CONCRETE DURABILITY
Through High Volume Fly ash Concrete (HVFC) A Literature review

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Abstract
The application of concrete in construction is as old as the days of Greek and roman civilization. But for numerous reasons, the concrete construction industry is not sustainable. It consumes a lot of virgin materials and the principal raw material of concrete i.e. cement is responsible for green house gas emissions causing a threat to environment through global warming. Therefore, the industry has seen various types of concrete in search of a solution to sustainable development. Infrastructural growth has witnessed many forms of concrete like High Strength Concrete, High Performance Concrete, Self Compacting Concrete and the latest in the series is High Volume Fly Ash Concrete (HVFC). The paradigm has shifted from one property to other of concrete with advancement in technology. The construction techniques have been modernized with focus on high strength, dense and uniform surface texture, more reliable quality, improved durability and faster construction. This paper discusses the development of high volume fly ash concrete for construction with reference to its predecessors like HSC and HPC. The literature available on use of fly ash in concrete has been extensively searched for getting a platform for the start of research on use of high volumes of fly ash in concrete pavements.

Keywords
High Strength Concrete, High Performance Concrete, Self Compacting Concrete, Fly ash, High Volume Fly Ash Concrete, Admixtures, Concrete.

Introduction
The use of High Volume Fly Ash concrete in construction is a solution to environmental degradation being caused by cement industry. The concept very much fits into the era of sustainable development. As cement industry, itself, is responsible for 7% of world’s carbon dioxide emissions, responsible for global warming, attention needs to be drawn by construction industry to solve the problem. High Volume Fly ash Concrete mix contains lower quantities of cement and higher volumes of Fly Ash (up to 60%) from the literature available, it is found that the proportions of Fly Ash in Concrete can vary from 30% - 80% for various grades of concrete.

History
The earliest literature available on the use of Fly Ash is in 1932 which was carried out by Cleveland Electric Illuminating Company and The Detroit Edison Company. However, the use of Fly Ash in concrete was first carried out by Davis and his associates in University of California in 1937. Though extensive research was carried out throughout the world to promote the use of Fly Ash in construction, only a few milestones could be achieved till
1960 and that too in developed countries only. As far as India is concerned, the first ever study on use of fly ash in concrete was carried out in 1955 by CBRI, Roorkee. In the form of a review of American and Australian research work on Fly ash. Later, Fly ash was used in small proportions in mass concreting for dams and other hydraulic structures.

**High Strength Concrete and High Performance Concrete**

Compressive strength of concrete is the most important parameter to assess its quality. Normal strength concrete by ACI definition is a concrete that has a cylinder compressive strength not exceeding 42 Mpa, Prasad and Jha. All other concretes with strength more than the specified one are referred as High Strength Concretes (HSC). With the advancements in technology, the demand of HSC increased in the construction industry but then came the new buzz word ‘High Performance Concrete’. According to Aitcin [1990] HPC is nothing but HSC as high strength concrete not only gives high ultimate strength but performs better in many aspects like durability, abrasion resistance and sulphate attack etc. ACI defines HPC as “Concrete meeting special combinations of performance and uniformity requirements that cannot always be achieved routinely using conventional constituents and normal mixing, placing and curing practices”. In fact, in HPC, the basic ingredients of normal concrete are proportioned in such a way so as to achieve efficiently the desired properties of strength and durability. A major criticism against the ACI definition of HPC is that durability of concrete is not mandatory; it is one of the options. The misconception that high-strength will automatically lead to high-durability has probably resulted in many cases of cracking and premature deterioration of HPC structures, as reported in the published literature, Mehta and Burrows [2001]. The reason lies in the mix proportions used to achieve very high-strength; for example, commercial high-strength concrete mixtures are often designed to obtain 50-80 MPa compressive strength at 28-days and at times high early-strength values of the order of 25-40 MPa at 1-day, together with 150-200mm slump for ease of constructability. Typically, these mixtures are composed of a high cement content, viz 450-500 kg/m3 Portland or blended Portland cement containing a relatively small amount of silica fume and fly ash or slag, a low water/cement on the order of 0.3 (with the help of a super plasticizing admixture), and an air-entraining agent when it is necessary to protect the concrete from cycles of freezing and thawing. Field experience shows that the foregoing high strength concrete mixtures are prone to suffer early cracking from a variety of causes, such as a large thermal contraction due to the high Portland cement content, a large autogenous shrinkage due to the low water-cementitious ratio, and a high drying shrinkage due to the high cement paste-aggregate ratio. Aitcin [1990] prefers to define HPC as a low water/binder concrete with an optimized aggregate-to-binder ratio to control its dimensional stability (i.e. drying shrinkage), and which receives an adequate water-curing (to control autogenous shrinkage). This definition adequately addresses the potential for lack of durability of HPC concrete except with massive structural members that may be subject to thermal cracking. In this regard, an earlier definition proposed by Mehta and Gjovr[1982] stated that the term HPC should be applied to concrete mixtures possessing the following three characteristics: high workability, high strength, and high durability.

**Use of Fly Ash in High Performance Concrete**

The use of fly ash in high performance concrete has been tried for long and sufficient literature and data is available on the topic but very little research has been done in India on this front. Moreover, the properties of fly ash available from various sources and even from same source at different times are not constant. Therefore, the results available on a particular fly ash in a particular country cannot be fit in everywhere. Hence, there is a scope of studying the effect of varying percentages of fly ash on various properties of different grades of concrete in India.

Fly ash is most commonly used as a pozzolana in concrete. Pozzolanas are silicious or silicious and aluminous materials, which in a finely divided form and in presence of water, react with calcium hydroxide at ordinary temperatures to produce cementitious compounds. The spherical shape and particle size distribution of fly ash improves the fluidity of flowable fill, thereby, reducing the demand of mixing water and contributing to long term strength of high strength concrete with fly ash. The use of fly ash in HSC and HPC has been studied by various researchers in past. The use of fly ash in concrete has been encouraged all over the world, Adams [1988], Naik et al. [1989] replaced 40% cement by fly ash and achieved an increase in strength of concrete of 23% and 38% at 28 days and 56 days, respectively. Raju et al. [1994] too tried a 40% replacement of cement by fly ash and achieved a characteristic strength of 45 Mpa at 28 days with W/C ratio 0.4. The benefits of incorporating fly ash in to concrete have been demonstrated through extensive research and countless highway and bridge construction projects. Benefits to concrete vary depending on the type of fly ash, proportion used and other mix ingredients, mixing procedure, field conditions and placement. Some of the benefits of fly ash in concrete are (American Coal Ash Association), [1995].
• Higher ultimate strength
• Improved workability
• Reduced bleeding
• Reduced heat of hydration
• Reduced permeability
• Increased resistance to sulphate attack
• Lowered costs
• Reduced shrinkage
• Increased durability

The dosage of fly ash in concrete is generally restricted to 15% - 20% by mass of total cementitious material for commercial purposes. However, this small percentage is beneficial in achieving a good workability and for cost economy but it may not improve durability to considerable extent.

High Volume Fly ash Concrete

For enhancing the durability of concrete, larger amounts of fly ash i.e. of the order of 25% to 60% should be used in PCC. Such a concrete with high volumes of fly ash in it is called High volume Fly Ash Concrete. From theoretical consideration and practical experience it is determined that 50% or more cement replacement by fly ash, it is possible to produce sustainable, high performance concrete mixtures that show higher workability, higher ultimate strength and high durability, Malhotra [1999]14. However, it is worth mentioning here that for achieving the above discussed properties, the use of superplasticizers [water reducing agents] is almost inevitable in high volume fly ash concrete. With superplasticizers, concrete with as low as 0.2 W/C ratio is possible with good workability and a strength as high as 83 Mpa is possible at test age of 28 days [ACI-211-1993]15. The maximum strength reported with fly ash and superplasticizer is about 60 Mpa, Swamy [1985]16. The use of high volumes of fly ash in concrete to achieve HSC at both early and later ages has been reported by Malhotra [1986]17. The fact that use of high volume fly ash along with superplasticizer in concrete exhibits good workability and high early strength is emphasized by Raju[1991]18. Kohubu [1968]19 provided a major breakthrough in using Fly Ash in Concrete as it was the first comprehensive study of its own kind. Bhanumathidas and Kalidas [2002]20 focused on inclusion of complementary cementitious materials such as fly ash, slag, silica fume and rice husk on durability aspect of concrete in the light of revised IS-456-2000. Malhotra and Ramezanianpur [1994]21 made a comparison in properties of concrete with varying percentages of fly ash in concrete. As per ASTM C 595 [1994]22, fly ash can be blended with cement to produce blended cement. It defined two blended cements – one with less than 15% pozzolana and other with 15% - 40% pozzolana. ASTM C311 [1994]23 recommends that Fly Ash to be used in Concrete should be monitored by a quality assurance program. Halstead, Woodrow J. [1986]24 explains the uses of Fly Ash in Concrete with special reference to time of setting, bleeding, heat of hydration and pumpability. Mehta [1983]25 explains the use of cementitious byproducts as mineral admixtures for concrete. Helmuth [1987]26 describes that the use Fly Ash in Concrete has increased in last 20 years. However, less then 20 % of the Fly Ash collected was used in Cement and Concrete Industry. It is explained that one can safely use Fly Ash in Concrete in Pavements for economic & ecological benefits. Adams, T.H [1988]27 encourages the use of Fly Ash in Concrete Pavements. The price of Fly Ash concrete is less than the price of mixes with ordinary cement and Fly Ash Concrete is also given preference as it is technically more appropriate. Aitcin and Mehta [1990]27 described the guidelines for using high performance Concrete. ACI 211 [1996]28 recommends Fly Ash replacement in cement between 15% to 35%. Mehta [2001]29 refers to Concrete technology for sustainable development with the aim to reduce greenhouse gas emissions by Cement industry. Malhotra and Mehta [2002]30 described high volume Fly Ash Concrete with larger replacement of Fly Ash [>30%] in cement as a beneficial practice for sustainable, durable and economic Concrete. Ujjwal Bhattacharjee et al[2002]31 has enlightened the areas in which fly ash usage has potential in India. He pointed out that despite quite optimistic levels of utilization of fly ash in India; only less than 25% of the total fly ash produced is being utilized. Cengiz Duran Atis[2002]32 studied the abrasion resistance of high volume fly ash concrete. His analysis of results showed that abrasion resistance increased as compressive strength increased. Rafat Siddique[2004]33 carried out experimental investigations on class F fly ash concrete with three percentages of replacement i.e. 40%, 45% and 50%. He concluded that partial replacement of cement by fly ash in concrete results in decrease in compressive strength, Split tensile strength, modulus of elasticity and abrasion resistance at 28 days of age. However, all these properties of hardened concrete show significant improvement at 90days and thereof. Suvimol Sujivanich et al[2005]34 investigated the effect of high volumes of fly ash in concrete on steel corrosion and chloride penetration. He concluded that HVFA concrete has lower chloride permeability and has a tendency to
minimize or cause no corrosion risk. Ozkan Sengül[2005]35 studied the effect of partial replacement [0% to 70%] of cement by fly ash in concrete on its compressive strength, brittleness index and chloride penetration. He reported that high volume fly ash concrete has decreased compressive strength at 28 days, better strength at later ages i.e. 56 and 120 days, increased brittleness index and better resistance to chloride ions penetration. Mullick [2006]36 has traced the development of high performance concrete in India and its adoption in practice for infrastructure and water resources projects. Naik H.K.[2007]37 reviewed some of the experimental studies in the laboratory to analyze the suitability of utilization of a particular type of fly ash sample with the aim to reduce environmental degradation being caused by disposal of high volumes of fly ash in landfills. Sukhvarsh Jerath, P.E. et al [2007]38 reported that increase of fly ash content from 30% to 45% increased the durability of concrete without loss of compressive and flexural strength. Binod Kumar et al [2007]39 studied the suitability of superplasticized HVFA concrete for pavements. He concluded that HVFA concrete with 50% - 60% fly ash can be designed to meet the strength and workability requirement of concrete pavements. Halit Yazıcı[2008]40 has compared self compacting concrete with fly ash 30% to 60% in it with mixtures having 10% silica fumes in addition to other similar concretes. He reported that addition of 10% silica fume positively affected both, the fresh and hardened properties of high performance high volume fly ash concrete. Vengata [2009]41 has reported that addition of fly ash in high volumes considerably decreases the permeability of concrete even though the strength of fly ash concrete at 28 days is not encouraging. Mehta [2004]42 has reviewed the theory and construction practice of concrete mixture with more than 50% fly ash. He has discussed the mechanisms of incorporating high volumes of fly ash in concrete for reducing water demand, improving workability, minimizing thermal and drying shrinkage and enhancing durability. The present study for which this literature has been collected is aimed at analyzing the use of fly ash in high performance concrete for pavements in India.

Conclusion

The literature surveyed reported that incorporating fly ash in concrete reduces the compressive strength at early ages but there is a drastic increase in the compressive strength at later ages. The early strength is reduced further if the percentage of replacement is increased. But, on the other hand when the percentage of replacement is increased the water/binder ratio gets reduced, thereby, increasing the later age compressive strength. Also, it is observed that the later age strength of concretes having more than 40% replacement of cement by fly ash suffers adversely though water/binder ratio is gradually reduced. For concretes with less than 40% replacement of cement, the characteristic strength at 28 days is on higher side. Whereas, for concrete with 40% replacement of cement, the 28 days compressive strength is at par with that of plain concrete. The concrete with more than 40% replacement of cement show lesser 28 days strength but gains better strength at 90days or later. The reason may be understood as explained by Rao and Vimal [1996]43 that water /binder ratio, quality of cement and the age of curing are inter-related and effects high strength of concrete.

References


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