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Role of ingredients for high strength and high performance concrete – A review

A.K. Parande*

CSIR-Central Electrochemical Research Institute Karaikudi-630 006, Tamil Nadu, India

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Abstract. The performance characteristics of high-strength and high-performance concrete are discussed in this review. Recent developments in the field of high-performance concrete marked a giant step forward in high-tech construction materials with enhanced durability, high compressive strength and high modulus of elasticity particularly for industrial applications. There is a growing awareness that specifications requiring high compressive strength make sense only when there are specific strength design advantages. HPC today employs blended cements that include silica fume, fly ash and ground granulated blast-furnace slag. In typical formulations, these cementitious materials can exceed 25% of the total cement by weight. Silica fume contributes to strength and durability; and fly ash and slag cement to better finish, decreased permeability, and increased resistance to chemical attack. The influences of various mineral admixtures such as fly ash, silica fume, micro silica, slag etc. on the performance of high-strength concrete are discussed.

Keywords: high performance concrete; high strength concrete; mineral admixtures; curing

1. Introduction

Although high-strength concrete is often considered as a relatively new material, the development of the material has been gradual, spreading over decades. As development continued, the definition of high-strength concrete underwent continual change. For example, high-strength concrete in the 1950s meant concrete with a compressive strength of 34 MPa. This rose to 41-52 MPa and 62 MPa in the 1960s and early 1970s, respectively. 138 MPa have been classified as high strength concrete instead of have come to be used. For many years, concretes with compressive strengths in excess of 41 MPa were available at only a few locations. However, they have become common place with increasing demands from the construction industry. Currently available grades of concrete may be classified as: M50 (as normal strength concrete); M50-M100 (high-strength concrete); and beyond M150 (ultra-high strength concrete). The evolution of high-strength concrete is driven by developments in materials technology and specialty requirements of the construction industry. Several modern high-tech structures and superstructures would have been possible had it not been for high-strength concretes. This review focuses on the role of ingredients (such as admixtures), design aspects for strength, water-cement ratio (w/c), curing of concrete, strength and durability.

*Corresponding author, Ms., E-mail: corrparande@yahoo.co.in

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1.1 High strength concrete (HSC)

In the early 1970s it was believed that the practical limit of ready-mixed concrete was unlikely to exceed a compressive strength of 43 MPa. However, the past two decades witnessed great momentum in the technology of HSCs. The primary difference between HSC and normal-strength concrete relates to compressive strength, which refers to the maximum resistance a concrete sample can offer to an applied load. There is no precise line of separation between HSC and normal-strength concrete although the American Concrete Institute defines HSC as concrete with a compressive strength greater than 41 MPa. Production of HSC involves making optimal use of the basic ingredients that constitute normal-strength concrete and manipulating parameters that contribute to its strength. Optimization and appropriate combination of materials (cement, aggregates, water and admixtures) are also crucial. Factors to be considered in selecting aggregates for HSCs include aggregate strength, aggregate size, bonding between the aggregate and cement paste, and surface characteristics of the aggregate. Durability of concretes, which is related to permeability, alkali silica reaction, resistance to chemical attack, etc., may be achieved by lowering w/c, selection of ingredients, planning and strict quality control measures.

In general, better durability performance of concrete has been accomplished using high strength with low water-cement ratio concrete. The approach leads to better design based on strength that ultimately results in better durability. In high performance concrete durability is addressed directly. This is done by optimizing the particle size through one of the following techniques.

1. Reducing the capillary pore system so that no fluid movement can occur.
2. Creating chemically active binding sites which prevent transport of aggressive ions such as chlorides.
3. Requirements for high performance characteristics.

Permeation is a plays major role that causes premature deterioration of concrete structures in chlorides contaminated environment with often drying and wetting process. The high performance concrete has ability on minimizing permeation through proportioning methods and suitable construction techniques (curing) to ensure that the exposure conditions do not cause ingress of moisture and other agents responsible for deterioration. Permeation can be divided into the following three distinct but connected stages of transportation of moisture, vapour, air, gases or dissolved ions.

Careful selections of materials make mechanisms in the concrete system possible to produce high performance concrete economically. Many studies carried out by researcher’s shows X-ray diffraction analysis and electron micrograph clearly the advantages of using mineral admixtures for producing high performance concrete. However, careful selection of ingredients and their blends is important for durability under different exposures. For successful adoption of high performance concrete, material selection, mix proportioning and construction procedures are important. Within each of these operations there is scope for identifying controlling parameters for achieving specific high performance demanded by a particular environment that a structure has to withstand.

1.2 Admixtures

Pozzolanas such as fly ash, ground granulated blast furnace slag (GBFS) and silica fume are the most commonly used mineral admixtures in HSCs. These materials impart additional strength to concrete by reacting with the hydration products of Portland cement through the formation of calcium silicate hydrate (CSH) gels, the part of the paste that bestows strength to the concrete. In the design and production process, cementitious materials are used to effect long-term strength to concrete formulations. Micro silica imparts high strength (both compression and flexural), low permeability and increased durability. For example, with silica fume, compressive strength of about 131 MPa can be realized under job site conditions. This pozzolana can be added in slurry form or in dry form. Silica fume contributes significantly to early age strength of concrete. One pound of silica fume, for example, produces about the same amount of heat as one pound of Portland cement, and yields about three to five times as much compressive strength. Fly ash is a valuable additive that makes concrete stronger and more durable. Fly ash aids in the formation of cementitious compounds to enhance the strength, impermeability and durability of concrete. Two main classes of fly ash are used in concrete: class-C and class-F. Class-C fly ash provides unique self-hardened characteristics and improves permeability (especially useful in prestressed concrete and other applications). It increases the ultimate strength, reduces drying shrinkage and permeability, lowers heat of hydration and reduces creep. Class-F fly ash reduces bleeding and segregation in plastic concrete. It is difficult to produce HSC mixtures without chemical admixtures. A common practice is to use a superplasticizer in combination with a water-reducing retarder. The superplasticizer gives the concrete adequate workability at low w/c ratios, leading to concretes with greater strength. The water-reducing retarder slows the hydration of the cement and allows more time to place the concrete. HSC is specified where reduction in weight is important. HSCs have high load-carrying capacity. Therefore their use reduces the total amount of material required, which reduces the overall cost of the structure. Moreover, such columns will be slimmer, which allows for more useable space, especially in the lower floors of buildings. Most ready-mixed concrete producers are familiar with the concept of ‘performance concrete.’ Performance concrete implies that, “specifications will stipulate minimum concrete strengths and leave the proportioning of the concrete mixture to the concrete producer.” However, lately, another similar term, ‘high-performance concrete’, is encountered in the construction industry. This review deals with the design and production of HSCs, their properties, and the role of the engineer in the application of high-performance concrete (HPC).

2. What is high performance concrete?

According to the Strategic Highway Research Program (SHRP), HPC is a concrete meeting one of the following requirements.

(a) 4-hour compressive strength > 20.68 MPa
(b) 24-hour compressive strength > 34.47 MPa
(c) 28-day compressive strength > 68.94 MPa
(d) Water-cementitious ratio < 0.35

Also, the concrete must have a durability factor greater than 80 after 300 cycles of freezing and thawing. The American Concrete Institute (ACI) takes a broader view of the definition to include performance aspects other than compressive strength (this definition is similar to an earlier one proposed by the National Institute of Standards and Technology). Table 1 shows some typical properties of HPC and Table 2 shows those of admixtures used for HPCs.

Table 1 Some typical properties of high performance concrete

Sl no	System	Range
1	High ultimate strength	41.36 to 68.94 MPa compressive strength @ 28
2	High early strength (18 to 24 hours)	17.23 to 27.57 MPa compressive strength 2.75 to 4.13 MPa flexural strength
3	High modulus of elasticity	Greater than 44815.94 MPa
4	High durability	Protection against corrosion of embedded steel, Protection against severe environments
5	High workability	Mid-range concrete: 6 to 8 in. slump
	Pumpability and finishability	Flowing concrete: greater than 8-in slump
6	Without segregation	Reduced pumping pressures, Easier finishing and self-consolidating
7	Placable in cold weather	Normal setting time, Accelerated strength gain, Low temperatures freeze protection
8	Normal slump retention	Control of hydration
9	Controlled hydration	Extended setting time as required by project conditions

Table 2 Admixtures for high performance concrete

	Admixture category	Applications	Standards	Most effective use
1	Conventional admixtures	Water reducers Retarders Accelerators Combinations	ASTM C: 494 Types A, B, C, D, E	Allow use as requested
2	Superplasticizers	Greater water Reduction 12 to 30%, Flowing concrete self-consolidation	ASTM C 494	Allow slumps in excess 0.2 m in, Allow free of fall 4.6 to 6.1 m; Allow redosing, Allow batch plant
3	Silica fume	High strength High durability	AASHTO M-307	Must include use of Superplasticizer specify, Specify amount suitable to the application
4	Non-chlorides accelerators	Improved setting at low temperature, Improved strength Gain characteristics	ASTM C 494 Type C and E	Reduces protection time, Allow early form removal
5	Cold weather admixtures	Allows concrete to set At ambient temperature as low as -16℃ Reduce winter protection	None	Reduce winter heating, Allow placements without protection
6	Hydration control Admixtures	Extend setting time long haul application.	None	Allow use of treated concrete, Allow increased haul time

2.1 Bond fracture and crack propagation

As concrete strength increases, the descending branch of the stress-strain curve gradually becomes steeper. For HSCs, yield points are almost on the vertical softening curve. In the absence of special precautions, very high explosive failures can occur during compression tests. Here, the fractured surface crosses the coarse aggregates and a fairly smooth fractured surface result. For these reasons, HSCs are generally considered brittle. This brittleness is cause for instead of its cause for concern especially in structural applications. However, HSC beams and slabs show a higher flexural ductility than corresponding normal strength specimens. Hence, it is of great practical importance to gain fundamental insights into the fracture process of HSCs and the factors that influence it. This can lead to appropriate measures to improve material toughness or to rational ways to account for it in design procedures.

2.2 Creep and shrinkage of high strength concrete

Since HSCs are often subjected to compressive loads, creep deformations are generally larger than the elastic deformations, which may have serious consequences in their structural behaviour. Long-term deflections of concrete structures, stress redistribution in reinforced concrete and loss of prestress in prestressed concrete are related to strains due to creep and shrinkage.

2.3 Steel fibers in high strength concrete

For design purposes under ultimate limit state conditions, the constitutive law for uniaxial compression is the well-known parabola-rectangle diagram. Due to the more brittle nature of HSCs, the ultimate strain decreases when the strength increases. Compression tests on cylinders indicate that steel fibers increase the toughness of HSC and that a higher and more stable softening branch of the stress-strain curve is obtained.

2.4 Early age thermal cracking in HSCs

Due to the heat of hydration, HSC elements might show some early age thermal cracking. Several groups have investigated this problem by adiabatic and isothermal hydration tests in combination with a study of the mechanical properties of the concrete during hardening. Also, the creep and shrinkage behaviour of HSCs at early ages has been examined. A simulation programme has been developed using the degree of hydration as a fundamental parameter.

3. Performance characteristics of HSCs

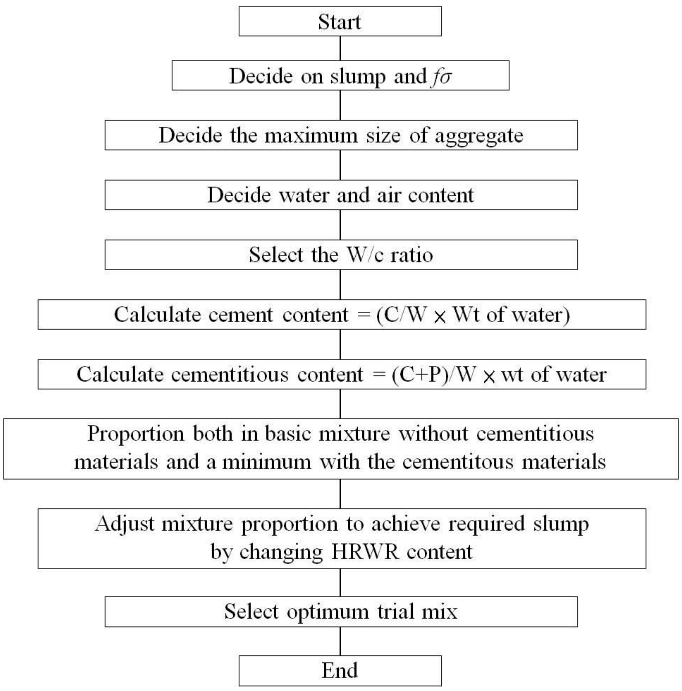
The cement paste microstructure has a great impact on the strength, permeability and volumetric stability (resistance to plastic shrinkage, drying shrinkage and creep) of HSCs. Factors affecting paste microstructure are mixture proportions, temperature and humidity during curing, w/c ratio, chemical and mineral admixtures, amount of shear during mixing, and degree of over-mixing (Nawy 1996). Fly ash and blast furnace slag, in addition to reducing the heat of hydration at early ages, tend to reduce the effects of the preceding parameters on the formation of the paste microstructure. Silica fume accelerates early hydration by reducing the effect of

Table 3 Classification of high strength concrete

Parameter	High strength	Very high strength	Ultra high strength
W/(C+P) Ratio	0.45 - 0.30	0.30 - 0.24	< 0.24
Chemical admixture [a]	WRA/HRWR	HRWR [a]	HRWR
Mineral admixture	Fly ash or combined with SF	Silica fume [b]	Silica fume
Permeability coefficient (cm/sec)	10^{-11} [c]	10^{-12}	$< 10^{-14}$
Freeze-thaw protection	Air entrainment	Air entrainment	No freezable water
Strength, MPa	42 – 100 MPa	100 - 150 MPa	> 150 MPa

[a] HRWR = High range water reducer (super plasticzer) also may contain fly ash
[b] mineral admixtures
[c] Coefficient for normal strength concrete vary 10-10, WRA = Water reducing agent

Table 4 Flow chart for mix proportioning of high strength, high performance concrete



lignosulfonate retarders. Lignosulfonates predominantly effect the hydration kinetics of the C_3S (silicate) phase of Portland cement. The sulfonate and hydroxyl groups in lignosulfonates allow them to adsorb onto and then incorporate into the CSH gel layer. This causes a change in the morphology of the CSH gel leading to a more impermeable structure. Thus, microstructure formation will be faster than expected when retarders are used (Boncukcuoğlu *et al*. 2002). HSCs have a compact, extremely low void structure, resulting from filling of pores with pozzolanic cementitious material. Thus, it has very low permeability. This helps to resist freeze-thaw attack, chemical attack, salt penetration, and corrosion of the embedded steel. Table 3 shows the classification of HSCs.

3.1 Design and production of HSC

The most common method of producing HSC is by optimizing the combination of cementitious material, aggregates, water, and admixtures. Typically, fly ash or GBFS substituted for part of Portland cement is an effective method to increase long-term strength. Low w/c ratios also increase concrete strength (up to a limit). A flow chart for mix proportioning of high strength, high performance concrete is given in Table 4.

Fineness modulus of sand = 2.6, Dry rodded weight of coarse aggregate = 1601.84 kg/m^3

Moisture absorption = 3% for coarse aggregate and 2% for fine aggregate

Several specific parameters are considered in the production of HSC;

1. High compressive strengths can be realized if the maximum size of the coarse aggregate is low. The combined aggregate of 8–18% for large top-size aggregate (12.7 mm) or 8-22% for small top-size aggregate (25-20 mm) are retained in each sieve.
2. Fine aggregates and high cement content proportionately increase the compressive strength. A fineness modulus of 2.70-3.00 is preferred.
3. Substantial slump loss can result in the absence of pozzolanic materials in HSC. Use of fly ash or blast furnace slag reduces slump loss as well as production costs. The optimum substitution level is usually controlled by a minimum value or by an acceptable loss in 12 h- or 24 h-strength. Pozzolanic materials produce lower short-term strengths.
4. For target strengths > 100 MPa, silica fume constitutes an essential ingredient in the mixture.

3.2 The pros and cons of HSC and HPC

There are distinctions between the characteristics of HSC and HPC. HPC is a terminology of recent origin. ACI Technical Activities Committee defines HPC as “concrete, which meets special performance and uniformity requirements that cannot always be achieved by using only conventional materials and normal mixing, placing, curing practices”. The requirements could be improved characteristics in terms of placement and compaction without segregation, long-term mechanical properties, early age strength, toughness, volume stability, and service life in extreme environments. Because many characteristics of HPC are interrelated, a change in one can affect one or more other characteristics. An HSC is always an HPC, but an HPC need not always be an HSC. ACI defines an HSC as one that has a compressive strength of 41 MPa or greater (ACI Committee 211 1993). Some countries define it as concrete with a minimum compressive strength of 48 MPa minimum, while some others specify a value. However, the ACI definition is open-ended. Use of HSC in durable concrete structures need not ensure their durability, for such structures should possess some key characteristics required for durability. In the past, durable concrete had specified air and cement contents and w/c ratio. Today, the specifications include performance characteristics such as permeability, deicer scaling resistance, freeze-thaw resistance, abrasion resistance, etc. Modern concrete materials with HSCs, in addition to Portland cement, contain mineral and chemical admixtures that help to improve compressive strength and durability.

Curing of concrete HPC is different from that of ordinary concrete because of differences in shrinkage behaviour. HPC that is not water-cured immediately after placement or finishing is prone to severe plastic shrinkage. HPC that is not protected by bleed water develops severe autogenous shrinkage due to its rapid hydration. A critical curing period (2-3 days) is adopted after placing and finishing, the latter being the most critical (12-36 h).

4. Results and discussion

4.1 Strength and durability

HSC mixtures, which have relatively high cement content and superplasticizing admixtures, and very low water content, can develop discontinuous pore structures and low permeability within a few days of cement hydration. Kim *et al.* (2002) studied the effect of curing temperature and aging on the strength and elastic modulus on HSC and normal cement. They found that concretes subjected to high temperatures at early ages attained high early-age compressive strengths, but lower splitting tensile strengths at later-age as compared to concretes subjected to normal temperatures. Even though the elastic modulus had a similar tendency, the variation of elastic modulus with curing temperature was not as obvious as compressive strength. Zain and Radin (2000) studied the compressive strength and modulus of elasticity of HSC made with four types of concrete mixes and exposed to temperatures between 20 and 50℃ under three types of curing methods. They showed that the compressive strength of concrete with mineral admixtures reached above 100 MPa from the age of 7 days. The maximum strength and modulus of elasticity were obtained with silica fume concrete under water and wrapped curing at 35℃. This suggests that the high pozzolanic reactivity and micro-filler effect of silica fume at medium temperatures modifies the open channels at the transition zone in the concrete. Temperature plays an important role in the hydration process leading to hardened concrete with high strength and elasticity.

Bastami *et al.* (2011) studied the effect of temperature on compressive strength, spalling and mass loss of High Strength Concretes (HSCs). Average compressive strength of the HSCs was varied from 65 to 93 MPa, by Taguchi's method. The experimental results showed that the effects of elevated temperature exposure on the mechanical properties and potential for explosive spalling of HSCs. The results indicate that the effect of silica fume, cement, fine aggregate, coarse aggregate and water on residual strength, spalling and mass loss of the HSCs. The presence of silica fume had no statistically significant effect on the relative compressive strength. The type of aggregate had a significant influence on the thermal properties of HSCs at elevated temperatures.

Self-compacting concrete (SCC) is a new category of HPC, characterized by its ability to spread under its own weight and is self-compact without any segregation or blocking. Ibhraim and Türkmen and Kantarcı (2007) studied the compressive strength, apparent porosity and capillarity coefficient of SCC containing expanded perlite aggregate (EPA) and natural aggregates under different curing conditions. It was found that both capillarity coefficient and apparent porosity increased by use of EPA, and that the compressive strength of EPA concrete generally decreases with increasing EPA content. Other studies showed that heating led to both chemical and physical changes and resulted in loss of strength and high risk of spalling in HSC than in normal strength concrete (Yazıcı 2007, Gettu *et al*. 1998).

An axial load could induce a restraint force on the failure of HSC columns and leading to spalling (Benmarce and Guenfoud 2005). By use of a mix compositions of polyvinyl alcohol and fiber reinforced lightweight concrete, Arisoy and Wu 2006, Eether *et al*. 2012) demonstrated a high performance composite. The resulting high performance fiber reinforced lightweight concrete (HPFRLWC) showed high flexural strength, high flexural ductility, and excellent toughness. The lower densities of HPFRLWC (0.8-1.6 g/cm^3) represent a 35-75% reduction from normal weight concrete.

Studies by (Reda *et al*. 1999, Folino and Etse 2012) on ultra-high performance concrete (UHPC) with target strengths > 200 MPa prove attractive for specialty structural applications that require superior mechanical performance. The UHPC had unique dense microstructures. The bonding between the fibres and cement paste was strong. Moreover, the cement paste in the vicinity of the fibres was dense and homogeneous. A new UHPC composite was developed by Parant *et al*. (2007), which strain hardens under tension and has high uniaxial tensile strength (> 20 MPa). Furthermore, the composite displayed an 8% gain in fatigue behavior. Surlaker (2002) described the properties and composition of HPC with special reference to self-compacting. An outline of the new generation super plasticizer for such concrete was also discussed.

The durability of concrete is associated with its environment and high water/binder ratio. HPCs that have a water /binder ratio (0.3-0.4) are usually more durable because they are less porous and their capillary networks are somewhat disconnected as a result of self-desiccation (Aictan 2003). Partial replacement of coarse aggregate by an equivalent volume of saturated lightweight aggregate has been used to counteract autogenous shrinkage (Duval and Hornain 1992, Costa *et al*. 2012). The latter particles act as small water reservoirs in the concrete. They fill most of the pores created by hydration reactions, allowing the water to be drained along with that contained in the fine capillaries of the HPC. Jaffar *et al*. (2003) investigated the effect of fine stone dust as a cement replacement on the mechanical and durability characteristics in HSC. The effect of curing by autoclaving was also considered. The results indicated that by autoclaving use of fine dust, HSC with improved strength and durability could be produced. Marine environments can be harmful to RCC due to a multiplicity of aggressive factors: chemical factors (ions in seawater, transport phenomena), geometrical factors (fluctuations of sea waves), physical factors (freezing, thawing, drying), and mechanical factors (erosion suspended sand in seawater, kinetic action of waves). Peng *et al*. (2007), Jalal *et al.* (2012) used an air-entraining agent along with silica fume and fly ash to meet the design strengths of 50-60 MPa and a frost resistance up to 300 cycles of freezing and thawing. It was shown that frost resistance might be independent of strength and that air entrainment, irrespective of the pozzolan, increased the size and volume of the pores. At a water/binder ratio of 0.32, air entrainment was shown to be key to enhance frost resistance. However, pozzolans could increase the long-term strength of concrete.

In their study of the durability of high-performance metakaolin (MK) and silica fume concretes, (Poon *et al*. 2006, Ramezanianpour and Jovein 2012) found that their mechanical and durability properties were related to their microstructure. It was found that MK concrete had superior strength development as compared to silica fume concrete although they both had similar chloride resistance (Tables 5 and 6).

Chloride ion penetration into the concrete could be better related with the porosity of the concrete than to Incorporation of pozzolans led to an improvement in the interfacial microstructure. Resistance to chloride ion penetration is a simple method to determine the durability of a concrete. HPC offers high resistance to chloride ion penetration. Oh *et al*. (2002), who studied the rapid chloride permeability (AASHTO T 277 and ASTM C 1202) of concretes, observed that concrete containing an optimal amount of silica fume showed high resistance to chloride penetration.

A study of the effect of curing duration, type of curing water, aggregate washing and degree of consolidation on the corrosion resistance characteristics of HSC was made by Rasheeduzzafar *et al*. (1989). Concrete cured for 28 days performed 4.4 times better in terms of corrosion of reinforcement and showed 59 percent strength reduction and 40% weight loss improvements to

Table 5 Chloride penetrability of control and blended concretes

Sl no	w/b	Mix	Total charge passed (C)			
			3 days	7 days	28 days	90 days
1	0.3	Control	2461	2151	1035	931
		5% MK	1327	2144	862	646
		10% MK	417	347	199	135
		20% MK	406	395	240	124
		5% SF	1060	945	664	426
		10% SF	567	445	360	336
2	0.5	Control	5312	4054	2971	2789
		5% MK	4215	3765	2079	1065
		10% MK	1580	1247	918	752
		20% MK	751	740	640	580
		5% SF	3156	2047	1641	1235
		10% SF	3140	1877	1523	1053

Table 6 Compressive strength of control and blended concretes

Sl no	w/b	Mix	Compressive strength (MPa) days			
			3 days	7 days	28 days	90 days
1	0.3	Control	68.5	81.1	96.5	192.5
		5% MK	73.0	88.2	103.6	112.9
		10% MK	85.9	99.8	116.8	120.3
		20% MK	70.8	87.6	99.6	113.8
		5% SF	67.0	79.3	106.5	110.2
		10% SF	63.2	76.9	107.9	115.6
2	0.5	Control	28.6	41.2	52.1	60.4
		5% MK	32.6	45.9	57.1	66.5
		10% MK	40.4	55.2	66.2	71.6
		20% MK	30.0	43.2	58.4	69.1
		5% SF	27.4	47.0	54.3	67.5
		10% SF	25.8	47.4	58.4	69.1

sulfate resistance compared to that cured for 7 days. Aggregate washing led to about 15-20% improvement in the aggregates tested in this study. Thus, the degree of consolidation has a significant effect on concrete durability. Lewis (2001) has reviewed the production of micro silica, efforts of standardization, comparison of current standards and properties of microsilica concrete both in the fresh and hardened states. It was observed that the superfine size and high pozzolanic reactivity make silica fume a basic ingredient for concrete requiring high strength or durability. It can also be used in conjunction with other cementitious materials like GBFS and pulverized fuel ash in order to achieve economic and highly durable concrete. (Kaushik *et al*. 2001, Nath and Sarker 2011) critically reviewed certain basic properties of HSC and their likely impact on structural design. Concrete compressive strength is a function of the closeness of the cement particles as well as cement dosage. In fact, reactive powder concretes testing 200 MPa are preferably made with coarse cements not so rich in C_3S and C_3A, that is, cements for which it is easy to control the rheology. Present cement acceptance standards that were very safe when 20 to 25 MPa concretes were the most used concretes are not always appropriate to test cements that are to be used in conjunction with superplasticizers to make high-performance concrete. Hitherto much emphasis has been placed only on 28-day compressive strength. It is very important to design concrete mixtures that keep their 28-day compressive strength over the life of the structure. Finally, cement and concrete will have to evolve with changing environments and developmental needs.

5. Conclusions

Most HSCs have high cementitious contents and w/c ratios of 0.40 or less. However, the proportion of the individual constituents varies depending on local preferences and local materials. Factors that can alter concrete properties include admixtures, aggregates and w/c. Substitution with alternative materials can result in change in performance. HSCs are being developed by designing proper mix ratios, using chemical admixtures and mineral admixtures such as silica fume, micro silica and high volume fly ash. Their use will also result in cost reduction. The new concretes also can lead to size reduction of concrete structures. This opens avenues for high constructability concrete–easily transported, placed and compacted even in structures with congested reinforcement. The degree of consolidation remarkably influences the durability of concrete. Superplasticizers help to improve durability rather than the workability of concretes. In sum, HSCs present a cost advantage through less dependence on reinforcing steel

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