The application of high performance in our lives

Li Ma

No.333 Bailongjiang Road,
Chenghua District, Chengdu, Sichuan Province

Abstract

This paper provides an overview of high-performance concrete (HPC), including its definition, behavior, development, design criteria, innovative structural application examples, prospects, challenges, and limitations. HPC is a special type of concrete with higher strength, durability, and other properties than conventional concrete. Several factors, such as shrinkage properties, thermal properties, flexibility, and durability, influence HPC behavior. Design criteria for HPC include High strength design, water-cement ratio, temperature resistance, and other design properties. Over the years, HPC has evolved to meet the growing demand for high-performance structures, such as using recycled aggregates in HPC, developing self-compacting concrete (SCC), and developing ultra-high performance concrete (UHPC). Innovative structural applications of HPC include the application of HPC in precast components, high-rise building structures, etc. The future of HPC is promising as it is continuously developed and optimized for various applications. However, there are still some challenges and limitations to overcome, such as high production costs, maintenance work requirements, difficulty mixing, and so on. This paper provides valuable insights for engineers, architects, and researchers interested in designing and constructing HPC structures.

Keywords: Corrosion resistance; High-performance concrete; High-performance durability

1. Introduction

Nowadays, the construction industry is developing rapidly, most buildings are still using traditional concrete to build buildings, but we also found that traditional concrete also has some disadvantages, such as its self-weight being very large, which will lead to an increase in foundation treatment costs, and it is for other new concrete, its tensile strength is also lower, crack resistance is also poor, at the same time it will also appear because of the environment and other reasons So I would like to introduce a newer construction material, High-Performance Concrete (HPC)

High-Performance Concrete (HPC) is a class of advanced concrete materials that exhibit superior performance compared to conventional concrete. HPC materials typically have high compressive strength, low permeability, excellent durability, and enhanced workability. The development of HPC materials is driven by the need to improve the performance and sustainability of concrete structures in various applications. High-Performance Concrete (HPC) has been widely adopted in the construction industry in Hong Kong. Its superior properties, such as high compressive strength, excellent durability, and low permeability, make it an ideal material for various applications in concrete structures.

2.1 Definition of the high-performance concrete

High-performance concrete can be defined as concrete with significant strength and durability beyond other concrete materials. And high-performance concrete has a cheaper price and higher strength compared to high-strength concrete of the same grade, saving 400 million yuan a year just in material savings, with the high strength and economy of HPC, allowing it to be developed in different construction and other engineering construction fields. Important characteristics of high-performance concretes include their high value in workability, strength, modulus of physical properties, density, dimensional stability, resistance to chemical erosion, and low permeability. There are generally three main categories of high-performance concrete whose properties are conducive to the construction process, resulting in enhanced mechanical properties, improved durability, and long-term performance. To classify high-performance concrete, the U.S. Concrete Commission lists six main criteria: ease of laying, long-term mechanical properties, early strength, toughness, and life in harsh environments. The unique properties of high-performance concrete depend on the properties of ordinary concrete available at a particular time or place. According to (C.K.Y. Leung, 2001), high-performance concrete in developed countries or areas such as Hong Kong normally refers to concrete that possesses 28-day compressive strength while greater than 70-80 MPa (ranging from 60 to 120 MPa) while its durability factor, i.e., the percentage of original modulus retained after 300 cycles must be above 80% and that its water content ration has to be below 0.35.[1] This concrete is typically made with premium quality aggregates, mixed with high cement content (450 - 550 km^{-3}) and a high dose of silica fume (5-15% of water content) and superplasticizer (5-15 lm^{-3}). To conclude, high-performance concrete's key elements are a low water-to-cement ratio, a large quantity of silica fume, small aggregates, fine sand, a rich amount of superplasticizers, serious heat treatment, and applying pressure after mixing during the curing stage.[2]

2.2 The different properties of the high-performance concrete

High-performance concrete has many excellent properties; permeability is an important factor determining the rate at which moisture enters the cement. It is mostly affected by the water-to-cement ratio(W/C). Moisture often contains different kinds of chemicals, expands and contracts in different temperatures, or even v enhances the corrosion of the steel structure, which may lower the durability of the concrete. Hence a lower W/C ratio is preferred to increase the strength and durability of the concrete, as it will be less possible for cracks to form. For HPC, the small pore structure and aggregate can effectively block the flow path and significantly reduce the porous area in a cross-section of the structure [3]. Besides, chloride permeability is also considered in HPC as chloride is one of the possible sources of corrosion. And the high strength for it one of the most important properties of HPC is having a relatively high strength compared to conventional concrete, including both early and long-term strength. According to the ACI code, concrete with a compressive strength greater than 41 MPa can be considered high-strength concrete, while the compressive strength for HPC is normally within 50-100 MPa [4]. With property, the whole structure can either withstand a higher load with the same amount of concrete used or fewer materials need to be used so that the structure's cost and weight can be reduced. The high strength of HPC can also extend the structure's service life longer than that of conventional concrete. The effect of temperature change should also be considered during concrete design, especially for structures in areas that have a great temperature difference. Freezing will likely happen with the low temperature in winter, causing water in unprotected cement pastes to change its form into ice and expand, leading to an increase in internal tensile stress, and cracking is likely to occur. HPC, normally has a lower W/C ratio and less moisture in the concrete. Hence HPC will have a higher freezing resistance compared with normal concrete.

HPC should have good resistance against carbonation. Carbonation is a possible source causing shrinkage as the hydration product of cement may react with CO2 in the air. It is often considered that the carbonation rate of cement is related to the W/C rate [5]. The low W/C rate of HPC can lead to a higher resistance to carbonation and less likelihood for carbonation shrinkage to occur. Hence the lifespan of the concrete structure can be extended. And concrete needs to provide great resistance against chemical attacks. Common chemical attacks include acid corrosion, sulfate attack, and chloride corrosion, especially chloride can cause corrosion of the reinforcing steel and damage to reinforced concrete structures [6]. HPC, with very low permeability and water-to-cement ratio, can effectively avoid these situations by having fewer chemicals entering the structure.

3. The relationship between high-performance concrete and self-compacting concrete

There are also innovative structural applications using high-performance concrete, firstly, an introduction to self-compacting concrete. Self-compacting concrete (SCC) is a type of high-performance concrete (HPC) that can flow and fill the formwork without the need for external vibration, making it a highly versatile material for various construction applications. This is achieved using a carefully designed mix with a high proportion of fine particles and a low water-to-cementitious ratio. In recent years, SCC has been the focus of much research and development. The composition of SCC typically consists of a combination of Portland cement, aggregates, water, and chemical admixtures. Using chemical admixtures is one of the key factors distinguishing SCC from conventional concrete. These admixtures include superplasticizers, viscosity-modifying agents, and air-entraining agents. Superplasticizers reduce the water content of the concrete mixture while maintaining workability. This results in a higher density of particles and better packing of aggregates, increasing the strength and durability of the concrete. Viscosity-modifying agents are used to control the rheology of the concrete, which affects its flowability and stability.

Air-entraining agents are used to create small bubbles in the concrete, which increase its resistance to freeze-thaw cycles. The choice of aggregates also plays a crucial role in the composition of SCC. The aggregates should be well-graded, with various sizes promoting good particle packing. Using fine aggregates, such as silica fumes, can also improve the strength and durability of SCC. The water-to-cementitious materials ratio (w/cm) is another important factor that affects the composition of SCC [7]. A low w/cm ratio is desirable to achieve high strength and durability properties. The principle of preparing self-compacting concrete is to reduce the yield stress of concrete enough to overcome the shear stress generated by its weight through the selection and matching of admixtures, cementing materials, coarse and fine aggregates, and carefully mixed ratio design so that the fluidity of concrete can be improved. At the same time, it has sufficient plastic viscosity to suspend the aggregate in the cement slurry without segregation and bleeding problems. It can flow freely and fill the space in the formwork to form a dense and uniform gelled structure.

4. Innovative applications of high-performance concrete

There is also now an ultra-high performance concrete is the latest development of high-performance concrete; it has superior properties compared to normal strength and high-performance concrete and is becoming more and more popular nowadays. UHPC is generally classified as Portland cement composite material. It has a water-cement ratio lower than 0.28, a high proportion of internal steel fiber reinforcement which is discontinuous, and a good gradation of granular constituents. The minimum compressive strength is 124 MPa, while the minimum tensile strength is 5 MPa. The minimum localization strain is 0.0025 to perform the ability to sustain the effective cracking strength. [8] UHPC is known as concrete having extremely low permeability, sustained tensile resistance, and, most importantly, a high compressive strength compared to conventional concrete. Usually, the compressive strength of UHPC is around 150 to 200 MPa, which is almost the same as steel's. Also, it has high stiffness and is around 1.5 to 2 times higher than conventional concrete. The post-cracking tensile resistance of UHPC is larger than 5 MPa [8], which makes UHPC a better tensile and durability than other concrete with fiber reinforced. The reason for UHPC having the above strengths is because of its dense microstructure. UHPC essentially contains no capillary pores. Therefore, it can prevent liquids and gasses from entering and further prevent corrosion. It is a good material for protecting the construction from elements like chlorides, alkalis, and de-icing salts without any other strategy. [9] The ductility and energy absorption of UHPC is larger than HPC, which is 300 times better when using steel fiber. Therefore, it has high durability and high strength characteristics, so it can be used in the construction of bridges to improve the span of the bridge, used to improve durability, and life of the bridge; it also has high toughness characteristics, its flexural strength than traditional high strength concrete two orders of magnitude higher, so it can also be used in the field of structural connection, so that with the concrete bridge deck plate and so on have better connection degree Nowadays, there are many projects with the use of UHPC completed. For example, the Glenmore/ Legsby footbridge in Calgary was built using UHPC in 2007. A prestressed T-beam with 33.6 m long was applied as a drop-in material for the 53 m long bridge, which the construction was completed in around 8 hours. Some tests were carried out to test the UHPS's strength. First, a load between 20 to 80% of the maximum design load was applied to the test materials for 1 million load cycles, followed by the same amount of load cycles with a load between 20 to 80% of the load leading to the first cracking, if the test materials did not appear any failure behavior, such as a decrease in stiffness, then one more million load cycles between 20 to 80% of the measured load of failure was applied. A minor reduction in stiffness, losing around 1/3 of the stiffness of the uncracked state, was found after the start of the final load cycle. It was also found that the ultimate load was higher than the estimated one. Moreover, the result of a loading test showed that the deflection of the UHPC was less than estimated, and the deflection returned to 0 after the load was relieved, which showed there was no plastic behavior, and no irreversible damage. Therefore, the UHPC is a good material for construction. [9]

5. Conclusion

In conclusion, high-performance concrete has been developed to the application level since the 1930s. It has been widely used in the construction industry because of its excellent behaviors like high compressive strength, durability, and low permeability compared to conventional concrete. Moreover, the characteristics, design criteria, and comparison between it and normal strength concrete are introduced. Nowadays, the industry widely adopted various kinds of HPC, such as HPC made of recycled aggregates, self-compacting concrete, and the latest development of HPC, ultra-high-performance concrete, which bring a great benefit for construction. Nevertheless, there are some challenges and limitations of the HPC, for instance, the low fire resistance and high manufacturing cost. It is believed that the problems can be solved with the enhancement of technology in the future.

Reference

[1] Christopher, L. (2001), "Science and Technology," *Encyclopedia of Materials*.

[2] Büyüköztürk, O., & Lau, D. (2007), "High Performance Concrete: Fundamentals and Application". Retrieved from: https://www.researchgate.net/publication/239925229_High_Performance_Concrete_Fundamentals_and_Application.

[Accessed from 17 March 2023]
[3] AÔtcin, P. C. (2003), "The Durability Characteristics of High-Performance Concrete, A Review,» *Cement and Concrete Composites*, Vol. 25, No. 4-5, pp. 409-420.
[4] Shi, C., and Mo, Y. L. (2008), "Chapter 2 High-Performance Concrete", *High-Performance Construction Materials : Science and Applications.* World Scientific. pp. 13.
[5] Persson, B. (1998), "Experimental Studies on Shrinkage in High-Performance Concrete," *Cement and Concrete Research*, Vol. 28, No. 7, pp. 1023-1036.
[6] Pettersson, K.(1994), "Chloride Threshold Value and the Corrosion Rate in Reinforced Concrete", *Cement and Concrete Research,* Vol. 20, pp. 461-470
[7] Okamura, H., and Ouchi, M. (2003), "Self-Compacting Concrete", *Journal of Advanced Concrete Technology*, Vol 1, No. 1, pp. 5–15
[8] El-Helou, R., Haber, Z. B., and Graybeal, B. A. (2022). "Mechanical behavior and design properties of ultra-high-performance concrete". *ACI Materials Journal,* Vol. 119, No. 1, pp. 181-194. Retrieved from: https://doi.org/10.14359/51734194 [Accessed 25 March 2023]
[9] Fehling, E., Schmidt, M., Walraven, J., Leutbecher, T., and Fröhlich, S. (2015) *Ultra-High Performance Concrete UHPC : Fundamentals, Design, Examples*, Wilhelm Ernst & Sohn Verlag fur Architektur und Technische. Retrieved from: http://ebookcentral.proquest.com/lib/cityuhk/detail.action?docID=1768909 [Accessed 25 March 2023]