Experimental Studies On Compressive Strength And Durability Aspects Of Eco-Friendly High Performance Concrete

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Abstract- *The paper presents experimental studies conducted on two grades of high performance concrete (HPC) mixes of M50 and M60 using mineral and chemical admixtures in various proportions. The main purpose of this investigation is to develop confidence among user agencies in India to use mineral and chemical admixtures in a desirable proportion in most of the construction works. Overall, the paper highlights the usage of admixtures to achieve high strength concrete mixes and from the experimental investigation it is clear that mineral admixtures contribute effectively a lot not only for achieving durability, also high strength.*

Keywords- Chemical Admixtures, High Performance Concrete, Concrete mix, Durability

I. INTRODUCTION

Concrete is considered as durable and strong material. Reinforced concrete is one of the most popular materials used for construction around the world. Reinforced concrete is exposed to deterioration in some regions especially in coastal regions. Therefore researchers around the world are directing their efforts towards developing a new material to overcome this problem. Invention of large construction plants and equipments around the world added to the increased use of material. This scenario leads to the use of additive materials to improve the quality of concrete. As an outcome of the experiments and researches, cement based concrete which meets special performance with respect to workability, strength and durability known as" High Performance Concrete" was developed.

High Performance Concrete can be designed to give optimized performance characteristics for a given set of load, usage and exposure conditions consistent with the requirements of cost, service life and durability. The high performance concrete does not require special equipments except careful design and production. High performance concrete has several advantages like improved durability characteristics and much lesser micro cracking than normal strength concrete.

1.2 High Performance Concrete

High performance concrete (HPC) is that which is designed to give optimized performance characteristics for the given set of materials, usage and exposure conditions, consistent with requirement of cost, service life and durability.

The American Concrete Institute (ACI) defines HPC ‘‘as concrete which meets special performance and uniformity requirements that cannot always be achieved routinely by using only conventional materials and nominal mixing, placing, and curing practices.” The performance may involve enhancements of characteristics such as placement and compaction without segregation, long-term mechanical properties, and early age strength or service life in severe environments.

"All high-strength concrete is high-performance concrete, but not all high-performance concrete is high-strength concrete," says Henry G. Russell, consulting engineer and former chairman of the American Concrete Institute's high-performance concrete committee. High-performance concrete (HPC) is not one product but includes a range of materials with special properties beyond conventional concrete and routine construction methods.

1.3 Need of High Performance Concrete

To put the concrete in to service at much earlier age, for example opening the pavement at 3-days. To build high-rise buildings by reducing column sizes and increasing available space. To build the superstructures of long-span bridges and to enhance the durability of bridge decks. To satisfy the specific needs of special applications such as durability, modulus of elasticity, and flexural strength. Some of these applications include dams, grandstand roofs, marine foundations, parking garages, and heavy industrial floors.

1.4 General Characteristics of HPC

High-performance concrete characteristics are developed for particular applications and environments; some of the properties that may be required include:

- High strength
- High early strength
- High modulus of elasticity
- High abrasion resistance
- High durability and long life in severe environments
- Low permeability and diffusion
- Resistance to chemical attack
- High resistance to frost and deicer scaling damage
- Toughness and impact resistance
- Volume stability
- Ease of placement
- Compaction without segregation
- Inhibition of bacterial and mold growth

Performance Characteristic	HPC Performance Characteristic Grade 1	2	3
Freeze-thaw durability (F/T=relative dynamic modulus of elasticity after 300 cycles)	70%<F/T<80%	80%<F/T<90%	90%<F/T
Scaling resistance (SR=visual rating of the surface after 50 cycles)	3.0>SR>2.0	2.0>SR>1.0	1.0>SR>0.0
Abrasion resistance (AR=avg. depth of wear in mm)	2.0>AR>1.0	1.0>AR>0.5	0.5>AR
Chloride penetration (CP=coulombs)	2500>CP>1500	1500>CP>500	500>CP
Alkali-silica reactivity (ASR=expansion at 56 d) (%)	0.20>ASR>0.15	0.15>ASR>0.10	0.10>ASR
Sulfate Resistance (SR=expansion) (%)	SR<0.10 at 6 months	SR<0.10 at 12 months	SR<0.10 at 18 months
Flowability (SL=slump, SF=slump flow	SL>190 mm and SF<500 mm	500<SF<600 mm	600 mm<SF
Strength (f'c=compressive strength)	50<f'c<69 MPa	70<f'c<97 MPa	98 MPa<f'c
Elasticity (E_c=modulus of elasticity)	34<E_c<41 GPa	41<E_c<48 GPa	48 GPa<E_c
Shrinkage (S=micro strain)	800>S>600	600>S>400	400>S
Creep (C=micro strain/pressure unit)	75>C>55/MPa	55>C>30/Mpa	30/MPa>C

1.6 Advantages of HPC

The advantages of using high strength high performance concretes often balance the increase in material cost. The following are the major advantages that can be accomplished.

- Reduction in member size, resulting in increase in plinth area/useable area and direct savings in the concrete volume saved.
- 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 with the accompanying reduction in shoring and stripping time due to high early-age gain in strength.
- Construction of High –rise buildings with the accompanying savings in real-estate costs in congested areas.
- Longer spans and fewer beams for the same magnitude of loading.
- Reduced axial shortening of compression supporting members.
- Reduction in the number of supports and the supporting foundations due to the increase in spans.
- Reduction in the thickness of 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.
- Greater stiffness as a result of a higher modulus of elasticity
- Higher resistance to freezing and thawing, chemical attack, and significantly improved long-term durability and crack propagation.
- Reduced maintenance and repairs.
- Smaller depreciation as a fixed cost.

1.7 Limitations

- High Performance Concrete has to be manufactured and placed much more carefully than normal concrete.
- An extended quality control is required
- In concrete plant and at delivery site, additional tests are required. This increases the cost
- Some special constituents are required which may not be available in the ready mix concrete plants.

II.MIX DESIGN PROPORTIONS

2.1 Mixture Design

Mixture design involves identifying the fresh and hardened concrete properties required for a specific application. The FHWA has developed a model based on performance grades that will guide mix designers in developing concrete mixtures to be placed in bridge elements. These performance grades can be found in Section 3 of this HPC guideline, and are determined by the environment and restrictions that are applied to the construction site location.

The designer should take into account performance issues in addition to the normal compressive strength at a particular age. The performance criteria should identify durability issues that the concrete will be exposed during its service life.

HPC is often required to have improved mechanical properties. The mix designer may require higher compressive strength, or specific requirements on shrinkage, creep or modulus of elasticity. Exposure conditions may dictate concrete that has specific levels of resistance to sulfate attack, abrasion resistance, resistance to alkali-silica reaction or frost damage. In order to meet this approach a clear understanding of the environmental demands must be developed. Tests to define the expected service life should be implemented in order to establish the resistance criteria needed to meet the environmental demands. If sulfate is found to be an attack mechanism then include tests for permeability and specific sulfate resistance criteria, or use sulfate resistance cements to ensure that this protection can be delivered in the final product.

Abrasion resistance on the other hand, can be addressed by including requirements for strength. In addition, identifying material requirements such as hardness of the aggregate in the specification can also be used in the development of the concrete mixture. It can be shown by graphical representation, that concrete produced with different sources and percentages of fly ash will be more resistant to abrasion. In this case, abrasion resistance can best be described by compressive strength. In other words, the high cementitious fraction of the mixture is a key factor in the mix to resist abrasion than the actual selection of the specific coarse aggregate.

Resistance to Alkali –Silica reaction in the concrete is best addressed by developing a low permeability concrete as well as the selection of the composition of the materials. A key here is to avoid using reactive aggregates when producing the concrete. Freeze thaw characteristics can be controlled by including specific acceptance criteria for permeability, as well as a conservative window for the air content of the concrete.

Permeability should be the controlling requirement if the concrete will be placed in an environment subjected to concentrations of chloride ions. The designer should understand that permeability will decrease with concrete age. With that, permeability values can be established at 28 days with an understanding that by the time the element is placed into service it will be considerably lower than when tested at 28 days. It can be shown that the permeability of plain cement concrete with no fly ash can decrease significantly up to about 60 days after placement. However no significant decrease in permeability will occur after 60 days. On the other hand, concrete containing fly ash continues to decrease in permeability for 100 to 200 days after casting.

2.2 Mixture Proportioning

Mixture proportioning is both an art and a science that involves determining appropriate amounts of various ingredients to produce a mixture fulfilling design requirements economically. To proportion high performance concrete, the designer should follow some general rules. The old rules of thumb no longer apply. Concrete will now be proportioned to be durable and perform its intended function in a long service life. Concrete fundamentals and experience are needed, and the importance of optimizing the materials is essential. The interaction between specific component materials is considerably more important than the individual materials themselves. It is important to be innovative and test ideas in the trial batch process. If it makes sense then give it a try.

2.3 Cement and Supplementary Cementitious Materials

Typically use only Type I or II cement; try to avoid Type III unless very high early strengths are needed. Look for medium range fineness in the cement, if the cement is too fine the concrete will produce excess heat during hydration that may develop additional problems. If possible, try to utilize cements with high C2S content for long-term strength. Understand that cements produced under the same specification, be it ASTM or AASHTO, and may not perform the same. Comparatively, the different types of cements will tend to produce higher or lower compressive strengths, will set at different rates, or will be more or less sulfate resistant than others. The mix designer will need to trial batch concrete with a specific cement and then continue to use this cement for the duration of the project. Alternate cement could be used, but the trial batch process should be repeated to ensure that the concrete produced will perform its intended function.

Understanding the performance of concrete, especially HPC, requires an understanding of the interaction of Portland cement with fly ash, slag or silica fume. Calcium hydroxide is developed as a result of the reaction of water and cement commingling and reacting. The reaction typically develops heat and initiates the hydration process. Fly ash meeting the requirements of ASTM C-618, on the other hand, may or may not contain a significant amount of calcium in its composition. Some fly ashes are rich in calcium and may initiate the hydration process with the addition of water. However, fly ashes that are low in calcium need cement to generate enough calcium hydroxide to aid in the development of strength. Usually this strength development is a long- term strength gain since the combination of fly ash and cement normally delays the setting time and thus the short- term strength development. This reaction is sometimes referred to as a “Pozzolanic reaction” because it requires the production of calcium hydroxide produced as a result of hydration of the Portland cement. This reaction occurs at later times than for cement mixed only with water. In addition, the "Pozzolanic reaction" will react differently based on the type and source of the cement.

Another cementitious material that is utilized during the proportioning of high performance concrete is ground granulated blast furnace slag meeting the requirements of ASTM C-989. With slag, the hydroxyl ions released as the cement initiates hydration provides the mechanism for the breaking down of the glassy slag particles into a cohesive paste and ultimately a hardened concrete. Unlike fly ash or silica fume, slag does not require calcium hydroxide to initiate hydration. When utilizing slag as a cementitious material trial batches are necessary since slag will normally require less chemical admixtures to ensure workability than mixes with silica fume or fly ash. Also, the rates of slag substitution are typically in a rage from 25 to 70 % of the cementitious material. This generates a slower rate of strength gain depending on the amount of slag proportioned into the mix. Slag provides an excellent supplementary material for mass concrete placements because overall heat is reduced as the cement content is lowered. Additionally, slag provides improved sulfate resistance, decreased permeability, and increased resistance to freeze thaw conditions.

Silica fume is another supplementary cementitious material utilized in the batching of HPC. It is produced to meet the requirements of ASTM C-1240. It has an extremely small surface area with the ability to react with calcium hydroxide to form a very hard and impermeable concrete. Silica fume is a by-product of the silicon and Ferro-silicon production industry. The particle size of the raw silica fume is smaller than cigarette smoke and as a result is only sold as condensed or granular form and normally has a specific gravity of 2.20 to 2.30. The production of silicon and Ferro-silicon materials requires extremely tight quality control measures to ensure a consistent end product. This provides a very consistent by-product in the form of silica fume that in turn provides some of the strongest and most durable concrete used in construction. However, one short coming of this material is its propensity for shrinkage cracking. This usually occurs when adequate moist curing is not provided after the finishing of the concrete surface.

The effect of different brands of cement in concrete containing fly ash, slag or silica fume cannot be fully explained on the basis of water to cementitious materials ratio. Different brands of cements achieve similar reductions in water to cementitious materials ratio, however each concrete produced with different brands of cement and different cementitious materials can also produce significantly different flexural and compressive strength which may or may not meet the design requirements. In short, the emphasis on trial batching cannot be overlooked.

2.4 Aggregates

Coarse aggregate is one of the most important materials in HPC. The following are some general guidelines to be considered when selecting a coarse aggregate for use in the production of HPC. These include limiting the maximum size of the aggregate to less than 1 inch, which ensures good compatibility. The use of coarse aggregate with lower percent voids results in the production of high compressive strength concrete because the mixing water can be reduced and still maintain good workability

Smaller maximum size aggregates are typically needed to ensure a high mortar to aggregate bond. Smaller size aggregate also allows for closer spacing between reinforcing steel. It has been found that the use of a coarser gradation of coarse aggregate often results in the achievement of higher compressive strength concrete as a result of being able to use less mixing water while ensuring the same workability. A general guideline developed by ACI Committee 211 suggests that for concrete less than 60 MPa compressive strength, use ¾ to 1 inch maximum size aggregate. For concrete compressive strength greater than 60 MPa, use 3/8 to ½ inch size aggregate.

In normal concrete mixtures the maximum aggregate size is utilized in order to reduce the aggregate surface area, which in turn reduces the water requirement for the mix. By doing, this, the cement content is increased to ensure complete coating of all aggregate particles. At some point the continued addition of cementitious materials will not increase the compressive strength. In these cases the surface area of the aggregate is reduced to ensure that the optimum cement content and aggregate size are combined to deliver the optimum concrete mixture.

Further increases in compressive strength can be realized by changing the type of aggregate in the mix. For instance, crushed aggregates are better than smooth because of the angular surfaces that are formed as a result of the crushing process. The rough angular surface forms a strong bond at the aggregate/cement paste interface. In addition, a good aggregate will usually influence the properties of the hardened concrete, especially strength, modulus of elasticity, creep and shrinkage.

Fine aggregate is also a very important part of the concrete mix which affects the workability during placement. In general, HPC can be produced by using natural or "uncrushed" rounded sand with a fineness modulus between 2.60 and 3.10. When designing for HPC consider reducing the ratio of the fine to coarse aggregate to ensure that the water demand can be reduced. In addition, the workability of the concrete is assisted by the use of high range water reducing admixtures. Always avoid the use of manufactured or crushed fine aggregate because they will typically increase the water demand of the mix.

2.5 Admixtures

An important issue to identify in the design of HPC is the control of the set time. Admixtures are specifically designed to help the contractor control the setting time of the mix in certain cases. These admixtures are designed to precondition the concrete and allow for greater placing time. They aid in the control of concrete by slowing the rate of hydration and should be used when the concrete temperature is expected to rise above 75 degrees F. They will normally reduce early strengths at 24 hours but after this initial delay typical strength gains occur.

High range water reducers (HRWR) should be used with good quality concrete. The purpose of the HRWR is to give the contractor additional time to place concrete and in some cases delay the set time. Its purpose is not to make quality concrete out of a poorly designed mix. HRWR should not be used if the design mix was not proportioned correctly or the correct materials were not included in the mix. A mix design targeting a 1 to 2 inch slump would normally indicate a low water to cementitious material ratio which is ideal for HPC. However, this is typically a very difficult mix to place and consolidate. If a HRWR is added at this point, the slump could be increased to 7.5 inches or more, which would allow the concrete to be placed and consolidated with less effort. Again, the drawback of adding a HRWR to the mix is the associated delay in the set time and lower early compressive strengths. Even with the addition of HRWR to the mix, compressive strengths in the 60 to 90 MPa range are attainable using an aggregate size of 1 inch or smaller.

As a general statement, the production of HPC will require the use of HRWR to ensure workability when a low water to cementitious materials ratio is specified. In addition, the dosage rate of these admixtures will typically be higher than normal concrete mixtures and higher than the manufacturer's recommendation. If a newer generation of HRWR is utilized, (admixtures specifically designed for flowing and self-consolidating concrete) the HRWR usage rates will be defined by trial batching the concrete and identifying the plastic properties of the mixture. Air entrainment is another admixture that is typically required in the mix to assist in the workability of the concrete. If the concrete will be exposed to cycles of freezing and thawing, air entrainment will be needed to allow the concrete to expand and contract. A typical amount of air entrainment to control expansion and contraction is approximately 3 to 4 %. However, air entrainment will typically reduce the strength of the concrete.

The typical rule of thumb is a mix with 3% air entrainment will have a 5% reduction in compressive strength. Therefore, do not include air entrainment if it is not needed for workability or to resist freeze/thaw conditions.

2.6 Durability

Durability of concrete identifies the ability of the concrete to resist degradation due to environmental exposure conditions. There are many factors that indicate the durability of concrete, one being permeability. Permeability is the ability of a concrete to pass pore water through the hardened matrix. In reality, a durable concrete should resist this passage of pore water, or in other words, the concrete should be impermeable. This important factor is affected by water to cementitious materials ratio, mineral admixtures and high range water reducers. In cases where severe exposure of the concrete is expected, such as in splash zones, marine environments and climates where deicing salts are applied, silica fume is another mineral admixture that can be added to the mix to increase density and significantly reduce the permeability of the concrete.

For concrete having compressive strengths in the 40 MPa to 60 MPa range, permeability is more dependent on the use of mineral admixtures. For HPC with compressive strengths in the range of 60 to 120 MPa, the use of high range water reducing admixtures results in significant reductions in permeability. However, for these concretes, permeability is still affected by the use of mineral admixtures. Water to cementitious materials ratio is not a good predictor of the permeability of concrete. Use of mineral admixtures has a more significant effect on concrete permeability than reductions in water to cementitious materials ratio. For concrete having very low water to cementitious materials ratios, permeability of the concrete seems to be more dependent on the composition of the cementitious material (cement, fly ash, silica fume, etc) than the water to cementitious materials ratio.

2.7 Temperature of Concrete

Another important consideration in the design of concrete mixtures is the temperature rise of the concrete during placement and the effects of this temperature rise on the performance of the concrete. As the temperature of concrete starts to rise, several things start to happen.

Conditions such as thermal cracking, formwork removal, and the effects on strength gain are all realities of rapid temperature rise in the concrete. In many instances the results of rapid temperature increase leads to cracking. Thermal cracking occurs as a result of the exterior surface of the concrete setting more rapidly than the internal portions of the concrete.

As a result the stress developed at the exterior surface(s) exceeds the stresses that the freshly placed concrete can withstand, until a crack develops. Additionally, as the temperature of the concrete increases to above 170 degrees its compressive strength decreases. This strength reduction is typical at any test date. The result is that the concrete will reach a compressive strength and then stop gaining strength even if the concrete has Pozzolanic materials that would normally allow the concrete to continue to gain strength. This phenomenon occurs even in HPC.

III. EXPERIMENTAL PROGRAMME

3.1 Material Properties

3.1.1 Cement

Ordinary Portland cement Zuari-53 grade conforming to IS: 12269 was used in concrete. The physical properties of the cement are listed in Table - 2

Table-2 Physical Properties of Zuari-53 Grade Cement

S No.	Properties	Test results	Requirements as per IS:12269-1987
1.	Specific gravity	3.14	-
2.	Normal consistency	32%	-
3.	Initial setting time	60 min	Minimum of 30min
4.	Final setting time	320 min	Maximum of 600min
5.	Compressive strength		
	(a) 3 days strength	29.40 MPa	Minimum of 27 MPa
	(b) 7 days strength	44.80 MPa	Minimum of 40 MPa
	(c) 28days strength	56.50 MPa	Minimum of 53 Mpa

3.1.2 Aggregates

A crushed granite rock with a maximum size of 20mm with specific gravity of 2.60 was used as a coarse aggregate. Natural sand from Swarnamukhi River in Srikalahasti with specific gravity of 2.60 was used as fine aggregate conforming to zone- II of IS 383-1970. The individual aggregates were blended to get the desired combined grading.

3.1.3 Water

Potable water was used for mixing and curing of concrete cubes.

3.1.4 Admixtures

In the present work Fly Ash, Micro Silica and Metakaolin were used.

3.1.5 Mix design

In the present work, proportions for high strength concrete mix design of M70 and M80 were carried out according to IS10262-2009 recommendations. The mix proportions are presented in Table-3 and Table-4.

Table-3 Mix Proportion for M50 Concrete

Cement	Fine aggregate	Coarse aggregate	Water
481 kg/	782.54 kg/	1080.66 kg/	153 kg/
1	1.62	2.25	0.31

Table-4 Mix Proportion for M60 Concrete

Cement	Fine aggregate	Coarse aggregate	Water
561 kg/	748.02 kg/	1032.98 kg/	153 kg/
1	1.33	1.841	0.27

IV. RESULTS AND DISCUSSIONS

The following tests were conducted on 120 concrete cubes of size 150mm x 150mm x 150mm

1. Compressive strength.
2. Type of cracking.
3. Durability

The test data and results obtained from the tests conducted in the present investigations on concrete cubes have been presented in figures1-6. During the investigation importance was given to workability, ultimate compressive strength, cracking and durability. The results of high strength concrete are compared with individual percentage replacements and different combinations of admixtures for two types of concrete (M50 & M60).

4.1 Compressive Strength

The cube specimens of various concrete mixtures were cast to test compressive strength. The cubes after de-moulding were stored in curing tanks and on removal of cubes from water the compressive strength was conducted at 7days and 28days. The test was carried out as per IS: 516-1959.

Fig-1 shows the variation of compressive strength with water-cement ratio of M50 mix with different cementitious materials.

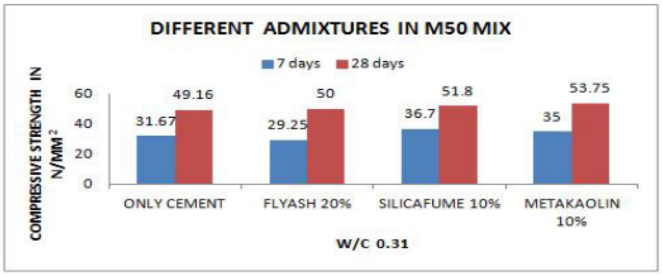

Figure-1 Compressive strength versus water-cement ratio of M50 mix

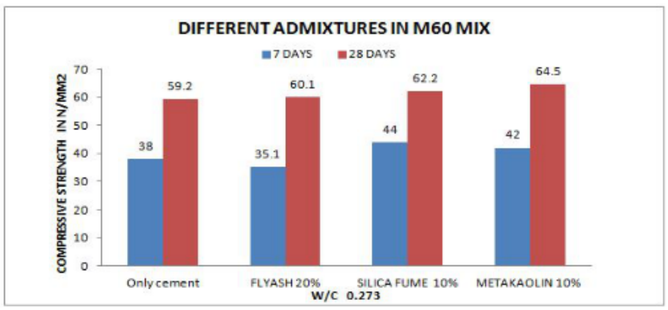

Figure-2 Compressive strength versus water-cement ratio of M60 mix

4.2 Crack Pattern

From the experiments it was observed that as soon as crack propagates the sudden failure occurred in high strength concrete cubes.

4.3 Durability

In the present investigation, an attempt was made to evaluate resistance of concrete admixed with Fly ash, Silica fume and Metakaolin by conducting Acid Attack Test and Alkaline Attack Test.

4.3.1 Acid Attack Test

The concrete cube specimens (of various concrete mixtures) of size 150 mm were cast and after 28 days of water curing, the specimens were removed from the curing tank and allowed to dry for one day. The weights of concrete cube specimen were taken. The acid attack test on concrete cube was conducted by immersing the cubes in the acid water for 30days after 28days of curing. Hydrochloric acid (HCL) with pH of about 2 at 5% weight of water was added to water in which the concrete cubes were stored. The pH was maintained throughout the period of 30 days. After 30 days of immersion, the concrete cubes were taken out of acid water. Then, the specimens were tested for compressive strength. The resistance of concrete to acid attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersing concrete cubes in acid water.

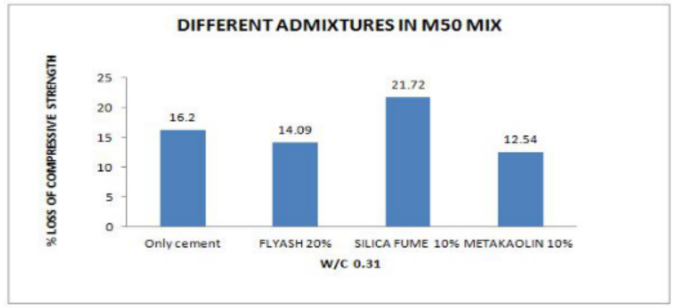

Fig-3 Percentage Loss of Strength Due to Acid Attack in M50 Mix

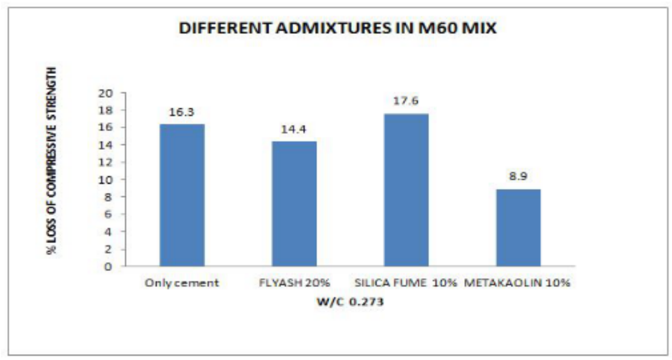

Fig-4 Percentage Loss of Strength Due to Acid Attack in M60 Mix

4.3.2 Alkaline Attack Test

To determine the resistance of various concrete mixtures to alkaline attack, the residual compressive strength of concrete mixtures of cubes immersed in alkaline water having 5% of sodium hydroxide (NaOH) by weight of water was found. The concrete cubes which were cured in water for 28 days were removed from the curing tank and allowed to dry for one day.

The weights of concrete cube specimen were taken. Then the cubes were immersed in alkaline water continuously for 30 days. The alkalinity of water was maintained same throughout the test period. After 30 days of immersion, the concrete cubes were taken out of alkaline water. Then, the specimens were tested for compressive strength. The resistance of concrete to alkaline attack was found by the % loss of weight of specimen and the % loss of compressive strength on immersion of concrete cubes in alkaline water.

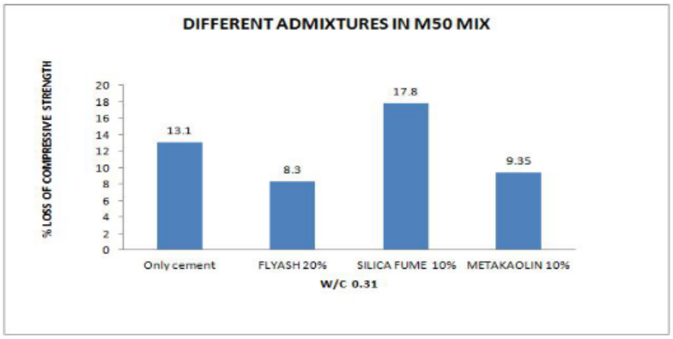

Fig-5 Percentage Loss of Strength Due to Alkaline Attack in M50 Mix

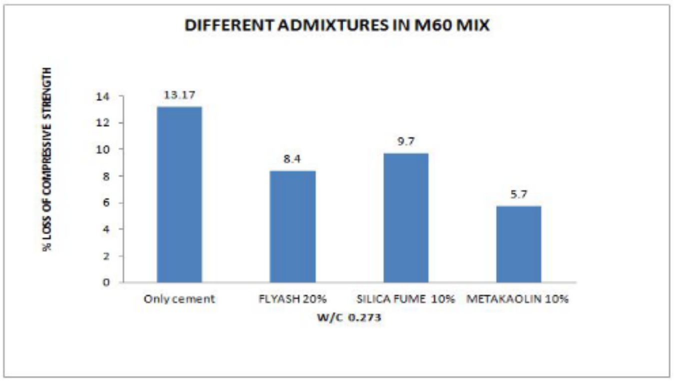

Fig-6 Percentage Loss of Strength Due to Alkaline Attack in M60 Mix

V. CONCLUSIONS

1) In high performance concrete mix design as water cement ratio adopted is low, super plasticizers are necessary to maintain required workability. As the percentage of mineral admixtures is increased in the mix, the percentage of super plasticizer should also be increased, for thorough mixing and for obtaining the desired strength.
2) In case of percentage replacement of mineral admixtures the maximum compressive strength achieved in M50 grade concrete is 53.75 Mpa with replacement of 10 % Metakaolin.
3) In case of percentage replacement of mineral admixtures the maximum compressive strength achieved in M60 grade concrete is 64.5 Mpa with replacement of 10 % Metakaolin.
4) Mineral admixture such as Flyash, micro silica, Metakaolin, also contributes effectively for achieving high strength.
5) In case of percentage replacement of mineral admixtures the minimum % loss of compressive strength due to acid attack is achieved in M50 grade concrete is 12.54% with replacement of 10% Metakaolin
6) In case of percentage replacement of mineral admixtures the minimum % loss of compressive strength due to acid attack is achieved in M60 grade concrete is 8.9% with replacement of 10% Metakaolin
7) In case of percentage replacement of mineral admixtures the minimum % loss of compressive strength due to alkaline attack is achieved in M50 grade concrete is 8.3% with replacement of 10% Flyash.
8) In case of percentage replacement of mineral admixtures the minimum % loss of compressive strength due to acid attack is achieved in M60 grade concrete is 8.4% with replacement of 10% Flyash.
9) The scope for using high performance concrete in our constructional activities are more such as precast, prestressed bridges, multi-storied buildings, bridges and structures on coastal areas. To affect this change, we will have to revive the designing of structures by encouraging use of high strength concrete mixes.
10) HPC is a durable and forgiving material, but in order to fully achieve the benefits of HPC, use of appropriate materials and adherence to proper construction practices must be improved.
11) Innovations are constantly being made to improve concrete curing. Some innovations are in the curing materials, such as the use of cotton mats and improved curing compounds or combinations of curing and sealing products.
12) Other innovations are related to the concrete itself. The use of absorptive aggregates to provide internal curing is progressing.

VI. ACKNOWLEDGEMENT

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