High Performance Concrete and Its Applications

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Introduction:

Traditionally, high performance concrete (HPC) may be regarded as synonymous with high strength concrete (HSC). At the turn of the 20th century, concrete compressive strength was in the range of 13.8 MPa, by the 1960s it was in the range of 27.6-41.4 MPa. Deterioration, long term poor performance, and inadequate resistance to hostile environment, coupled with greater demands for more sophisticated architectural form, led to the accelerated research into the microstructure of cements and concretes and more elaborate codes and standards.

As a result, new materials and composites have been developed and improved cements evolved. Today concrete structures with a compressive strength exceeding 138 MPa are being built world over. In research laboratories, concrete strengths of even as high as 800 MPa are being produced.

Such concretes can be either normal strength or high strength. Normal strength concrete by ACI definition is a concrete that has a cylinder compressive strength not exceeding 42 MPa. All other concretes are considered High Strength Concretes.

Comparison between the Microstructure of HPC (high performance concrete) and NSC (normal strength concrete):

What makes HPC to be different from NSC? In order to answer this question, the microstructure of the material should be studied. Interrelationships between microstructure and properties of both HPC and NSC need to be established. The microstructure of concrete can be described in three aspects, namely composition of hydrated cement paste, pore structure and interfacial transition zone.

The hydrated cement paste is in fact the hydration products when cement is reacted with water. The pore structure refers to the gel pores, capillary pores and voids, as well as their connections within the hardened concrete. The interfacial transition zone refers to the boundaries between the cement paste, and aggregates or particles of admixtures. The composition of NSC is relatively simple, which consists of cement, aggregate and water. Figure 1 shows the microstructure of NSC.

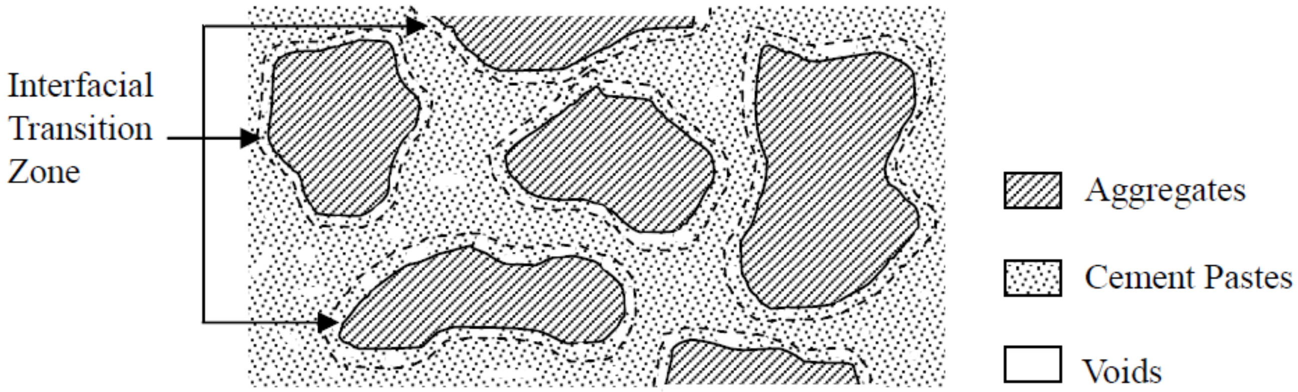


Figure 1: Microstructure of NSC

In order to improve the concrete performance, the following three aspects are considered: (a) the hydrated cement paste should be strengthened, (b) the porosity in concrete should be lowered, and (c) the interfacial transition zone should be toughened.

a) the hydrated cement paste can be strengthened by reducing the gel porosity inside the paste,

b) the porosity in concrete can be lowered by adding suitable fine admixture which can fill up the empty space inside concrete,

c)the interfacial transition zone can be toughened by lowering the locally high water-to-cement ratio and by improving the particle packing in this zone. Superplasticizer is added into the concrete mix so that a very low water-to-cement ratio (less than 0.2) become feasible to be adopted. Fine admixtures, like silica fume or fly ash, is added as well to improve the particle packing in the interfacial transition zone. It is noticed that in order to improve the concrete performance, admixture is a necessary component which must be added into the design mix in order to generate HPC. The porosity and the pore connectivity of

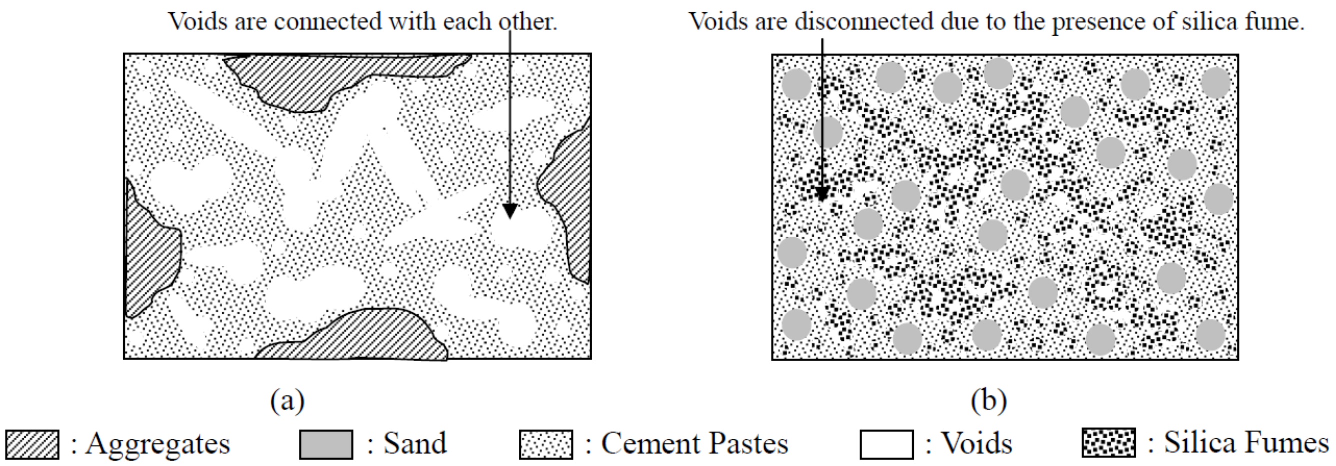


Figure 2: Pore Connectivity in (a) NSC and (b) HPC

NSC are usually higher than that of HPC due to the absence of fine particles (see Figure 2).

Figure 3) shows the microstructure of HPC,

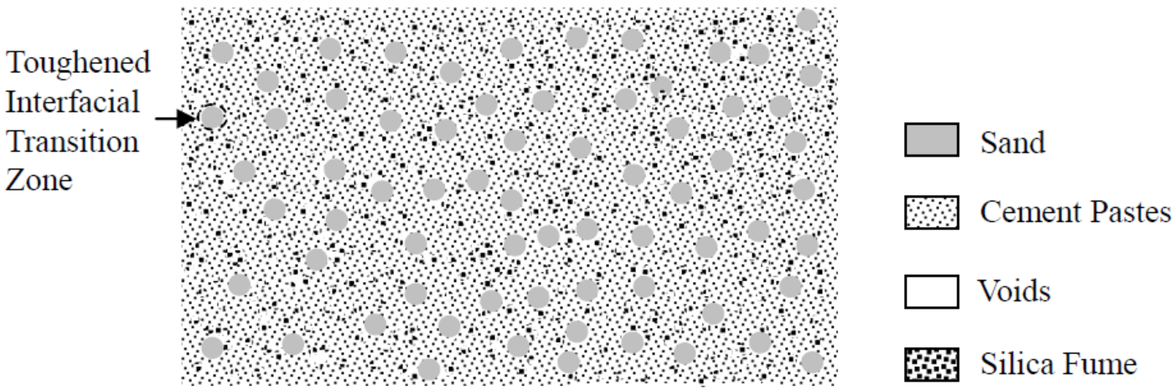


Figure 3: Microstructure of HPC

Important governing factors for HPC

Important governing factors for HPCs are strength, long term durability, serviceability as determined by crack and deflection control, as well as response to long term environmental effects.

CONCEPTS IN THE DESIGN OF HPC

In order to achieve High Strength Concrete, various important factors that govern the strength of concrete are to be understood. They are:

- Properties of cement paste
- Properties of aggregate
- Various chemical and mineral admixtures to used
- Properties of the admixtures used
- Proportions of the constituents to be used
- Paste-Aggregate reaction
- Mixing, Compaction and Curing
- Testing procedure

CHARACTERISTICS OF HPC

The key elements of HSC can be summarized as follows:

- Low water-binder ratio (ranges from 2.5 to 3.5)
- Use of mineral admixtures like Silica Fume, Meta Kaolin, Fly Ash etc.
- Small aggregates (12.5 mm and 10 mm) and fine sand
- High dosage of super plasticizers
- Heat treatment and application of pressure at curing stage
- (Applicable for Ultra High Strength Concrete)

ADVANTAGES OF HPC

The advantages of using High Strength Concrete have been described in various researches. These include

- Reduction in member size
- Reduction in the self-weight and super imposed dead load with the accompanying saving due to smaller foundations
- Reduction in form work area and cost
- Longer spans and fewer beams for the same magnitude of loading,
- Reduced axial shortening of compression members
- Reduction in the number of supports and the supporting foundations due to increase in spans
- Reduction in thickness floor slabs and supporting beam sections which are a major component of the weight and cost of the majority of structures
- Superior long term service performance under static, dynamic and fatigue loading
- Low creep and shrinkage.

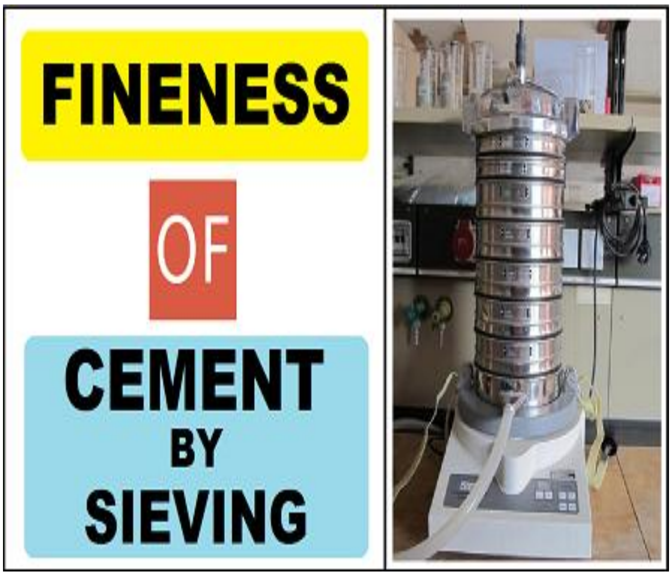
Materials Used in HPC

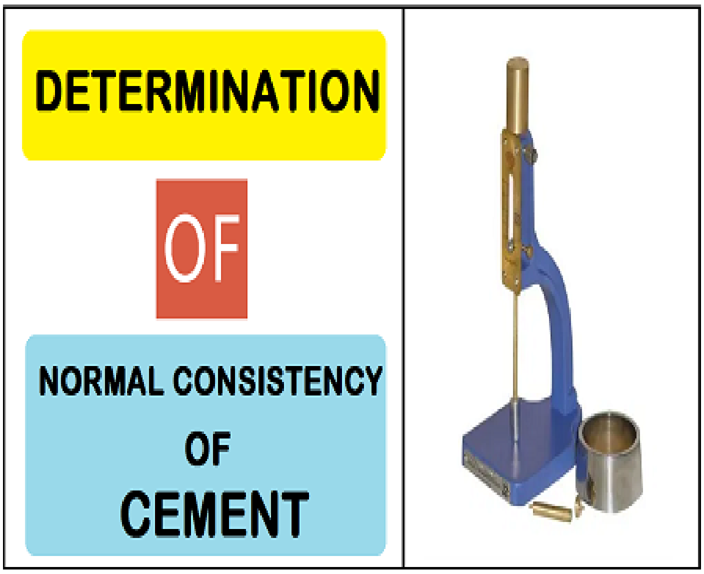
- Cement: The primary binding material in HPC. High-strength cements or modified types of cement are often used to increase the concrete's strength and durability.
- Aggregates: Fine and coarse aggregates that are carefully selected to ensure uniformity and minimal impurities. Aggregates with high density and low water absorption are often chosen for HPC.

- Water: Water quality and the water-to-cement ratio play a critical role in determining the strength and durability of HPC. The water-to-cement ratio is typically kept as low as possible without compromising workability.
- Admixtures: Special chemical admixtures are used to enhance properties like workability, set time, and durability.

TESTS ON CEMENT:

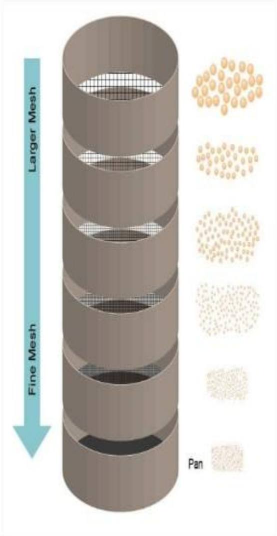
- ❖ Fineness
- ❖ Normal consistency
- ❖ Initial and final setting time
- ❖ Specific gravity

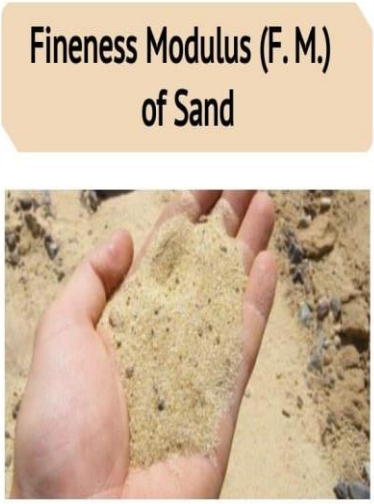


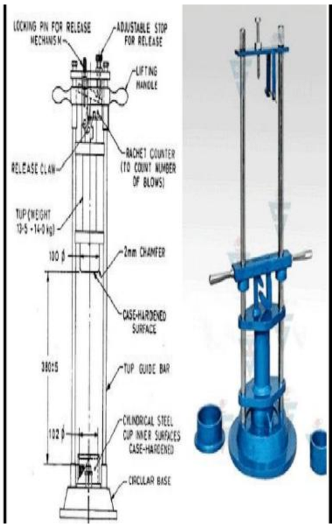


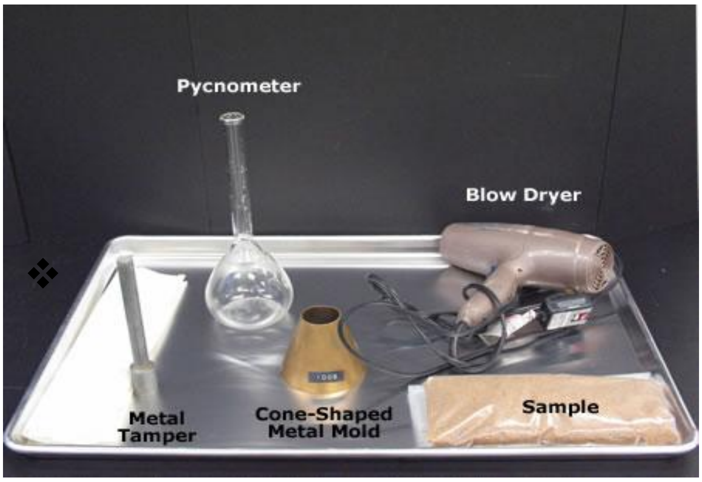
TESTS ON AGGREGATES:

- ❖ Fineness modulus of fine aggregate,
- ❖ Aggregate impact test
- ❖ Aggregate crushing test
- ❖ Specific gravity









- ❖ Fine Aggregates Specific gravity

COMPOSITION OF HPC

The ingredients of HPCs are almost same as those of Conventional Cement Concretes (CCC). But, because of lower Water Cement Ratio, presence of Pozzolans and chemical admixtures etc., the HPCs usually have many features which distinguish them from CCCs.

From practical considerations, in concrete constructions, apart from the final strength, the rate of development of strength is also very important. The High-performance concrete usually contains both pozzolanic and chemical admixtures. Hence, the rate of hydration of cement and the rate of strength development in HPC is quite different from that of conventional cement concrete (CCC).

The proportioning (or mix design) of normal strength concretes is based primarily on the w/c ratio 'law' first proposed by Abrams in 1918.For high strength concretes, however, all the components of the concrete mixture are pushed to their limits.

Therefore, it is necessary to pay careful attention to all aspects of concrete production,

i.e., selection of materials, mix design, handling and placing

The proportioning of HPC concrete mixtures consists of three interrelated steps:

1) Selection of suitable ingredients - cement, supplementary cementing materials (SCM), aggregates, water and chemical admixtures,

2) DETERMINATION OF THE RELATIVE QUANTITIES OF THESE MATERIALS in order to produce, as economically as possible, a concrete that has the rheological properties, strength and durability,

3) Careful quality control of every phase of the concrete making process.

TYPES OF SUPPLEMENTARY CEMENTITIOUS MATERIALS:

The most commonly used supplementing cementitious materials/mineral admixtures for achieving HPC are:

1. Silica Fume

2. Fly Ash

3. GGBFS (Ground granulated blast furnace slag)

1.Silica Fume:

Silica fume is a waste by-product of the production of silicon and silicon alloys. Silica fume is available in different forms, of which the most commonly used now is in a densified form. In developed countries it is already available readily blended with cement.

It is possible to make high strength concrete without silica fume, at compressive strength of up to 98 MPa. Beyond that strength level however, silica fume becomes essential. With silica fume it is easier to make HPC for strengths between 63-98 MPa.

2.Fly Ash:

Fly Ash of course, been used extensively in concrete for many years. Fly ash is, unfortunately, much more variable than silica fumes in both their physical and chemical characteristics.

Most fly ashes will result in strengths of not more than 70 MPa. Therefore, for higher strengths, silica fume must be used in conjunction with fly ash.

For high strength concrete, fly ash is used at dosage rates of about 15 % of cement content.

3.GGBFS:

Slags are suitable for use in high strength concrete at dosage rates between (15% - 30%). However, for very high strengths, in excess of 98Mpa, it is necessary to use the slag in conjunction with silica fumes.

MIX PROPORTIONS FOR HPC/HSC

Only a few formal mix design methods have been developed for HPC/HSC to date. Most commonly, purely empirical procedures based on TRIAL MIXTURES are used. Therefore, it calls for extensive field trials for designing desired strength of concrete using various mix proportions of SCMs, admixtures and W/Binder ratio.

Use of Super-plasticizers:

Use of super-plasticizers becomes essential for designing mixtures to achieve HPC.As can be seen, the w/binder ratio has an important bearing on achieving the strength parameters. In order to achieve dense concrete with reduced permeability, super plasticizers of following types are in general use:

1.SNF-Sulphonated Naphthalene sulphonate based

2.Melamine sulphonate based

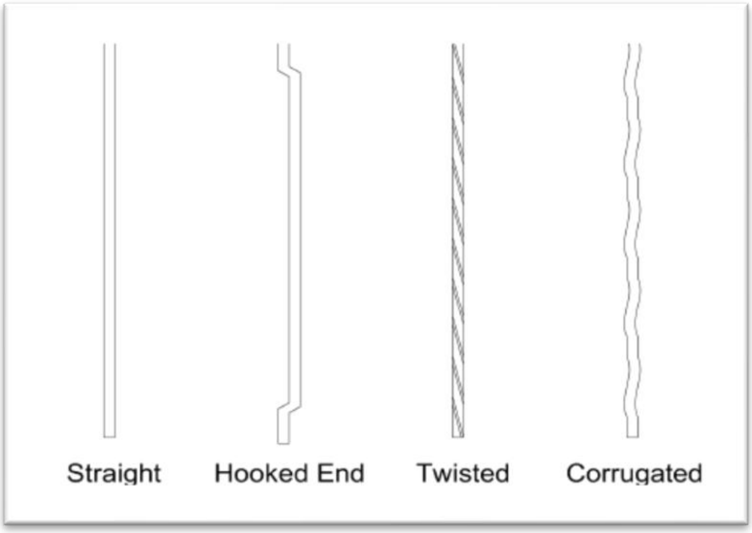
3.Lignosulphonate based.

the latest and the most effective super-plasticizer if SNF based. ASTM also has recommended use of this type for attaining the optimum benefits like good workability and minimum w/binder ratio. Around 2% by weight of cementitious materials is normally used for achieving required workability.

UHPC, Ultra High Strength Concrete

Use of Steel Fibers

Due to its very high strength and homogeneity, UHPC is very brittle; yet it can be made ductile by adding steel fibers. Fibers provide greater resistance to crack generation and propagation. Figure below shows the shape of fibers used for UHPC as per past studies.



General parameters for Ideal HPC:

1.Due to Controlled placing and curing > yields High performance

- Good quality of paste
- Low W/C ratio
- Optimal cement content and cementitious material
- Sound aggregate, grading and vibration
- Low air content
- High strength

2.Due to Controlled material quality control >yields Resistance to wear and Deterioration

- Low W/C ratio
- Proper curing
- Dense, homogenous concrete
- High strength
- Wear resisting aggregate
- Good surface texture

3.Due to Controlled proportions > yields Resistance to weathering and chemicals

- Appropriate cement type
- Low W/C ratio
- Proper curing
- Alkali-resistant aggregate
- Suitable admixture
- Use of super-plasticizers, fly-ash, polymers or silica fume as admixtures
- Air entrainment.

4.Due to Controlled handling > yields Economy

- Large maximum aggregate size
- Efficient grading
- Minimum slump
- Minimum cement content
- Optimal automated plant operation
- Admixtures and entrained air
- Quality assurance and control

5.Appropriate cement type: low C3A, MgO, free lime, low Na2O and K2O.

Applications of High-Performance Concrete:

- Bridges

The use of high-performance concrete in the construction of bridge structures provides several structural improvements. For instance, it improves the durability of the structures and hence increases their life span. Moreover, longer span prestressed concrete girders can be constructed when high-performance concrete is employed. This is because such concrete results in a smaller loss in pre-stress and consequently larger permissible stress and smaller cross-section being achieved.

❖ High rise buildings

The use of high-performance concrete in the constructions of high-rise buildings leads to the reduction of dead load, deflection, vibration, and maintenance concrete.

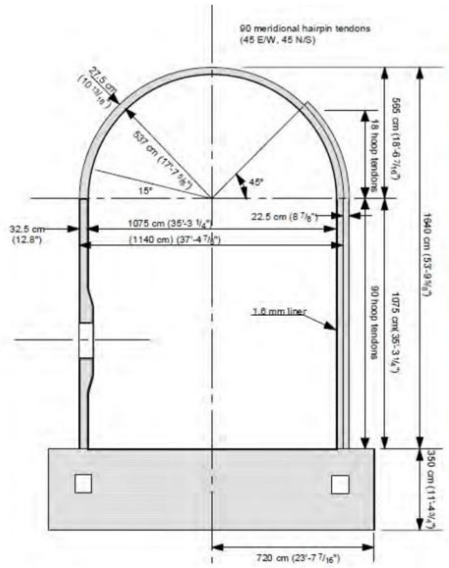
❖ Pavements

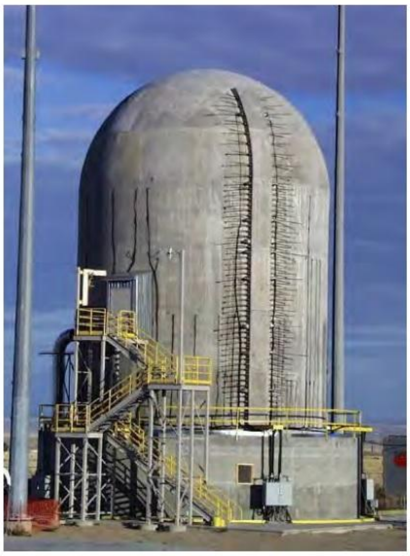
Application of high-performance concrete in highway pavements is greatly advantageous due to the potential economic benefits that can be derived from the early strength gain of high-performance concrete, reduced permeability,

improved abrasion resistance to steel studded tires, and enhanced freeze-thaw durability. The high-performance concrete can also be used to repair damaged pavement since it can be put into service quickly.

- ❖ Nuclear structures

In nuclear facilities, Concrete becomes more and more important materials for radiation protection and high durability when used in nuclear construction compared to the other materials. Where production of special structures dealing with radioactive sources or radiation protection, requires special type of concrete as radiation shielding barrier based on good shielding performance, high compressive strength, high density, high durability, reduced permeability and low cost.





- ❖ Hydropower Structures

High-performance concrete has been used for lining spillway, diversion tunnel, headrace tunnel, slit flushing tunnel, tailrace tunnel to increase the performance of these structures in handling high velocities of water and a large amount of silt. The use of High-Performance concrete has resulted in lesser repairs, on one hand, and increased durability, on the other hand.

Conclusion

High-Performance Concrete (HPC) is an advanced material that has transformed the construction industry by offering superior strength, durability, and resistance to environmental factors. As infrastructure demands evolve, the adoption of HPC continues to grow, contributing to the construction of long-lasting, sustainable structures. While challenges such as cost, complexity, and quality control remain, the benefits of HPC in terms of performance and longevity make it a highly valuable material for modern construction.

Further research into the development of cost-effective, high-performance mixes and innovations in materials is expected to enhance the adoption of HPC in future infrastructure projects.

References:

1)Young, J.F. (2000), “The Chemical and Microstructural Basis for High Performance Concrete”, Proceedings of High-Performance Concrete – Workability, Strength and Durability, Hong Kong, v 1, 2000, p 87-103

2) Malathy, R. (2003), “Role of super fine fly ash on high performance concrete”, Role of Concrete in Sustainable Development - Proceedings of the International Symposium dedicated to Professor Surendra Shah - Celebrating Concrete: People and Practice, 2003, p 425-434,

3) M.L.Gambhir, “Concrete Technology, Theory and Practice”, Fifth Edition. (2014)

4) Meng, W.; Valipour, M.; Khayat, K.H. “Optimization and Performance of Cost-Effective Ultra-High-Performance Concrete”. Mater. Struct. 2017, 50, 29. [CrossRef]

5) Mahmoud Gharieb, etl. “Effect of using heavy aggregates on the high-performance concrete used in nuclear facilities”, 6 December 2021

6) Mehta, P. K., & Monteiro, P. J. M. (2014). *Concrete: Microstructure, Properties, and Materials*. McGraw-Hill Education.

7)Bentz, D. P., & Garboczi, E. J. (2007). “Permeability of High-Performance Concrete: Modeling and Experimentation.” *Cement and Concrete Research*, 37(9), 1414-1426.

8)Poon, C. S., & Lam, L. (2002). "Properties of High-Performance Concrete with High-Volume Fly Ash." *Cement and Concrete Research*, 32(2), 203-211.