proliferate to the pressure end of the part lastly, the part breaks. The arrangement of breaks in the solid may likewise happen because of the drying shrinkage. These breaks are fundamentally miniaturized scale splits. These breaks increment in size and extent as the time passes and the at long last makes the solid to fizzle. The arrangement of splits is the fundamental explanation behind the disappointment of the solid. To expand the elasticity of cement many endeavors have been made. One of the fruitful and most normally utilized strategy is giving steel fortification. Steel bars, be that as it may, fortify cement against nearby pressure as it were. Splits in fortified solid individuals expand unreservedly until the point when experiencing are bar. Along these lines requirement for multidirectional and firmly divided steel support emerges. That can't be essentially conceivable.

Hussein, A. furthermore, Marzouk, H. (2000) Fiber fortification gives the answer for this issue. So to build the elasticity of cement a system of presentation of filaments in concrete is being utilized. These filaments go about as break arrestors and keep the proliferation of the splits. These filaments are consistently dispersed and haphazardly orchestrated. This solid is named as fiber fortified concrete-American Concrete Institute (ACI) characterizes High Performance Concrete "A solid which meets uncommon execution and consistency prerequisites that can't generally be accomplished routinely by utilizing just traditional materials and typical blending, setting and curing hones". The necessities may include improvements of attributes, for example, situation and compaction without isolation, long haul mechanical properties, and early age quality or administration

Galano, L. furthermore, Vignoli, A. (2000) The break properties of superior cement (HPC) containing two broadly utilized sorts of strands. The trial examination comprised of the tests on 3D squares, barrels and scored kaleidoscopic specimens made of plain HPC and fiber HPC (FHCP) with variable substance of steel or/and polypropylene strands extending from 0.25 % to 1 %. Broad information on compressive, part and flexural tractable practices, modulus of versatility and crack vitality were recorded and broke down. The exploratory examinations demonstrated that HPC in break mode I show weak/softening conduct. The FHPC materials demonstrated a more pliable conduct contrasted with that of the HPC materials. Fiber spans broke on the crack surface amid the stacking and deferred splitting, along these lines the component did not break. The aftereffects of the bowing tests demonstrated an expanded post-top softening conduct. The state of the dropping branch was reliant on geometrical and mechanical properties and in addition the amount of the strands utilized. The aftereffects of the examination were assessed and it was demonstrated that the strands contributed extensively to the basic trustworthiness and solidness of the HPC components, along these lines enhancing their strong administration life.

Naaman AE.(2000). The higher the quality of cement, the lower is its pliability. Strands are added to the framework as a fortification to control the splitting, to build the pliability and to enhance the general flexibility of a material.1– 4 Fiber-solid research has been led for more than fifty years5,6 and future bearings for its improvement are as yet being set.7– 9 Nowadays, there are various sorts of filaments made of various materials that are of various geometric properties. With each kind of fiber certain properties of cement can be made strides. With a specific end goal to enhance mechanical properties, particularly the malleable and flexural qualities and long haul solid shrinkage, steel filaments are normally utilized. Low-modulus polypropylene strands can decrease early-age shrinkage and help control the marvel of the spelling of cement amid flame. One of the current ideas is the hybridization of strands, the ideal mix of a few sorts of filaments with various properties to make an intricate composite with a high imperviousness to breaking in an extensive variety of split width

3.0 METHODOLOGY

Mixture Design of UHPC The mixture design of UHPC should be economical and sustainable for achieving denser matrix, reduced porosity and improved internal microstructure, leading to superior mechanical and durability properties. Various models have been reported for the mixture design of UHPC. For instance, proposed a linear packing density model (LPDM) for the mixture design of UHPC. However, the LPDM model did not focus on the relationship between materials proportions and packing density due to the linear nature of LPDM model. Therefore, this model was improved considering the virtual density theory and a new model known as solid suspension model (SSM) was developed Afterwards, based on the compaction index concept and virtual packing density, the compressible packing model (CPM) for the mixture design Ultra-high performance concrete (UHPC) is a new class of concrete that has superior flowability, as well as mechanical and durability properties. The low water-tobinder ratio (w/b), high binder content, the use of steel fibers, and the absence of coarse aggregate make UHPC significantly different from conventional concrete in both the fresh and hardened states. Since the use of UHPC will result in significant improvements in the structural capacity and durability of structural components, various issues, such as cracking and leakage in bridge connections, can be mitigated to a significant extent. The superior strength and durability properties are general due to the optimized particle packing of the materials

Table: Typical composition of UHPC.

UHPC constituents	Range (% by weight)
Cement	27–40
Silica fume	6–12
Quartz powder	7–14
Sand	35–45
Superplasticizer	0.5–3
Water	4–10
Steel fiber	0–8

Table: Effect of w/b and super plasticizer on air content of UHPC

w/b	Superplasticizer	Air content (%)
0.25	–	4.3
0.18	45 kg/m^3	3.5
0.13	46 kg/m^3	1.8
0.17	20 kg/m^3	1.0
0.11	15 kg/m^3	2.5
0.13	52 kg/m^3	4.6

designed a locally produced UHPC mixture based on particle shape, size and density. Moreover, it was reported that the cement content can be lessened by utilizing multi-grained fine particles. An ecological UHPC mixture was developed by based on particle packing technology, which reduced the cement content by 50 %. A robust mixture design of UHPC was proposed by Lohas based on super plasticizer for achieving desired workability of the paste depending on the water-to-powder ratio. developed UHPC using local materials without any special type of mixer and heat treatment based on spread flow properties. Using a modified Andreasen and Andersen particle packing model, a densely compacted UHPC was developed with a cement content lower than 675 kg/m3

Concrete Mix:

The concrete mixes used in specimen construction were sourced from local ready mix concrete suppliers or precast producers. The 5 ksi concrete specimens were constructed using a standard Iowa DOT bridge deck mix ordered from a local ready mix plant. The higher strength specimens were fabricated using the standard mix designs at the Core slab Structures precast plant in Omaha, Nebraska. All the normal concrete mixtures contained Portland cement, water, coarse aggregates, fine aggregates, and high-range water reducers (where applicable). A total of 4 cylinders (4 in. × 8 in. and 6 in. × 12 in.) were used to determine the concrete compressive strengths at 28 days and at the time of slant shear specimen testing. The measured concrete strengths of the all mixes used for slant shear tests conducted in this project are presented.

Sand:

The sand particles in UHPC serve the role of minimizing the maximum paste thickness (MPT). MPT is the mean distance between two coarse aggregates. As MPT increases, the compressive strength of UHPC was found to decrease This provides evidence that the aggregate has a positive confining effect on the paste. As the MPT is directly proportional to the diameter of the aggregate, an aggregate with a minimal diameter, e.g. uniformly sized sand, should be selected Sand with mean particle diameter of 250µm should be selected to maintain a diameter factor of thirteen, as previously discussed, between granular classes (Richard and Cheyrezy 1995). Sand is also a readily available low cost material.

Figure: cement M30 grade

Crushed Quartz:

The crushed quartz is in the same granular size class as cement. As not all of the cement is hydrated, a portion of it can be replaced by crushed quartz. Work completed by Ma and Schneider showed that up to 30 percent of the volume of cement could be replaced by crushed quartz with no reduction in compressive strength. Along with reducing the cement content, crushed quartz also improves the rheological properties of UHPC This could be due to a filling effect since the crushed quartz particles are slightly smaller than the cement particles

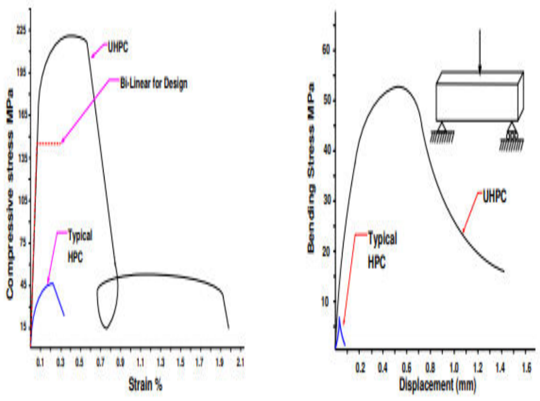
Silica Fume:

The modifying effects of silica fume in concrete are attributed to its pozzolanic reaction with calcium hydroxide to form calcium silicate hydrate, a secondary hydrate. Silica fume also has a filler effect in the voids around various particles in the mix, thus increasing the density of the mix. Along with providing improvements in strength, silica fume also improves the rheological properties of the mix due to the near perfect sphericity of the particles.

Figure: Silica Fume

MECHANICAL PROPERTIES OF ULTRA HIGH PERFORMANCE CONCRETE :

Ultra high performance concrete (UHPFRC) was developed based on advances in nano-technology to achieve a concrete with very low permeability and very high strength. UHPFRC is designed through ultra-high dense packing by means of refined mix-design involving minimum water cement ratio (w/cm < 0.2), high percentages of cement and silica-fume, fine sand and no coarse aggregates UHPFRC is reinforced at the micro level by means of uniformly distributed short fibres with a percentage that can vary from 2 to 12 % (by volume of concrete). The fibre length is ranging from 1 to 20 mm and either constant or variable. Depending on the fibres length and the volumetric proportion, there are three major types of UHPFRC: (i) UHPFRC with high proportions of short fibres, (ii) UHPFRC with intermediate proportion of long fibres, introduced in France 1995; and (iii) UHPFRC with very high proportion of fibres of various lengths, introduced in France 2000 The fibre reinforcement of UHPFRC, heat treatment and its high homogeneity contribute to eliminate the initiation of extensive early age cracks that are the major disadvantage of high strength/ high performance concrete. The superior macro-level mechanical properties of UHPFRC, such as very high compressive and tensile strengths and high modulus of elasticity, high ductility, and high fatigue strength, could enable the development of lighter bridge superstructures that would reduce the number of girders and/or support longer spans than conventional HPC/HSC. The compressive strength of UHPFRC can vary in a very wide range from 120 to 400 MPa, its direct tensile strength can vary from 8 to 30 MPa, and its modulus of elasticity is in the range of 60 – 100 GPa (Acker et al. 2004). Typical stress-strain relationships and typical tensile (bending) stress versus displacement of UHPFRC are compared to those of a typical high performance concrete in Figures respectively. the conservative elasto-plastic approximation of compressive behaviour of UHPFRC that is assumed in design. The uniform distribution of the fibres in the UHPFRC matrix is hard to achieve and different fibre orientations are observed in practice. Since the fibre alignment could result in local or overall anisotropy in UHPFRC, the mechanical properties are affected locally or throughout the entire structural element depending on the affected region, location and size. Furthermore, the anisotropic behaviour adds more complications in the structural analysis of UHPFRC systems; nevertheless, in some situations the anisotropy could improve the overall performance of the structural element if it is properly accounted for in the structural design. To simplify the analysis and design procedure and given the lack of comprehensive experimental data on UHPFRC behaviour, it is generally recommended to use a reduction factor applied to the homogenized properties from the standard material test.



(a) (b)

Figure: Mechanical properties of UHPFRC and OC: (a) Stress-strain relationships; and (b) Flexural stress – displacement

4.0 RESULTS

A response surface design of experiments was developed for identifying the optimum values of coarse-to-fine aggregate weight ratio, superplasticizer content and steel fiber volume fraction in an ultra-high-performance concrete mix with a specific cementitious binder composition, binder content and water-to-binder ratio. The fresh mix flow and the hardened concrete compressive strength were examined. For each UHPC mix design, the values of packing density, water film thickness and excess paste film thickness were also calculated. The following conclusions could be derived from the test results produced for the ranges of variables considered in the experimental program.

The UHPC packing density ranged from 0.825 to 0.855. Within this range, compressive strength increased with increasing packing density, although compressive strength seemed to approach a plateau for the higher end of the packing densities considered here. It should be noted that the higher packing densities achieved here would probably compromise the fresh mix workability without the high superplasticizer contents used in this UHPC mixture.

The distinctly low water content of UHPC seems, based on calculations, to produce a film on the surfaces of all particles, but leave the voids formed between particles empty. A water film thickness on particles was calculated based on this assumption. The UHPC mixtures considered in this investigation had water film thicknesses ranging from 0.058 to 0.07 µm. Within this range, higher water film thicknesses produced lower values of compressive strength. A minimum water film thickness would be required to lubricate the granular matter and produce a viable fresh mix workability. This minimum was probably exceeded in the UHPC mixtures considered here, which were designed to provide adequate workability. The calculated values of water film thickness for UHPC are lower than those reported for high-strength concrete. The use of relatively large superplasticizer dosages enabled lowering the UHPC water film thickness while still achieving adequate fresh mix workability

Testing Procedures

In general, well-established testing procedures for conventional concrete are applicable to UHPC. However, in some instances, procedures may need to be modified to appropriately capture the true behaviors of the UHPC Compression testing is a prime example. The conventional test method is generally appropriate, but compressive strengths as high as 35 ksi (240 MPa) may necessitate smaller specimen sizes, different specimen shapes, higher test machine capacities, or different specimen preparation techniques.

The torque was applied as using an actuator with capacity of 1000 kN. The torsional moment lever arm was 0.9 m and the torsional load was applied at the 2.3 m spot of the 3 m long box beam specimens. One support of the member was fixed to restrain rotation while the other support was installed with an arc bearing to allow free rotation in the transverse direction. For the prestressed member, a hydraulic jack for the introduction of the prestress force in the tendon and a load cell for the measurement of the prestress force were installed in series at the fixed end of the member as shown in Figure 8(a) and Figure 8(c). Moreover, at the hinged end, a spherical roller trust bearing with vertical capacity of 600 ton was installed in series between the anchor plate for the tendon and the end of the member as shown in Figure 8(b). This roller was installed to prevent the risk of damage of the tensioned tendons inside the member box due to twisting or change in the axial load under the rotation of the beam. Different amounts of prestress were applied as 0.0 MPa, 12.5 MPa, 25.0 MPa, and 50.0 MPa according to the test member, and the corresponding behavioral change was observed through the crack inclination and torsional strength. A loading beam was installed at the rotating support. The load was applied at the position of the loading located at a distance of 0.9 m from the centerline of the member, which corresponds to the lever arm. Loading was applied through displacement control at speed of 0.03 mm/s. The rotating end was fabricated considering the rotation radius with respect to the centerline of the member

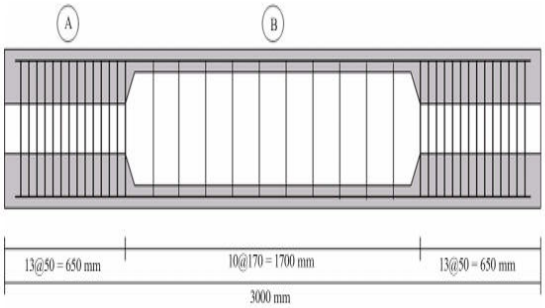


Figure: Side elevation view of UHPC box beam specimen

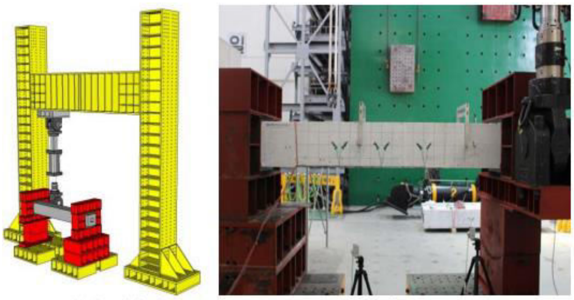

(a) Schematic drawing
(b) View of test setup

Figure: Schematic drawing of test configuration and view of test setup

Chloride Penetration Testing

Conventional, ponding-type chloride penetration tests, such as AASHTO T259, can be completed on UHPC specimens. Exposed steel fiber reinforcement may corrode during long-duration tests, but this should not impact the overall test results. When completing such a test, recognize that UHPC frequently contains un hydrated cementitious constituents. Thus, initial water penetration can lead to additional hydration and a further reduction in permeability. Also recognize that testing extracted powder samples for chloride concentration may require extra processing in order to remove included fiber pieces.

Rapid chloride penetrability testing can be completed on UHPC samples as well. Whether reinforced by steel or organic fibers, the reinforcement within the UHPC matrix is generally dispersed and discontinuous. Tests have shown that steel fiber reinforcement within UHPC does not provide a direct path to complete an electric circuit. As such, completing the ASTM C1202 test on a UHPC cylinder containing 0.5-inch (13-mm)-long steel fiber reinforcement can provide a comparative result indicative of chloride ion penetrability.

UHPC Permeability:

- Chloride Ion Diffusion Coefficient 2 x 10-11 m2/s
- for conventional concrete 2 x 10-12 m2/s
- for HPC 2 x 10-13 m2/s for UHPC

Freeze-Thaw Durability Tests

Conventional freeze-thaw test methods, such as ASTM C512, can be applied to UHPC However, the un hydrated cementitious particles frequently present in UHPC can hydrate when contacted by water. Thus, any exposure of the UHPC to liquid water can result in surface penetration of the water, localized hydration, and increased dynamic modulus. In practice, freeze-thaw testing can indicate that the UHPC performance is bolstered through exposure to these conditions, while in actuality the thaw portion of the cycle is facilitating delayed hydration and a requisite dynamic modulus increase.

Scaling and Other Durability Tests

Other conventional concrete durability test methods can generally be applied to UHPC specimens. Many of these tests can provide comparative results indicating the relative durability of UHPC in terms of conventional concrete. However, many of these tests use subjective, qualitative measures to assess performance. Since these measures have been developed for use with conventional concrete, UHPC may exceed the anticipated performance range, thus making comparisons between individual UHPCs difficult.

Sample Preparation and Extraction

The creation and/or acquisition of UHPC samples for material testing does not differ significantly from methods used for conventional concrete. Cast specimens may be fabricated into any shape desired through the use of conventional concrete molds. However, it is important to recognize that UHPC flow during casting can cause preferential fiber orientation that may impact later test results.

Extraction of specimens from larger components may be completed through methods normally used for conventional concrete. In general, UHPC and conventional concrete are both composed of similar constituent materials. Not surprisingly, conventional cutting and grinding equipment has been found to be both applicable and effective.

Figure: Tensile Behavior: Cracking

Overall, the lateral deformation is adequately small. With an assembly consisting of 6 layers of UHPC elements, the maximum lateral deformation is 0.8 mm when t = 15 mm, or less than 0.2 mm when t = 25 mm.

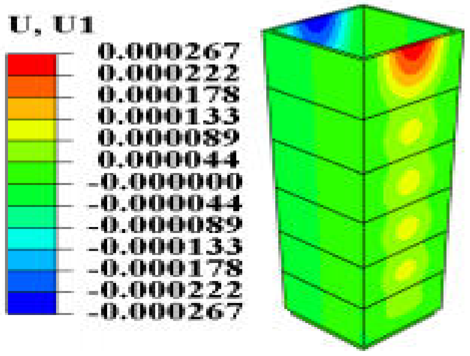
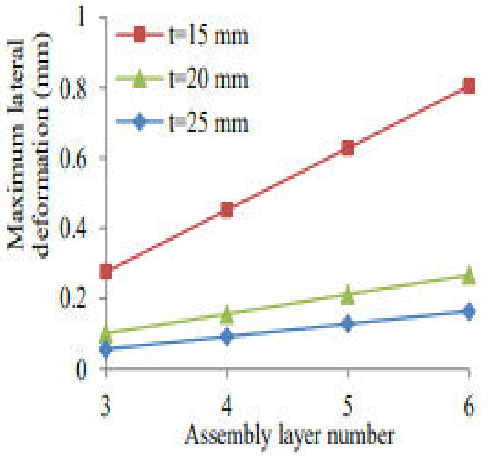


Figure: Distribution of lateral deformation



Graph: Effects of assembly layer number and wall thickness on lateral deformation.

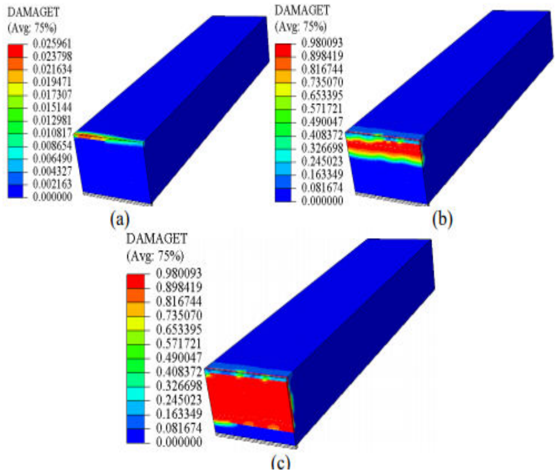


Figure: Damage evolution in CC slab at different mid-span deflections: (a) 0.27 mm, (b) 0.35 mm, and (c) 0.47 mm.

5.0 Conclusion

Whether used to facilitate accelerated construction, lengthen span ranges, or rehabilitate substandard infrastructure, UHPC can facilitate the development of unique solutions to existing challenges. As with any new material, utilization will grow as innovative applications are developed and market demand intensifies. A decade of research and deployment efforts by groups associated with the highway transportation sector has demonstrated that UHPC is a material both capable of and poised for future deployment in infrastructure-scale applications.

this study on the distinctive features of UHPC. The unique properties of UHPC have several advantages over normal-strength concrete (NSC) owing to its material ingredients and composition. The key factor in producing UHPC is to improve the micro and macro properties of its mixture constituents to ensure mechanical homogeneity and denser particle packing. UHPC yields high compressive strength (i.e. [150 MPa (22 ksi)) due to its improved internal micro- and macrostructure, leading to denser concrete. The application of thermal curing further densifies UHPC, which results in higher compressive strength properties. The typical heat treatment applied for UHPC is 90–400 C (194–752 F) for 2–6 days. The specimen size significantly affects the measured compressive strength of UHPC. Smaller size specimens can be used if the test machine capacity is limited. Furthermore, it was observed that the loading rate did not significantly affect the measured compressive strength of UHPC. The compressive stress–strain response of UHPC shows a linear elastic behavior up to 80–90 % of the maximum stress value

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