Study on the Properties of High-Performance Concrete: A Review

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Abstract - *India uses more than 100 million cubic meters of concrete per year, making it the most common building material there. Numerous varieties come in a variety of uses. High performance special concrete is one such variety that has greater durability and strength than regular special concrete with lower water cement ratio. The primary benefits relate to placement and consolidation without compromising strength. By using this, slender sections can be made with longer life in severe environments thus reducing the total quantity of material. The purpose of this paper is to describe the various supplementary cementitious materials used for HPC along with their impacts and other ingredients and their properties.*

Key Words: High performance concrete, water cement ratio, Durability, supplementary cementitious materials, strength,

1. INTRODUCTION

Concrete is a composite construction material whose major constituents are aggregate, cement, and water. According to the American Concrete Institute (ACI), HPC is concrete that satisfies unique sets of performance and homogeneity standards that are difficult to meet when utilising standard constituents and mixing, placing, and curing procedures [1]. Contrary to conventional concrete, which typically only contains the basic components, high performance concrete (HPC) incorporates additional cementitious materials such as fly ash, blast furnace slag, silica fume, and superplasticizer [2][3]. As a result, HPC is stronger, more durable, and performs better than conventional concrete. Utilizing HPC for various purposes has increased recently like high-rise buildings, bridges, and other structural application nuclear structures and tunnels. Its high compressive strength and other advantageous characteristics, including excellent durability, high strength, adequate workability, high abrasion resistance, low permeability and diffusion, high resistance to chemical attack, and high modulus of elasticity, are responsible for its increased use.

2. HIGH PERFORMANCE CONCRETE

High-performance concrete is a type of concrete with specific properties tailored to a certain purpose and environment, ensuring that it performs well in the structure in which it is installed. In other words, high performance concrete is a type of concrete that is meant to provide a number of advantages in the construction of concrete structures that are not always possible to achieve using standard materials, mixing, and curing techniques. In the 1990s, the appearance of high-performance concrete (HPC) was a phenomenon. In Europe, HPC is defined as a concrete with a high compressive strength at 28 days (usually > 60 MPa) and a low water-binder ratio (0.40).

Enhancements to features such as placement and compaction without segregation, long-term mechanical qualities, early-age strength, volume stability, and service life in harsh settings may be required. HPC gives pre-cast concrete structural elements better mechanical qualities, such as stronger tensile and compressive strengths and a higher modulus of elasticity (stiffness). A high-performance concrete is always a high-strength concrete, while a high-strength concrete is not always a high-performance concrete.

3. SUPPLEMENTARY CEMENTITIOUS MATERIALS AND ITS EFFECTS

HPC involves the use of supplemental cementitious materials such as fly ash and blast furnace slag, as well as chemical admixtures such as superplasticizer, in addition to the three main constituents in ordinary concrete. Micro fillers and additional cementing chemicals are increasingly being used in concrete as partial substitutes for Portland cement. The majority of these blending ingredients are either industrial by-products or raw materials. They help the environment by recycling industrial waste, minimising harmful emissions discharged into the atmosphere as a result of cement manufacturing, protecting raw materials, and conserving energy.

Several investigations have shown that the quantity of extra materials in the mix affects concrete strength development in addition to the w/c ratio. The more we learn about the relationship between concrete composition and strength, the better we'll be able to understand the nature of concrete and how to make the best concrete mixture. (Yeh et al., 1998) To produce high-strength concrete, a lower w/b ratio is required, often in the range of 0.22–0.35 [4].

3.1 Silica Fume

Silica fume (SF) is a widely used additive that has risen in popularity over the last three decades. The most effective filler from a rheological standpoint, silica fume, increased the superplasticizer demand while maintaining consistent workability. This could mean that a large surface area isn't the only factor determining the superplasticizer demand of silica fume blends, and that silica fume has a great affinity for superplasticizer molecule multi-layer adsorption [5].

By replacing 15% of the cement mass with silica fume, about 2,000,000 particles are added to each cement grain replaced, densifying the matrix, filling gaps with strong hydration product, increasing bonding with aggregates, and reinforcing materials [6]. The addition of SF was found to speed up the hydration process by approximately two hours and have a superior impact on concrete strength development, with an increase in mechanical qualities noted when less than 20% OPC was replaced with SF. In a concrete with w/b = 0.25, gravel as coarse aggregate, and sand as fine aggregate, replacing 8% of OPC with SF increased the compressive strength by 23% compared to plain concrete. When SF is replaced in the range of 10% to 15%, it will significantly boost strength; however, higher amounts will result in strength loss [7]. The hydration process progresses with time, and the effect of silica fume with fineness provides a filler effect, while high silica content provides a pozzolanic reaction, all of which cause an increase in the amount of products, pore refinement, and further densification of the interfacial transition zone (ITZ) between the aggregate particles and the cement matrix, resulting in a decrease in total porosity and an increase in compressive strength.

In the case of self-compacting HPC, the addition of silica fume in the concrete should be carefully optimised. When silica fume is added above 5% self- venting in cement mixture become more difficult, which has a smaller diameter of slump flow (high yield stress) thus increasing the amount of silica fume might sometimes result in a decrease of concrete strength qualities (due to large air content in the mixture [8].

3.2 Alccofine

Alccofine 1203 is ultrafine product of GGBS with high glassy content and high pozzolanic reactivity. The use of alccofine ingredients improves the concrete's compressive strength as well as its fluidity and workability, resistance against chloride attack and when used with marble dust powder it acts as filler. When compared to control concrete, Alccofine with fibre reinforced concrete has better durability and strength properties. In Binary Blended Concrete, 15% of the cement was replaced with Alccofine, resulting in optimal workability and strength. Alccofine 1203 can be used to make high-strength concrete and can be utilised as a cement replacement in two ways: as a means to reduce cement content and as a way to increase concrete qualities. It lowers the cement content, which saves money, and it also lowers the temperature rise[9].

3.3 Metakaolin

Metakaolin (MK) is one of the most quality-enhancing SCMs in both high-strength and high-performance concretes, and its capacity to turn portlandite into C-S-H gel via pozzolanic reaction can improve concrete strength. At 28 and 90 days, employing 15% MK as the only mineral admixture was determined to be ideal, resulting in compressive strength increases of 21.88 percent and 21.95 percent (relative to the reference specimen) at 28 and 90 days, respectively. Another study found that increasing MK content decreased HPC's mechanical and durability qualities, but lowering the w/c ratio to 0.34 enhanced compressive strength, particularly for 10% and 15% MK replacements, with the best compressive strength seen at 10% MK replacement with w/b = 0.35. Many other investigations have concluded that 10% of cement is the best proportion of MK for improving concrete characteristics [4].

3.4 Rice Husk Ash

Rice husk ash (RHA) is made by burning rice husks, and because these husks are agricultural waste, using RHA as a mineral additive has environmental and economic benefits. Furthermore, RHA has a pozzolanic reactivity that is comparable to that of SF[10].) This makes it an excellent SF alternative in HPC, owing to its similar chemical compositions and large specific surface areas, and their ability to effect compressive strength and durability qualities equally. RHA has also been shown to boost compressive strength considerably. RHA was discovered to be able to absorb free water in RHA-blended Portland cement paste, resulting in increased compressive strength. By incorporating 20% RHA, compressive strength increased by 13.41 percent and splitting tensile strength increased by 11.84 percent, but replacing more than 20% RHA lowered strength [11]

3.5 Bamboo Leaf as Addictive

BLA can be used as a pozzolan in High Performance Concrete if the percentage composition of $SiO2$, $Al2O3$, and $Fe2O3$ is greater than 70%, as stipulated by ASTM C-618, 2001. The percentage of OPC that should be replaced by BLA is 5%. When compared to the control sample, this replacement level resulted in HPC having higher compressive and breaking tensile strengths. In comparison to other percentages, the concrete with 5% BLA replacement had superior interlocking of concrete grains in the micrograph. The mechanical properties of BLA mixed HPC are improved when the curing time is extended beyond 28 days [12].

4. AGGREGATES

Aggregates must have a high strength so that they do not obstruct the concrete's ability to generate the requisite high strength. In the manufacturing of concrete, a variety of aggregates have been used. It has been demonstrated that excellent aggregates are free of alkali-aggregate reactivity and have a track record of reliability.

4.1 Natural Aggregate

Natural aggregates are strong, and using them desirable mechanical properties can be achieved for HPC. Crushed stone sand, with particle sizes ranging from 4 mm to dust (less than 0.075 mm), is a feasible alternative to river sand in concrete, especially where stronger compressive and flexural strengths are desired. Studies have demonstrated that a stronger coarse aggregate (CA) leads to higher concrete strength [13] and a mass ratio of CA to fine aggregate of less than 0.5 can lead to the most compact CA skeleton and improved compressive strength. The strength of Dmax = 10 mm crushed granite sand with a w/b ratio of 0.35 and SF was improved. The mechanical characteristics of HPC made using crushed granite CA, river sand fine aggregates, steel fibres, were investigated. CA concentrations of 16%, 28 %, and 38%, respectively, enhanced compressive strength by 31.5%, 54.4%, and 30.8% [14]. This was due to moderate aggregate and fibre integration, which resulted in a more compact and rigid skeleton capable of preventing microcrack propagation and internal degradation, with 28 percent CA being proposed as the ideal content.

4.2 Lightweight Aggregate

Several types of materials, such as expanded clay, have been used as LWAs for internal curing to improve the performance of high-performance concrete. LWA has benefits over natural aggregates including its smaller weight which leads to reduced transportation and construction costs. When LWA is oven-dried and then mixed into concrete, it absorbs water and releases it later as internal curing (IC), resulting in a faster hydration process and higher compressive strength [15]. In other words, the released water increases ITZ between aggregate and cement paste by increasing C-S-H formation and producing a thick and slightly porous paste structure, both of which contribute to increased strength. HPC autogenous shrinkage was reduced when LWA was used. The presence of internal water reservoirs that provide the required extra water may account for the reduction in autogenous shrinkage of concrete mixtures [16]. On another investigation it was found that addition of LWA beyond that limit for IC reduces the strength of HPC [17].

4.3 Recycled Aggregate

The use of recycled aggregate (RA) in new high-performance concrete (HPC) could be a green option. Reusing RA in the manufacture of HPC can help to reduce the amount of trash delivered each year by combining low-density RA as fine aggregate with natural coarse aggregate to achieve higher concrete strength levels. Furthermore, recycling and reuse would help to reduce global CO2 emissions. As the percentage of RA increases, tensile and flexural strength decreases. When compared to natural aggregates, however, using RA increases splitting and flexural strength. In HPC composites, RA enhances both the durability and the ITZ between the aggregate and the cement paste [18]. In a study the durability of HPC get also increased with recycled aggregate as it improves the ITZ between aggregate and cement by filling the micro voids with silica fume [37].

5. FIBRES

5.1 Steel Fiber

It can help to improve split tensile strength significantly. The addition of 1%, 2%, and 3% steel fibres to the 28d compressive strength significantly increased it by 58.13 percent, 59.25 percent, and 70.35 percent, respectively[14]. The ability of the fibres to prevent mechanical cracks by taking on the produced stress was attributable to this increase. Steel fibres were also found to boost tensile strength by up to 30% when compared to a control mix, but they also reduced the young's modulus [19]. The addition of 1% hooked steel fibres to recycled aggregate concretes boosted the splitting tensile and flexural strengths of HPC by 60% and 88 percent, respectively, at 28 days [20].

5.2 Polypropylene And Basalt Fiber

HPC reinforced with basalt and/or polypropylene fibres showed that the effect of polypropylene fibre is superior to that of basalt fibre in terms of improving flexural and splitting tensile strengths, with a significant improvement when the volume fraction of a single fibre was less than 7.2 percent [21]. A number of research have shown that basalt and polypropylene fibres have a negative impact on HPC compressive strength [22]. Hooked-end steel and polypropylene fibres were found to have acceptable self-compacting properties, with compressive, tensile, and flexural strengths increasing as the fibre percentage rose [23].

5.3 Synthetic Fiber

A study found that adding steel or synthetic fibres to LWSCC (light weight self-compacting concrete) made with ECA, RA, SF, and fibres as partial replacements increased compressive strength [24]. Furthermore, because concrete is a typical quasi-brittle material with low tensile strength, strain capacity, and fracture toughness, fibres have been claimed to inhibit and control crack initiation, propagation, and coalescence, hence improving the strength [25].

6. FRESH PROPERTIES

Slump test was used to evaluate the fresh concrete. This quick and easy test was sufficient for determining the concrete's fresh qualities. Concretes with the largest slumps at 15 minutes tended to have higher slumps at 60 minutes. Only the silica fume combinations had much greater super plasticizer doses, it should be noted. As a result, for the rest of the combinations, the variation in superplasticizer dosage had a minimal effect on slump loss and a slump of 180±10 mm expected for all RA mixes [26]. In a study with LWA the slump values were shown to decrease as the LWA content was increased. The addition of superplasticizer to the mix design, on the other hand, improved the workability of the combinations. Concrete mixes containing fine LWA had somewhat greater slump values than mixes containing coarse LWA, according to the findings [16]. In general, the slump intensified as the amount of SCM in HPC rose. The hydration of cement is delayed as the SCM replacement ratio is increased, which is beneficial to the slump. Fly Ash had a substantially bigger increase in slump than MK and GGBS, owing to its round shape and poorer water absorption than cement, MK, and GGBS. FA might fill the spaces between the sand and particles in the mix, allowing the fresh concrete to flow more easily.

7. MECHANICAL PROPERTIES

7.1 Compressive Strength

The compactness of the hardened matrix has a direct impact on the compressive strength of concrete. The compressive strength of the aggregate will not be much greater than that of the HPC. The only approach to increase strength when the coarse aggregate is limiting compressive strength is to utilise a stronger aggregate. But even if the compressive strength isn't raised when the W/B ratio is reduced, the matrix's compactness and HPC's durability are increased [27]. The compressive strength of HPC might be improved by both lowering FA and raising GGBS and MK. Because of the FA's sluggish pozzolanic response and retarding effect, HPC's compressive strength may be reduced. The compressive strength of HPC in all ages gradually increased as a result of GGBS. However, with time, this upward trend in compressive strength started to decline. The pozzolanic reaction between GGBS and cement hydration products enhances HPC's compressive strength [28]. Concrete specimens fail rapidly due to their brittle nature in the ultimate load condition, where it was discovered that the compressive strength improves with increasing the RA content [18]. In research it was determined that HPC made with natural aggregates can reach lower strength values than employing RA with mineral admixtures such as SF and FA [29]. The compressive strengths of the HPC specimens were somewhat decreased as a result of using fine and coarse LWAs as internal curing agents to replace NWA up to 20% [16].

7.2 Flexural Strength

Flexural strength is equivalent to value of 10% to 20% of compressive strength. Using a universal testing device, the three-point, four-point bending test was used to study the flexural behaviour [18]. According to investigations, every HPC made with RA had flexural strength values that were higher than or comparable to those made with natural aggregates [29]. In research it demonstrates that, independent of the existence of PP fibres, the residual flexural strength declines abruptly and continuously as the temperature rises [30]. Flexural and compressive strength diminishes as temperature rises in both regular and HPMC (micro high-performance concrete) materials exposed to high temperatures. When they are cooled with water, this decline is higher [31]. The flexural strengths of HPC 88 percent at 28d were dramatically enhanced by adding 1% hooked steel fibers to recycled aggregate concretes [20]. Alccofine increased compressive and flexural strength with a lower w/c ratio. Even with a decreased w/c ratio, workability was still very high. Flexural strength reached its peak when 12 percent Alcofine was used (22.5%). Alccofine was used in place of cement to increase workability without the addition of plasticizers (Saurav et al., 2017). Flexural strength was observed to increase slightly when SF was added to HSCC but significantly increased when SF replaced OPC [4].

7.3 Splitting Tensile Strength

One of the mechanical parameters of concrete that is employed in structural design is splitting tensile strength (STS). According to studies, employing RA to partially substitute natural aggregates significantly improved the results for splitting tensile strength [29]. Increased SF and MK could enhance HPC's pore structure and splitting tensile strength [7]. Also, the splitting tensile strength can be improved by the inclusion of fibers [22]. 2It was also discovered that the steam curing regime greatly increased the concrete's splitting tensile strength [32].

7.4 Modulus Of Elasticity

Not only compressive strength but also modulus of elasticity is significant from the perspectives of structural design and behaviour. According to Kuennen (1997), HPC gives pre-cast concrete structural elements improved mechanical qualities, such as better tensile and compressive strengths and an improved modulus of elasticity (stiffness). The stiffness of the cementitious matrix and the aggregates both affect the modulus of elasticity [26].

8 DURABILITY PROPERTIES

The performance of concrete during its service life can be determined in large part by how durability [26]. Due to the tight packing of micro and nanoparticles in concrete, its strength and durability have risen [9]. Concrete is susceptible to sulphate attack, which can lead to cracking, expansion, spalling, and strength loss [18]. Studies on the penetration of chloride ions into HPC produced with RA found that, because of its porous nature, resistance to chloride ions reduces as RA content increases [35]. The maximum resistance to chloride ion was, however, generated by traditional HPC made with natural aggregates

[18]. The more compact microstructure of concrete improves its resistance to the entry of damaging ions (such as sulphate, chloride, etc.) [36]. According to a study, adding 5% MK and 15% SF to concrete increased its mechanical and durability properties [34].

9 CONCLUSIONS

From the above studies it can be noted that supplementary cementitious materials such as silica fume, rice husk ash, metakaolin, alccofine, bamboo leaf ash etc improves the strength of HPC. With the usage of stronger aggregate higher is the strength and using a CA to FA ratio of 0.5 it provides a compact skeleton of aggregate. Use of LWA provide internal curing a faster rate of hydration. Steel fibers improve the split tensile strength, with hooked end steel fiber and polypropylene fibers strength and self-compacting property is improved. Important property of HPC is the resistance to adverse environment which can be improved by tight packing of particles. Resistance against chloride, sulphate penetrations and water absorption improve the durability property.

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