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High Strength High Performance Concrete

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Abstract - *High strength concrete (HSC) refers to the mixture having characteristic compressive strength in the range of 65 MPa to 100 MPa; however, greater strengths have been achieved and practiced. Strength ranges between 80 MPa and 100 MPa, sometimes even higher, are being used at many construction sites across the world. HSC finds its application in highway works, long-span bridges, columns of RCC skyscrapers, offshore structures, etc. High Performance Concrete (HPC) is a mix, designed to possess special characteristics like improved resistance to harmful environmental effects, abrasion resistance, low water absorption, less permeability, etc. Due to this, HPC obviously leads to desired high strength. This paper throws light on the different materials used and various considerations taken in to account for producing High Strength High Performance Concrete (HSHPC), through the literature survey.*

Key Words: **HSC, HPC, UHPC, HSHPC, Silica Fume, Metakaoline, Fly Ash, Slag, Workability, etc.**

1. INTRODUCTION

Concrete, as the most widely used construction material in the world, plays a crucial role in the development of modern infrastructure. However, the growing demands for longer-lasting structures with reduced maintenance costs and better performance have led to the evolution of advanced types of concrete. Among these, High Strength Concrete (HSC) and High-Performance Concrete (HPC) have emerged as significant advancements. When the attributes of both are combined, the result is a material referred to as High Strength High Performance Concrete (HSHPC).

Traditional concrete typically achieves a compressive strength of 20–40 MPa. In contrast, HSC exhibits compressive strengths exceeding 60 MPa, while HPC is engineered for enhanced durability, workability, and long-term performance, often independent of strength. HSHPC, therefore, offers a hybrid solution—marrying the mechanical strength of HSC with the workability, durability, and serviceability of HPC.

1.1 NEED FOR HIGH STRENGTH HIGH PERFORMANCE CONCRETE

The demand for high-rise buildings, long-span bridges, and complex infrastructural elements has necessitated the use of concrete with superior properties. The limitations of ordinary concrete—such as susceptibility to environmental degradation, reduced performance under high loads, and poor workability—can be overcome with HSHPC.

Key benefits of HSHPC include:

- Enhanced load-carrying capacity, allowing for slimmer structural elements.
- Improved durability against aggressive environmental conditions.
- Reduced permeability, which improves resistance to chemical attack.
- Lower maintenance and lifecycle costs.
- Improved aesthetic flexibility, allowing more complex architectural forms.

These properties make HSHPC ideal for projects such as high-rise buildings, marine structures, nuclear power plants and heavily trafficked bridges.

1.2 EVOLUTION AND DEVELOPMENT

The development of HSHPC is rooted in material science advancements and the availability of high-quality supplementary cementitious materials (SCMs) such as silica fume, fly ash, and ground granulated blast furnace slag (GGBFS). Additionally, advancements in chemical admixtures, particularly high-range water reducers (superplasticizers), have made it feasible to produce highly workable yet dense and strong concrete mixtures.

The evolution of concrete technology has been marked by milestones such as:

- Introduction of HSC in the 1960s, primarily in prestressed structures.
- HPC gaining traction in the 1980s, focusing on durability and long-term performance.
- The 1990s and beyond, where integration of strength and performance led to HSHPC, driven by high-profile infrastructure demands and sustainability goals.

1.3 DEFINING CHARACTERISTICS OF HSHPC

HSHPC is not defined solely by compressive strength. While strength is a major component, HSHPC must meet multiple performance criteria simultaneously. These may include:

- Compressive strength exceeding 60–80 MPa or higher.
- High modulus of elasticity and abrasion resistance.
- Very low permeability to water and aggressive ions (e.g., chloride, sulfate).
- Excellent workability, including pumpability and self-compaction (if self-consolidating is desired).
- Superior freeze-thaw resistance and long-term durability.

Achieving these characteristics often involves a carefully optimized mix design, tailored curing methods, and stringent quality control during production and placement. Concrete is the second most consumed material in the world, after water. Its usage has been exponentially increasing owing to the infrastructure development projects. Material selection and precise mix design are vital for producing HSC. Varied range of aggregates can be used to produce HSC. At comparatively lower strength, rounded and/or smooth aggregates show aggregate bond failure. Crushed rock aggregates of 10 to 20 mm sizes, which are not too elongated and angular are preferred. Smaller size aggregates result in to better strength owing to the fact that they have better bond strength.

The ways of producing HSC are similar to that required for producing Normal Weight Concrete (NWC). However, the (water/binder) ratio for HSC is in the range of 0.25 to 0.35 or even less than that depending upon the strength to be attained. Using workability superplasticizers for reduction of water content is a must for producing HSC. Obtaining cohesive mix with minimum void contents is a key to develop HSC.

Microcracks, known as faults, are already present in the transition zone (aggregate-cement interface), even before the concrete is stressed. When loads get applied, microcracks in transition zone propagate quickly, thereby developing larger cracks than rest of the concrete mass. The weakest link is the transition zone. (Water/binder) ratio affects the transition zone in low and moderate strength concretes. However, the (water/binder) ratio is not showing the same effect on HSC, having low (water/binder) ratio. For very small decrease in (water/binder) ratio, considerable improvement in concrete compressive strength can be attained for (water/binder) ratio less than 0.3.This is due to the fact that, at very low (water/binder) ratio, there is a considerable strength improvement at transition zone.

Aggregate parameters, other than strength, like gradation, texture, shape, size, etc. influence the concrete strength.

Currently, Ready Mixed Concrete (RMC) plants are an integral part of the Indian construction industry.

HSC is being produced in RMC plants on a large scale in metropolitan cities. A special care has to be practiced in connection with the mix proportioning, shape and size of aggregates, supplementary cementitious material use, silica fume, superplasticizers, etc. HSHPC having 75 MPa compressive strength was first time used for JJ flyover, Mumbai in 2002 shown in fig. 1.1

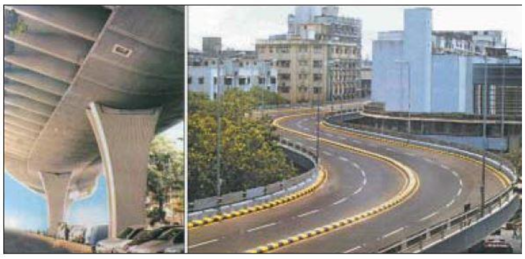

Fig. -1: JJ Flyover, Mumbai, 2002 (Courtesy: Gammon India Ltd.)

HPC is a concrete which meets required performance specifications. It exhibits enhanced fluidity, greater strength, higher modulus of elasticity, better dimensional stability, higher density, resistance to aggressive environment, low permeability, etc. American Concrete Committee lays down five criteria for HPC, viz. ease of placement, long-term mechanical properties, early-age strength, toughness and performance in severe environments.

As per Strategic Highway Research Program (SHRP), HPC has to satisfy one among the criteria like, 4-hour strength of 17.5 MPa, 24-hour strength of 35 MPa, 28-day strength of 70 MPa, durability factor > 80% after 300 freezing and thawing cycles and (water/binder) ratio ≤ 0.35.

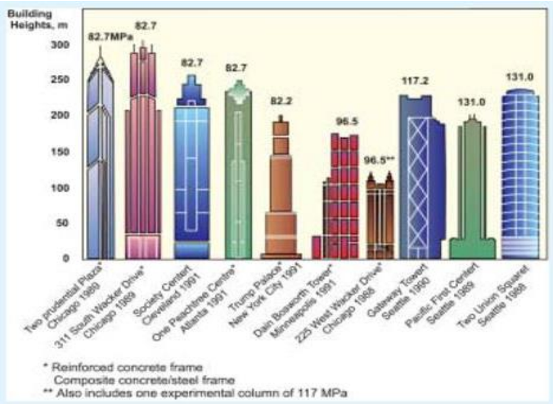

Fig.-2: HPC Used in Iconic Structures across the World (Source: Internet)

2. LITERATURE SURVEY

The concrete having 15% replacement of cement by metakaoline exhibited optimum compressive strength [1]. Metakaoline helps in increasing pozzolanic activity, thereby reducing the corrosion effect, especially in coastal climates. The use of waste ashes from thermal power plants [2] was studied. It helps in improving workability, strength, durability, etc. Use of metakaoline as a partial replacement of cement resulted in the reduction of plastic density of the mix [3].

Using low water/binder ratio along with addition of metakaoline led to the production of HSHPC having compressive strengths >100 MPa. The optimum replacement of cement by metakaoline was found to be 10%. This is because of the dilution effect created due to partial replacement. Split tensile strength and Young's modulus were observed to be highest at this dosage [3].

Concrete exhibited highest strength at replacement of cement by 10% marble powder and 9% metakaoline [4]. With increasing addition of metakaoline, reduction in permeability was observed. Abram's water/cement ratio based law which was proposed for the concretes having only cement as powder content is equally valid for concretes with fly ash addition [5]. Replacement of cement by fly ash at 30% to 35% is beneficial for the concrete. HSHPC with fly ash can have water/binder ratio of 0.34.

Addition of mineral admixtures such as fly ash, metakaoline and silica fume along with steel fibres enhances the strength properties [6]. HSC cubes exhibit sudden failure under applied load and microcracks can be observed. Fly ash helps in increasing the workability; however, it is reduced by the addition of silica fume and metakaoline [6].

Cement replacement by 10% metakaoline, along with the better performing superplasticizer, leads to increased compressive strength, split tensile strength, modulus of elasticity and flexural strength [7].

Cement can be replaced up to 15% by metakaoline for the optimum performance of concrete [8].

Silica fume incorporated in the concrete, as a partial replacement of cement, showed desirable effects on the compressive and tensile strengths of concrete. It helped in improving the resistance to acid attacks [9]. It is available in excess and it cannot be disposed off easily, as it requires large area. It can contaminate groundwater if disposed in the open without proper treatment. Cement can be replaced by 10% to 30% of silica fume [9]. It enhances concrete strength significantly. Concrete cost reduces by about 20% to 30% by adding silica fume [9].

With 10% usage of metakaoline, the maximum compressive strength obtained was 78 MPa [10]. A compressive strength of 78 MPa was achieved with 7.5% slag and 7.5% fly ash. Fly ash, slag and silica, 5% each resulted in a compressive strength of 79 MPa [10].

The sustainable high strength concrete (SHSC) with 75% of quaternary blends and 3% nano-silica exhibited improved mechanical properties at 28 and 91 days, reflecting that this mix can attain highest sustainability performance [11].

The SHSC mix having 3% nano-silica and 50% quaternary blends could show the maximum strength parameters of 80.7, 6.46 and 10.09 MPa for compressive strength, split tensile strength and flexural strength, respectively, at 28 days. This SHSC mix could also achieve low water permeability; chloride permeability was observed to be 2.54×10^{-11} (cm/sec) and 1370 coulombs at 28 days [11]. Mechanical properties and shrinkage of Ultra-High Performance Concrete (UHPC) with maximum aggregate size of 5 mm was studied [12]. UHPC having dolomite and more than 1% volume fractions of steel fibres exhibited strength values >150 MPa after 56 days [12].

A green Ultra-High-Performance Glass Concrete (UHPGC) exhibiting a compressive strength of 220 MPa was developed [13]. Its fresh, mechanical and microstructural properties were investigated. In all the mixes, a Poly-carboxylate Ether (PCE)-based high-range water-reducing admixture (HRWRA) having a specific gravity of 1.09 and solids content of 40% was incorporated. The replacement of quartz powder as well as cement by glass powder considerably reduces UHPC cost and decreases the carbon footprint of a typical UHPC [13].

Limestone powder incorporated as a partial cement replacement and partial or complete replacement of silica powder slightly reduced the mixing time needed to manufacture UHPC [14].

Partial replacement of cement showed a desirable influence on the workability. Replacement of silica powder exhibited less influence on the workability [15]. The tensile and compressive strengths of UHPC were determined and compared with that of Normal Strength Concrete (NSC) for developing a numerical model in order to simulate UHPC behaviour with the help of Finite Element.

Compressive strength of UHPC was observed to be 3 to 4 times higher than that of NSC [15]. Mechanical interlocking force between steel fibers and concrete cylinders and cubes stayed intact even after reaching the failure load. However, NSC was seen to split into large concrete pieces [15].

M60 grade HPC was developed with the addition of fly ash and silica fume with 15% and 10% replacement by cement mass. Coarse aggregates were partially replaced by ferro-slag aggregates in different up to 40% [16].

HPC is distinguished by its dense microstructure, which contributes to its improved durability characteristics, such as low permeability, high resistance to chloride ingress, and superior freeze-thaw resistance [17].

The integration of HSC and HPC leads to the development of High Strength High Performance Concrete, which benefits from both high load-carrying capacity and excellent durability. The synergistic use of silica fume and superplasticizers significantly improves the strength and durability of concrete, making it suitable for HSHPC applications [18].

The investigations on the mechanical and durability performance of HSHPC led to the conclusions that it could achieve compressive strengths above 80 MPa while exhibiting superior resistance to sulfate attack and chloride penetration. Microstructural refinement due to SCMs and chemical admixtures plays a crucial role in the performance enhancement [19].

Durability is a key feature of HSHPC. It is often assessed through parameters like water absorption, rapid chloride permeability test (RCPT), acid resistance, and freeze-thaw resistance. It was demonstrated that concrete containing silica fume and fly ash showed significantly reduced ion permeability and improved sulfate resistance [20].

The use of high-range water reducers (HRWR) or superplasticizers has been critical in maintaining high workability without compromising strength. Advancements in admixture technology have enabled the development of self-consolidating high-performance concretes, which combine workability with strength and durability [21].

In a review paper [22], researchers found out that for resistance to chemical attack on most structures, HPC offers a much-improved performance. Resistance to various sulfates is achieved primarily by the use of a dense, strong concrete of very low permeability and low water-to cementing materials ratio; these are all characteristics of HPC. The study was done about High-Performance Concrete under biaxial and triaxial loads which include tests on various high-performance concretes.

HPCs have uniaxial compressive strengths ranging from 58 MPa to 94 MPa. Stress ratios of biaxial compression-tension, compression-compression and triaxial compression tests were noted. Servo hydraulic jack with variable stress ratios were used to conduct experiments. The load was transferred to the specimen by using steel brushes. Obtained normalized multi-axial strength decreased with the increasing uniaxial strength. The objective of this study was to develop concrete with good strength, less porosity, less capillarity, thus the durability was achieved. M60 grade of concrete was produced using silica fume in different percentages- 0%, 5%, 10%, 15% by the mass of the cement [22].

As per research paper [23], along with mechanical properties, environmental properties of concrete can be improved with efficient use of mineral and chemical admixtures. The research investigated the effect of microsilica on high-strength concrete. The cement content in the concrete was replaced by Microsilica in varying percentages.

Different specimens of standard sizes were tested to check compressive, tensile and flexural strength of concrete. To check environmental property of high-strength concrete, water permeability test was carried on cube specimens. It was concluded that, use of micro silica increases strength of concrete for small amount of replacements to cement. With more increase in content of microsilica, the strength of concrete decreases. Along with strength, permeability of concrete was also improved [23].

Author mentioned the characteristics of high performance concrete as very low porosity through a tight and refined pore structure of the cement paste, very low permeability, high resistance to chemical attack, low heat of hydration, high early strength, continued strength development, high workability, control of slump and low bleeding and plastic shrinkage [24]. Study was carried out on the methods for achieving high performance concrete.

The development, properties, and applications of HSHPC, alongside the materials and technological advances that contribute to its performance were studied [25]. Effects of supplementary cementitious materials, aggregates, fibres, curing method, superabsorbent polymer (SAP), expansion-promoting additive (EPA), shrinkage reducing additives (SRA) and water-to-binder (w/b) ratio on the strength of HPC were reviewed.

Influences of admixtures including silica fume, fly ash, metakaolin, GGBFS, calcined clay, limestone powder and rice husk ash were studied and their influence on the strength of HPC was reported. The strength of HPC was significantly improved by addition of SCMs Optimal replacements of OPC by MK, SF, RHA, AAM, CS-LS, NS have generally been reported to be 10%, 10–15%, 20%, 100%, 30% and 0.5–1.5% respectively [25].

Research work on HPC [26] highlighted the advancement in concrete technology, including the development of material that improves the concrete's long term performance in aggressive environments. The research paper discussed about the careful control of the mix design to optimize both strength and durability.

3. CONCLUSIONS

This paper was an attempt to review some of the literature available in connection with HSC and HPC, including UHPC. Compressive strength is most important for various concreting works. HSC finds its applications in bridges, skyscrapers, structures built on weak soils, etc. Keeping low water/binder ratio is a key to produce HSC. However, use of superplasticizers is recommended to impart fluidity to concrete having low water/binder. Mineral admixtures such as fly ash, metakaoline, silica fume, slag, ultra-fine material, etc. facilitate in improving the strength to a great extent. HSC leads to reduced maintenance and repair. The sizes of the various structural elements can be reduced. This results in economy in formwork material requirement.

HPC shows enhanced durability, better resistance to chemical attack and desired workability. It shows strong transition zone. It finds its special applications in repair and retrofitting works. It increases the service life of the structures. HPC facilitates construction in severe and extreme climatic conditions.

With so much infrastructure woks going on, use of HSHPC is imperative and beneficial from the point of view of long-term durability and more importantly, the highly desired sustainable development.

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