Full Paper Transactions, SMiRT 28
Toronto, Canada, August 10-15, 2025

POTENTIAL APPLICATION OF HIGH STRENGTH AND ULTRA HIGH PERFORMANCE CONCRETE MATERIALS FOR NUCLEAR SAFETY-RELATED STRUCTURES

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ABSTRACT

Extended operational and service lifespans are expected to enhance the durability and safety performance of nuclear facilities. The use of High-Performance Concrete (HPC) and Ultra High-Performance Concrete (UHPC) materials with high strength is of great interest in chemical infiltration, leakage, missile impact, blast, shielding and high temperatures. A review conducted in this paper indicates that HPC exceeding 60 MPa will often cost double or even triple the price of Regular Strength Concrete (RSC) due to special ingredients such as silica fume, HSF cement, and superplasticizer. The cost of raw UHPC materials ranges from 15~22 times that of RSC; however, designed UHPC beams are approximately 2.5~3.4 times the price of RSC beams, and UHPC structural volumes are 30~57% lower than RSC structural volumes. As well, HPC and UHPC structures have significantly longer service lives before required repairs. Thus, considering systematic material selection, structural design, construction, aging management, structural repair, durability, and safety, the overall cost of using HPC/UHPC structures would be acceptable within the nuclear industry. Interestingly, compared to RSC, the life-cycle carbon emissions of UHPC beams are approximately 38.5%~51.0% lower, which highlights that the application of HPC/UHPC is an efficient way to achieve the net-zero emission goal. Therefore, the overall improved performance of HPC/UHPC, in conjunction with code/standard developments, will enable their potential application to the structures such as containment structures, water tanks, spent fuel storages, and calandria vault, as well as to repairing existing structures in nuclear power plants.

INTRODUCTION

The operating lifetimes of old-generation nuclear facilities generally range from 20 to 40 years. The operation and maintenance shall follow CSA N287.7 (2022) for periodic examination and systematic testing to maintain structural integrity and leak tightness of concrete containment structures. Meanwhile, CSA N287.8 (2020) shall be followed for aging management related to the owners, operators, designers, manufacturers, fabricators, and constructors. Applications of High Strength Concrete (HSC)/HPC and UHPC may be one of the ways to extend the operating life and reduce the maintenance costs of nuclear facilities.

HSC can be obtained by introducing mineral admixtures with pozzolanic characteristics, which, in turn, may compromise durability. To overcome this drawback, HPC with higher strength and durability than RSC is a better option. Improved HPC properties can be achieved by modifying the microstructure with the use of chemical and mineral admixtures, appropriate grading of solid materials starting from coarse to the finest aggregates, and low water binder ratio. The three factors, including reaction mechanism among ingredients, physical process, and curing, are considered for the desired modification. Consideration can also be given to self-compacting concrete (SCC), which is a HPC mix with good performance in self-compaction or consolidation under self-weight action. SSC can fill all spaces within the formwork; pass through the reinforcement and embedment; and is resistant to segregation. HPC and UHPC enhance the safe operation of nuclear facilities by providing superior durability, and hence, prevent the release of radioactive materials. This can also improve aging management of NPP structures over their intended lifespan. Resistance to severe accidents, such as missile impact and blast loads, are other factors to consider when using HPC/UHPC in nuclear facilities.

DESIGN AND CHALLENGES

Design Code Requirements for HPC and UHPC

In CSA A23.1 (2024), HPC is defined to have specified a compressive strength of at least 70 MPa at a specified age not exceeding 91 days. However, according to ACI 363R-10 (2010), HSC is defined as a concrete with a specified compressive strength of 55 MPa or higher at a given age of 28 days. Annex U of CSA A23.1 (2024) defines UHPC as a cementitious composite material with enhanced strength, durability, and ductility compared to HPC. UHPC containing steel fibres for post-cracking ductility has a specified compressive strength of at least 120 MPa at 28 days.

One specific requirement for nuclear structures is the control of concrete heat of hydration during construction. According to CSA N287.4:19 (2019), the core (centre) temperature of concrete shall not exceed 50°C during prequalification tests, and temperature difference between the core and the surface shall not exceed 20°C. These requirements must be considered in the design and application of HPC and UHPC in nuclear structures. To address this issue, corrugated ducts for post-tensioning can be used as cooling ducts by blowing air, with the airflow velocity determined to maintain the required temperature. With proper construction practices and control of quality, thermal cracking can be mitigated to satisfy design requirements. As there are no explicit design requirements or limitations in the CSA N287 series and N291 on the use of HPC and UHPC, it is recommended that code developers review and address their application.

Challenges Faced in Concrete Structures

Designers face crucial challenges on concrete cracking, crazing and other surface-level defects from construction to the end of service life of a structure. A well-known example is the extensive damage of the horizontal concrete modules located on the site of Three Mile Island Unit 2 due to cracking from freeze-thaw cycles (USNRC, 2024). Two samples from the damaged horizontal storage modules are shown in Figure 1.

Figure 1. Concrete cracking at northwest (left) and northeast (right) corners (USNRC, 2024).

Associated with concrete cracking, corrosion of steel bars occurs in concrete structures due to penetration of water and oxygen into concrete through cracks. General corrosion is a relatively uniform reduction of rebar cross-sectional area, while pitting corrosion is localized. Particularly in prestressed containment structures, corrosion in localized areas of the steel cables/tendons would cause losses of prestressing forces. Figure 2 shows examples of steel reinforcement corrosion in general structures.

Figure 2. Corrosion of sea water structure (left) and bridge structure (right) (Naus, 2007).

The low porosity, high packing density and minimal permeability of HPC or UHPC, compared to that of RSC, can help mitigate the issues of concrete cracking, aging and degradation. Moreover, the addition of steel fibres can enhance tensile and flexural strengths and increase ductility. However, HPC and UHPC applications still faces challenges from production costs, heat of hydration, and mixer failures in large-scale operations. Technical challenges may also arise from different chemical compositions of supplementary cementitious materials such as fly ash, rice husk ash and metakaolin used to achieve better mechanical properties. Despite the challenges, it is expected that HPC and UHPC are potentially beneficial for concrete long-term performance through improved mechanical strength, durability, multi-functionality, nanotechnology, environmental impact, life-cycle cost, and CO_2 emissions.

HPC/UHPC APPLICATIONS

A comprehensive study on the applications of UHPC in nuclear industry has recently been performed (Androuët, 2024). Such applications included prestressed girders at the France Cattenom NPP, which were built during the 1980s to enhance the durability against significant sulphates and chlorides exposure, freeze-thaw cycles. It is demonstrated that the use of UHPC in reactor buildings may result in improved overall structural performance and integrity, with better seismic resistance of the shear walls, as well as reduced construction duration. UHPC used in radioactive waste containers and spent fuel storage casks can decrease thermal stresses, reduce shield damage during transportation, and reduce steel rebar corrosion due to UHPC high electrical resistivity, low diffusion coefficient and low permeability.

HPC for Nuclear Containment Structures

A research project has been conducted to assess the leak tightness and durability of nuclear containment structures, utilizing HPC/HSC with a maximum compressive strength of 72 MPa, a split tensile strength of 4.52 MPa and a flexural strength of 6.7 MPa in several trials (Chakrabortyet al., 2001). Based on investigations on the effect of silica fume (SF) on concrete mixtures, SF of 7.5% and above can achieve reasonably low absorption value and drying shrinkage; 10% and 12.5% are acceptable for adequate workability, strength, shrinkage and absorption; fumes greater than 12.5% and 15% would lead to more strength-loss than the other mixtures. Thus, from the test results and analysis, HPC mixtures with SF content between 7.5% and 10% are recommended for nuclear containment structures if heat of hydration can be controlled.

It is expected for HPC containment structures to have salient features of high cracking resistance and very high durability, moderate compressive but high tensile strength, low permeability and shrinkage/creep, good missile impact resistance, low heat of hydration, and good workability. A strategy for developing such HPC mix was presented by Basu and Mittal (1999) in three stages (trial mix, detail trials and field trials) to achieve the optimized mix proportions. The target HPC compressive and tensile strengths were 69 MPa and 4.37 MPa, respectively, in stage 1. In stage 2, the averaged cube compressive strength of 35 specimens from testing at 28 days was 75.9 MPa, and the corresponding averaged split tensile strength was 4.36 MPa. In stage 3 of field trails during the dome construction, the averaged in-situ compressive and tensile strengths from the samples cured under field conditions were 74 MPa and 4.34 MPa, respectively.

In France, HPC with 28-day compressive strength of about 70 MPa has been used in the construction of France Civaux-2 NPP with cement (266 kg/m^3), water (161 litre/m^3); and high workability achieved by using SF and calcareous fillers. Laboratory testing was conducted on a full-scale containment element that demonstrated that using HPC reduced the temperature rise by 25% in 1.2 m thick concrete, resulted in nearly no cracking, and achieved approximately a tenfold reduction of air leakage. The project demonstrated that HPC can be applied for crack-free concrete structures (Larrard et.al., 1990).

In India, HPC mixes were applied in generation 2 and 3 NPPs constructions with two types of chemical admixtures, plasticizer/super plasticizer and viscosity modifying agents. HPC was employed for the containment dome of Kaiga Unit-1. SF-based HPC was used to achieve a compressive strength of 60 MPa (M60 HPC) and a split tensile strength of 3.87 MPa, and this mix was established by conducting a series of trial mixes for the Kaiga-1 dome. To meet low heat of hydration, trials were conducted on M60 HPC with reduced cement quantity of 425 kg/m^3 for the containment structure of a different NPP project (Paghavan and Niranjana, 2005). The inner HPC containment (IC) under construction is shown in Figure 3(a), and the completed reactor building is shown in Figure 3(b).

(a) IC under Construction

(b) Completed Containment

Figure 3. M60 HPC applied for nuclear containment structure in India (Paghavan and Niranjana, 2005).

Paghavan and Niranjana (2005) presented detailed information on temperature control of HPC during the construction of a reactor building, including construction techniques for prestressing, special formwork systems, use of automated climbing formwork system, increase of height of concrete pours after mock-ups, and use of threaded couplers for rebars. The reactor building base slab and the containment were designed using M60 HPC for higher structural strengths and better functional performance. A peripheral curing pipe with perforations was installed to facilitate curing of the containment wall. To control temperature and contain cracking due to temperature differentials between the concrete and the outside atmosphere, concrete was placed at temperatures below about 19°C using flaked ice and chilled water. Mixers were provided with polyurethane foam insulation to reduce the temperature losses during transit. In addition, pipes carrying concrete were also insulated and, during concreting, these pipelines were covered with wet burlap to avoid increase in temperature of the concrete. Pre-cooling of the aggregates, choosing cooler periods of the day for concreting, and shading the materials, etc. are recommended in summer weather conditions. However, it is evident that these measures to control temperature increase the construction cost of HPC structures.

HPC for Water Tanks

From experiments, the water tightness was investigated with on-site observations and measurements using RSC (C25/30) and HPC (C70/80) with steel fibres in water tanks (Al-Obaidi et al., 2021). The three tanks depicted in Figure 4 have the following layout: a cast-in-place RSC tank with 100 mm thick walls, a cast-in-place HPC tank with 60 mm thick walls, and a precast HPC tank with 30 mm thick wall panels supported by cast-in-place HPC columns having section of 200×200 mm^2. A particular focus was on the use of steel-fibre reinforcement in HPC to enhance tank durability. Site testing was carried out for the three tanks after one year post construction and a pilot test was conducted based on the observed cracking. The EN1992-1 1 methodology was applied to evaluate the shrinkage crack widths at the top areas of RSC and UHPC walls. The calculated crack widths were compared to those measured in the tanks. The results demonstrated that HPC has better performance in crack-width limits and tightness, with the ability to heal and seal small cracks after being filled with geothermal water. Using precast HPC panels causes the steel fibres to be more evenly distributed, in addition to reducing wall thicknesses and satisfying serviceability design requirements. HPC tanks were shown to resist a hydrostatic pressure 1.5 times higher than the service load level before collapse, while having nearly the same safety factor as RSC tanks.

Figure 4. Filled water tanks and monitored cracks with sealing in a pilot testing.

UHPC for Containment Structures

A parametric study has been performed for the application of UHPC with steel fibres to relieve rebar requirements for prestressed containment structures (Kang et al., 2022). A specified UHPC compressive strength of 172.4 MPa was determined based on PRC-239-18 with adequate concrete durability, tensile ductility and toughness properties. A design considering prestressing loads was performed for the actual force-bending moment interaction. Due to the UHPC compressive strength, the results indicated that the required longitudinal rebar decreases as the level of prestressing increases for loading associated with serviceability, tangential shear and beyond design-basis accidents.

UHPC for Buildings and Bridges

From Kravanja et al. (2024), UHPC materials have been applied in the France Marseille building, the foundation and roof in Paris, and the roof in Switzerland. In 1997, UHPC was used for the first time in the construction of a pedestrian bridge in Quebec, Canada. In 2000, the UHPC girder bridge “Mars Hill Bridge” was built in Iowa, United States of America (USA). In 2013, the United States Federal Highway Administration (FHWA) published a report stating that 55 bridges were built with UHPC in the USA and Canada, 22 in Europe, and 27 in Asia and Australia. Moreover, it is worth noting that UHPC has been actively used in the repair of bridge beams, bridge decks, bridge piles and wind turbine towers. For example, UHPC has been applied to the redecking of the Pulaski Skyway to connect the precast concrete panels (McDonagh & Foden, 2019). UHPC was used for the narrow transverse connections between adjacent precast deck panels (Figure 5), the deck panel shear connections and haunches to steel framing, and the longitudinal connection between the northbound deck panels and the southbound deck panels under the median barrier. The construction problems include placement issues related to pumping, fibre segregation derived from low ambient temperature, cracking due to early age loading, and under-filled pockets and joints due to leaking or blown-out forms**.** The provided solutions serve as a practical resource for engineers and construction inspectors to use UHPC for structural connections, which would benefit engineering to avoid similar problems.

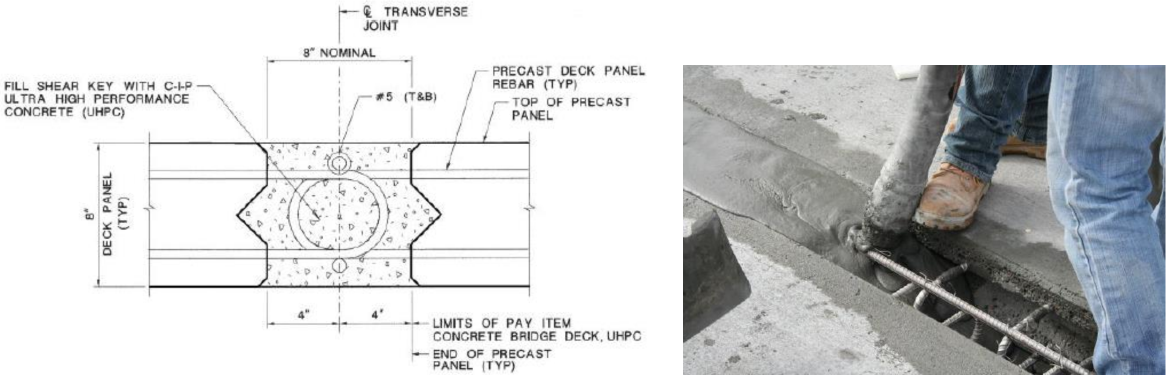

Figure 5. UHPC applied for panel connections: joint (left), under construction (right).

COST ESTIMATES

Prices of HPC/HSC, based on the CSA-A23.1 strength mixes, are listed in Table 1, along with the CSA class and w/c ratio from Dufferin Concrete (2025). For concrete with strength of 50 MPa, Hydraulic Portland/Silica Fume (HSF) cement and superplasticizer are included. For concrete with strength not less than 65 MPa, in addition to higher HSF cement and superplasticizer, temperature control cost is included.

Table 1 CSA Specification Mixes CSA-A23.1 (Dufferin Concrete, 2025).

Strength Mixes	CSA Class	w/c ratio	Price CAD$/$m^3$	Price Increase (%)
25 MPa	F-2, C-4	0.55	274	-
30 MPa	F-1, C-3, S-3	0.5	283	3.28
35 MPa	C-1	0.4	290	2.47
40 MPa	C-1	0.4	298	2.76
50 MPa	CXL	0.4	395	32.55
65 MPa	-	-	on request	-

It is evident from Table 1 that the price increase from 25 MPa to 30 MPa is 3.28%, the price increase from 30 MPa to 35 MPa is 2.47%, the price increase from 30 MPa to 40 MPa is 5.3%, and the price from 40 MPa to 50 MPa is significantly increased by 32.55%. This price increase tendency indicates that HPC exceeding 65 MPa will be significantly more expensive than regular concrete. The costs are often double or even triple the price per cubic metre due to the special ingredients like SF, HSF cement, and superplasticizer required to achieve such high strength/performance, along with stricter quality control required during production.

In the USA market, around 2019 (Tadros et al., 2019), open-recipe UHPC cost between \$518 and \$637/m^3; UHPC with domestically sourced fibres cost between \$664 and \$783/m^3; and UHPC with lower cost mixture proportions cost between \$549 and \$732/m^3. However, pre-bagged UHPC has sold for over \$1829/m^3, and sometimes the materials used cost nearly \$2743/m^3. These variable market prices are comparable with the UHPC applied in the research as performed by Fan et al. (2024) for the designed beam sections with steel reinforcement ratios shown in Figure 6(a).

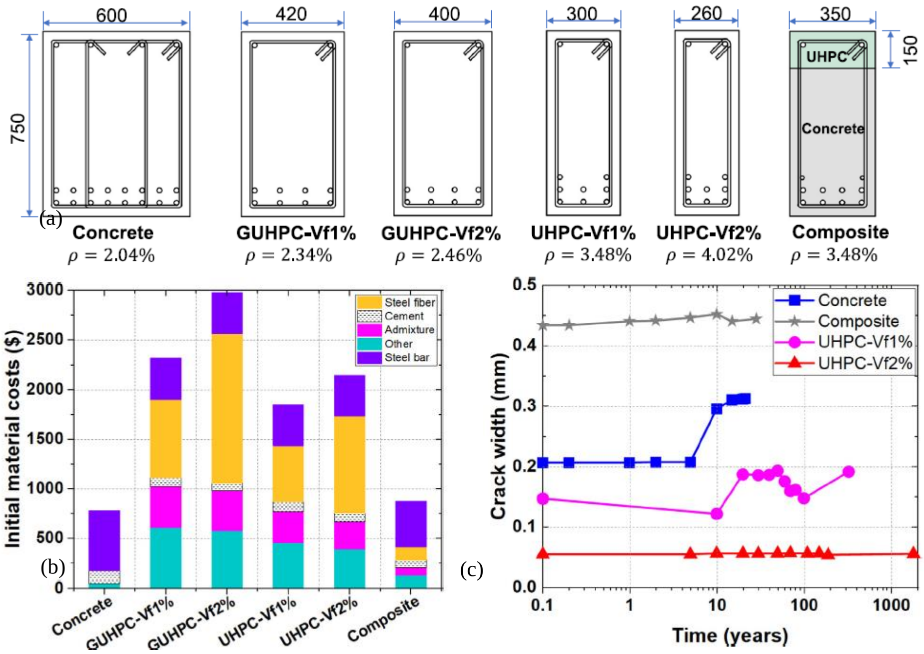

Figure 6. (a) RSC and UHPC sections, (b) costs and (c) cracking performance.

RSC, low cement green ultra-high-performance concrete (GUHPC), low cement UHPC, and composite design were used for beams, where Vf1% means steel fibre is 1% of the gross concrete volume. Table 2 lists the used cement contents, and other mixture proportions can be found in Fan et al., 2024. From Table 2, RSC has a compressive strength of 41.9 MPa, GUHPC and UHPC have compressive strengths of 137 MPa and 185 MPa, respectively. The price of 1%- and 2%-fibre UHPC is about 15 and 22 times the price of RSC, respectively. As shown in Figure 6(b), 1%- and 2%-fibre UHPC beams are 3.4 times and 2.55 times the price of RSC beams, respectively. Thus, for design and construction, the overall price of UHPC is between 2.4 to 3.8 times the price of RSC. When using composite RSC and UHPC, the cost is only increased by approximately 10%. However, it is noted that the structural costs in Table 2 are the costs for design, disregarding life-cycle maintenance.

Hossain and Chang (2023) studied bridge components affected by loads and environmental stressors. They noted that lack of effective maintenance and rehabilitation strategies often led to quicker deterioration or even collapse. However, the application of UHPC can significantly reduce the total life cycle cost. Analysis results showed that 40% of spalling damage is expected for RSC after 30 years, but the same amount of spalling damage is projected for UHPC after 80 years. Fan et al. (2024) demonstrated that, if the load capacities were maintained at the same level after corrosion, using UHPC-Vf1% and UHPC-Vf2% can achieve 15.4 and 84.9 times longer service life span, respectively, compared to the RSC beam, as shown in Table 2. Considering the coupled sustained loading and environmental conditioning over service life, the cracking development for the RSC, RSC+UHPC, UHPCVf1%, and UHPCVf2% beams is shown in Figure 6(c). For the RSC beam, the crack width was 0.43 mm until the life of 30 years; for RSC+UHPC beam, the crack width was 0.21 mm until the life of about 5 years and then increased to 0.31 mm after 10 years. In the case of low-fibre (1%), the crack width was approximately 0.15 mm prior to 10 years of service, but slightly increased to about 0.2 mm until 300 years. However, when the steel fibre volume is increased to 2%, the cracking width remains relatively constant at 0.06 mm up to 1000 years. Therefore, by adjusting the usage of steel fibres, concrete cracking can be congealed to a desired level. As evident in Table 2, raw UHPC materials cost 22 to 25 times the RSC price; however, the UHPC structures cost only 3.4 to 3.8 times the price of RSC structures. To achieve the same structural integrity, compared to the RSC volume, the volumes are reduced by 30%, 33%, 50%, 57%, and 42% for GUHPC1, GUHPC2, UHPC1, UHPC2, and composite beams, respectively. Therefore, using UHPC for structures with longer service life could save significant construction time and cost.

Table 2. Comparison of design parameters and costs between RSC and UHPC (Fan et al., 2024).

Item	RSC	GUHPC1	GUHPC2	UHPC1	UHPC2	Compos
Cement (kg/m^3)	424	430	430	712	712	-
Tensile strength (MPa)	3.1	4.3	6.6	7	10.5	-
Compressive strength (MPa)	41.9	136.8	138.0	185.3	185.8	-
Elastic modulus (GPa)	31.2	43.7	44.6	53.5	53.5	-
Service life span (years)	21	322.5	1783	322.5	1783	28
Service life span ratio (times)	1	15.4	84.9	15.4	84.9	1.3
Raw material cost (USD/m^3)	58	900	1275	925	1326	96
Material price ratio (times)	1	15.5	22.0	15.9	22.9	1.7
Structural cost (USD/m^3)	784	2320	2981	1852	2148	880
Structural price ratio (times)	1	3.0	3.8	2.4	2.7	1.1
Structural volume (cm^3)	450	315	300	225	195	262.5
Volume change (%)	0	-30	-33	-50	-57	-42

LIFE-CYCLE EMISSION OF CO$_2$

Using the Green-Concrete LCA software, Fan et al. (2024) performed life-cycle analyses to estimate the emission of CO$_2$ by assuming the raw materials to be transported to the concrete plant via trucks. The initial carbon emissions predicted for the concrete, GUHPC-Vf1%, GUHPC-Vf2%, UHPC-Vf1%, UHPC-Vf2%, and composite beams were 2312 kg, 2239 kg, 2516 kg, 2134 kg, 2172 kg, and 1720 kg, respectively. As shown in the left in Figure 7, compared to the emission of RSC beam, the CO$_2$ emission of GUHPC-Vf2% beam increases by 9%, the emissions for other UHSC beams decrease from 3% to 8%, and the emission for the RSC+UHPC beam decreases by 26%. Another analysis was carried out for the life-cycle carbon emission which also considered maintenance and repairs in a life span of 75 years. It is assumed that there were no repairs prior to the service life span in Table 2. The preventive interval from minor maintenance to major repair was assumed to be 10 years for RSC, and intervals for minor maintenance were 20 and 30 years for UHPC-Vf1% and UHPC-Vf2%, respectively, due to different crack widths. The analyses results are shown in the right in Figure 7, where the total carbon emissions of the RSC, UHPC-Vf1%, UHPC-Vf2%, and RSC+UHPC beams are 5319 kg, 2774 kg, 2606 kg, and 3268 kg, respectively. This indicates that, compared to the RSC emission, the life-cycle carbon emissions of the UHPC-Vf1%, UHPC-Vf2%, and RSC+UHPC beams are 47.8%, 51.0%, and 38.5% lower, respectively.

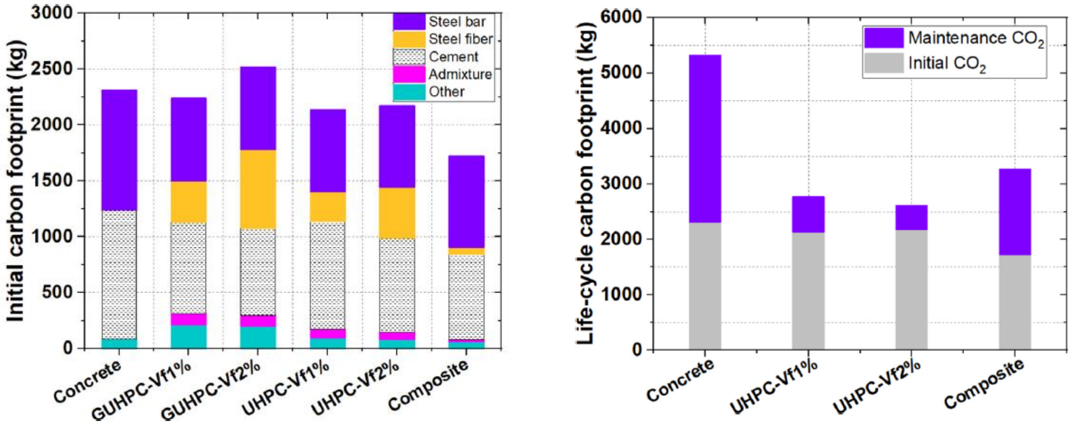

Figure 7. Initial (left) and life-cycle (right) CO_2 emissions.

SUMMARY

The advantages and disadvantages of HSC and UHPC materials are evaluated in this paper considering the design requirements and practical applications. It is observed that HPC exceeding 60 MPa may often cost double or even triple the price of RSC due to the special ingredients like silica fume, HSF cement, and superplasticizer. The price of UHPC is approximately 15~22 times the price of RSC; however, when the cost of steel rebars is considered, the cost of UHPC beams ranges from 2.55~3.4 times that of RSC beams. Thus, based on structural design and construction, the overall price of UHPC structures should be about four times the price of RSC structures, which is far less than the price of UHPC alone. Moreover, UHPC with higher volume of steel fibres may achieve over eighty times longer service life span. Therefore, the application of HPC and UHPC can significantly reduce the total life cycle cost. The cost also includes the measures to control temperature due to heat of hydration. In comparison to RSC emissions, the life-cycle carbon emissions of the UHPC beams are approximately 38.5%~51.0% lower, which is very attractive to achieve carbon-zero emission. Despite the lack of applicable current codes and standards provisions on the design of HSC and UHPC structures in nuclear industry, HPC and UHPC are promising materials for nuclear safety-related structures. Due to their strong performance in chemical seepage, leakage, and impact loading, they are ideal choices for designing containment structures, water tanks, spent fuel storages, and repairing existing structures. However, it is worthwhile to conduct further research to explore potential applications with code/standard development and to find viable ways to meet design requirements.

REFERENCES

ACI 363R-10, (2010). High-Strength Concrete, American Concrete Institute Committee, USA.

Al-Obaidi, S. et al. (2021). Innovative Design Concept of Cooling Water Tanks/Basins in Geothermal Power Plants Using Ultra-High-Performance Fiber-Reinforced Concrete with Enhanced Durability. *Sustainability*, 13, 9826. https://doi.org/10.3390/su13179826.

Androuët, C. (2024). “Benefits of Ultra-High-Performance Concrete (UHPC) in the Nuclear Industry,” Division X, Transactions of the SMiRT 27, Yokohama, Japan.

ASTM, (2022). Standard Specification for Portland Cement, C150/C150M − 22.

Basu, P.C. and Mittal, A. (1999). “High Performance Concrete for Indian Nuclear Power Plants”. SMiRT-15, Seoul, Korea.

Basu, P. C. et al., (2013). Nuclear Power Plant Concrete Structures, Transactions, SMiRT-22, San Francisco, California, USA.

Chakraborty, A. K. et al., (2001). “High-performance concrete for containment structures”, Transactions, SMiRT 16, Washington DC.

CSA A23.3:24, (2024). Design of Concrete Structures, Ontario, Canada.

CSA A23.1:24/A23.2:24, (2024). Concrete materials and methods of concrete construction/Test methods and standard practices for concrete, Ontario, Canada.

CSA N287.3:25, (2025). Design Requirements for Concrete Containment Structures for Nuclear Plants, Ontario, Canada.

CSA N287.4:19, (2019). Construction, fabrication, and installation requirements for concrete containment structures for nuclear power plants, Ontario, Canada.

CSA N287.7-17, (2022) In-Service Examination and Testing Requirements for Concrete Containment Structures for Nuclear Power Plants, Includes Errata (2018) and Errata (2022), Ontario, Canada.

CSA N287.8:15. (2020). Aging management for concrete containment structures for nuclear power plants, Ontario, Canada.

CSA N291:24, (2024). Requirements for nuclear safety-related structures, Mississauga, Ontario, Canada.

Dufferin Concrete. (2025). 2025 Price List -Effective January 1, 2025, https://dufferinconcrete.ca/app/uploads/2024/11/2025DufferinConcrete-FINAL.pdf

Fan J. et al. (2024). “Sustainable reinforced concrete design: The role of ultra-high performance concrete (UHPC) in life-cycle structural performance and environmental impacts.” Engineering Structures, 316, 118585.

Hossain, A. & Chang, C. M., (2023) “Life-Cycle Cost Analysis of Ultra High-Performance Concrete (UHPC) in Retrofitting Applications”, International Interactive Symposium on Ultra-High Performance Concrete 3(1): 82. doi: https://doi.org/10.21838/uhpc.16694.

Kang T. et al. (2022). “A Novel UHPC Based Containment Design Methodology", Transactions, SMiRT-26, Berlin/Potsdam, Germany.

Kravanja G., Mumtaz A.R., and Kravanja S. (2024). A Comprehensive Review of the Advances, Manufacturing, Properties, Innovations, Environmental Impact and Applications of Ultra-High-Performance Concrete (UHPC). Buildings 2024, 14, 382. https://doi.org/10.3390/buildings14020382.

Larrard, F., et.al. (1990). High-Performance Concrete for a Nuclear Containment, ACI Special Publication, Volume: 121, Pages: 549-576.

McDonagh, M. D. & Foden, A. J., (2019). “UHPC Joint Fill Construction Problems and Solutions on the Pulaski Skyway”, International Interactive Symposium on Ultra-High Performance Concrete 2(1). doi: https://doi.org/10.21838/uhpc.9629.

Naus, D.J. (2007). NUREG/CR-6927, Primer on Durability of Nuclear Power Plant Reinforced Concrete Structures - A Review of Pertinent Factors, Oak Ridge National Laboratory for U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001.

Paghavan, N. and Niranjana, (2005). "Construction Aspects of Containment Structures of a Typical Large Atomic Power Project". SMiRT 18, Beijing, China.

Tadros M.K. et al. (2019). Ultra-High-Performance Concrete- a Game Changer, Structure Magazine.

USNRC (2022). Status of Subsequent License Renewal Applications, https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html.

USNRC. (2024). "Backgrounder on the Three Mile Island Accident," https://www.nrc.gov/reading-rm/doc-collections/fact-sheets/3mile-isle.html.