A Review of High Volume Low Lime Fly Ash Concrete

Dr. Shirish V. Deo

***Abstract*---**High volume fly ash concrete (HVFAC) has economical and environmental advantages. It also makes concrete sustainable. In India presently less than 50% of fly ash produced is consumed. Lower consumption may be attributed to low lime in fly ash, quality of fly ash and codal provisions. Suitably designed HVFAC can solve major problems of concrete construction, if sufficient early strength can be achieved as required by the Indian construction industry. In the present study a large number of relevant papers are discussed to understand the problems associated with low lime fly ash HVFAC concrete.

***KeyWord*--**High Volume Fly Ash Concrete, Curing, Mix Design, Compressive Strength.

I. Introduction

SAFE disposal of fly ash is a growing problem in India. With rising fly ash production more efforts must be put on higher consumption of fly ash. The World Bank has reported that by 2015 disposal of fly ash will require 1000 square km area or one square meter of land per person (CANMET, 2005). If not handled properly management of fly ash shall require huge land area for dumping and it will be an environmental threat for coming generations.

High volume fly ash concrete is a tailor made solution for India to effectively use produced fly ash. Available resources indicate that presently codes (IS 1489) do not allow cement companies to replace more than 25% of cement with fly ash. The lower percentage replacements of cement by fly ash are attributed to lower 3, 7 and 28 days strength. For sustainability it is high time to shift from fast construction, which generally reduces the effective life of construction to a structure with HVFA concrete requiring long curing period. The slower strength gain of HVFA concrete will increase the durability and life of structure.

Presently all the efforts of Indian construction industry are focused on early removal of shuttering and fastest possible completion of construction work. Industry is more focused on 3 hour strength for early removal of formwork. This is leading to high heat of hydration cracks and lower durability of structures. (IS 456, 2000) recommends at least 10 days of curing where mineral admixtures are used. However for sustainability focus must be shifted to long term strength and durability over short term gain. Hence at least 28 days of curing should be made mandatory for high volume fly ash concrete.

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II. Partial Replacement of Cement with Fly Ash in Concrete

(Chatterjee,2011) reported that about 50 % of fly ash generated is utilised with present efforts. He also reported that, one may achieve up to 70% replacement of cement with fly ash when high strength cement and very high reactive fly ash is used along with the sulphonated naphthalene formaldehyde superplasticizer. He reported improvement in fly ash property could be achieved by grinding and getting particles in submicrocrystalline range.

(Malhotra & Mehta, 2002) with their experience with fly ash reported following benefits of using fly ash in concrete:
Water reduction: It was reported that Depending upon the quality of fly ash and percentage replacement up to 20% reduction in water requirement is possible.

1) The book mentions that, the water reducing property of fly ash can be used advantageously for achieving a considerable reduction in drying shrinkage of concrete mixes.
2) With their experience the authors reported that the heterogeneities in the microstructure of the hydrated Portland cement paste, especially the existence of large pores and large crystalline products in transition zone, were greatly reduced by introduction of fine particles of fly ash.

Moreover they reported that low calcium fly ashes from bituminous coals contain aluminosilicate glass which is less reactive than the calcium aluminosilicate glass present in the high calcium fly ashes.

(Bhanumathidas, & Kalidas, 2002) with their research on Indian fly ashes reported that the increase in ground fineness by 52% could increase the strength by 13%. Whereas, with the increase in native fineness by 64% the strength was reported to increase by 77%. Looking in to the results it was proposed that no considerable improvement of reactivity could be achieved on grinding a coarse fly ash. Authors also uphold that the study on lime reactivity strength had more relevance when fly ash is used in association with lime but preferred pozzolanic activity index in case of blending with cement.

Considering the formation of CSH gel authors compared the fly ash with insulin in human body as the fly ash converted the surplus lime to form secondary mineralogy like the reduction of glucose in to energy by insulin. They also reported due to pozzolanic action complimentary cementing materials were formed causing grain size refinement influencing the transition zone towards densification thereby minimizing the chances of micro cracking. Also pore size refinement was discussed greatly reducing the permeability of concrete influencing positively the durability of concrete.

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Reduction of carbonation depth by about 30% was reported for M45 concrete due to addition of fly ash, as it reduced the surplus lime and permeability due to pozzolanic reaction. Considering carbonation and durability aspect a service life of about 100 years was predicted for fly ash concrete.

Finally they reported the pozzolanic nature of Indian fly ashes. They also concluded that when low calcium fly ash is added to concrete it increases long-term strength and durability of concrete and recommended more and more use of fly ash in concrete for sustainable development.

(Subramaniam, Gromotka, Shah, Obla & Hill, 2005) investigated the influence of ultrafine fly ash on the early age property development, shrinkage and shrinkage cracking potential of concrete. In addition, the performance of ultrafine fly ash as cement replacement was compared with that of silica fume. The mechanisms responsible for an increase of the early age stress due to restrained shrinkage were assessed; free shrinkage and elastic modulus were measured from an early age. In addition, the materials resistance to tensile fracture and increase in strength were also determined as a function of age. Comparing all the test results authors indicated the benefits of using ultrafine fly ash in reducing shrinkage strains and decreasing the potential for restrained shrinkage cracking. Based on the experimental results authors had recommended the following points:

1 Cement replacement with UFFA results in a comparable development of elastic modulus, and fracture parameters with age when compared with the control mixture. They also however reported, a significant decrease in the autogenous shrinkage and an increase in the age at restrained shrinkage cracking. In comparison, concrete with identical replacement of cement with silica fume was reported to have significantly higher autogenous shrinkage and a decrease in the age of cracking.

2 The autogenous shrinkage in concrete obtained by cement replacement with UFFA was reported to be significantly smaller in magnitude than the drying shrinkage. They reported an increase in the autogenous shrinkage while the drying shrinkage was relatively unaltered on increasing the volume of UFFA in the mix and decreasing the w/cm ratio.

3 Authors reported that increasing the volume of UFFA and decreasing the w/cm ratio resulted in an increase in the compressive strength, rate of strength gain, and further improvements in age when the concrete cracks in restrained shrinkage tests.

(Yijin, Shiqiong & Yingli, 2004) tested fluidity of cement paste, mortar and concrete with different fineness of fly ash and with their replacement levels of 20%, 30% and 40% respectively. Based on these test results they concluded that

1. The incorporation of ultra fine Class C fly ash may increase the setting time of cement paste
2. The water demand ratio of ultra fine ash decrease with the increasing fineness
3. Ultra fine Class C fly ash has significantly increased the slump and reduced the slump loss of concrete.

(Malhotra, 2005) discussed the role of supplementary cementing materials and superplasticizers in reducing green house gas emissions. Author also discussed different ways of reducing CO_2 emission. With emphasis on developing countries the author discussed that their infrastructure needs lead them to use huge amounts of cements. This huge need of cement can be reduced by replacing cement with easily available good quality of fly ash from the thermal power stations. Author also mentions the development of high performance; high volume fly ash concrete that incorporates large dosages of super plasticizer which enhances the durability of concrete. The paper also discussed about different cementing materials that can be used in concrete making as replacement of cement to reduce the cement consumption and also reduce the CO_2 emission to atmosphere.

(Poon, Lam & Wong, 1999) from their experimental results concluded that replacement of cement by 15% to 25% by fly ash results in lower porosity of concrete and plain cement mortars.

Literature discussed has shown improvement in the workability and durability of concrete by partial replacement of cement with fly ash. However 28 days strength was reported to be lower by replacement of cement with fly ash, than concrete without replacement of cement with fly ash. Analysing the literature it is seen than grinding of fly ash is less effective. This may be due to destruction of spherical shape of fly ash which is helpful in increasing workability and reducing voids. Grinding cost also offsets partial cost advantage of cheaper fly ash over cement.

Low reactivity of low lime Indian fly ashes as compared to high lime fly ash restricts use of higher volumes of fly ashes for cement replacement. Lower reactivity of fly ash makes it urgent to develop a method for replacing higher volumes of cement with fly ash without grinding or activation of fly ash.

III. Partial Replacement of Sand with Fly Ash

(Hwang, Noguchi & Tomosawa, 2004) based on their experimental results concerning the compressive strength development of concrete containing fly ash, the authors concluded that the pores in concrete reduce by addition of fly ash as replacement of sand.

(Siddique, 2003) carried out experimental investigation to evaluate mechanical properties of concrete mixes in which fine aggregate (sand) was partially replaced with class F fly ash. Fine aggregate was replaced with five percentages (10%, 20%, 30%, 40% and 50 %) of class F fly ash by weight. The test result showed that the compressive strength of fly ash concrete mixes with 10% to 50% fine aggregate replacement with fly ash were higher than control mix at all ages. Also the compressive strength of concrete mixes was increasing with increase in fly ash percentages. This increase in strength due to replacement of fine aggregate with fly ash was attributed to pozzolanic action of fly ash. The splitting tensile strength also increased with increase in percentage of fly ash as replacement of fine aggregate. The tests on flexural strength and modulus of elasticity also showed improvement in the results as compared to control concrete.

(Namagg & Atadero, 2009) described early stages of a project to study the use of large volumes of high lime fly ash in concrete. Authors used fly ash for partial replacement of cement and fine aggregates. Replacement percent from 0% to

50% was tested in their study. They reported that concrete with 25% to 35% fly ash provided the most optimal results for its compressive strength. They concluded that this was due to the pozzolanic action of high lime fly ash.

(Jones & McCarthy, 2005) made an extensive laboratory based investigation in to unprocessed low lime fly ash in foamed concrete, as a replacement for sand. For a given plastic density, the spread obtained on fly ash concretes were up to 2.5 times greater than those noted on sand mixes. The early age strengths were found to be similar for both sand and fly ash concrete, the 28-day values varied significantly with density. The strength of fly ash concrete was more than 3 times higher than sand concrete. More significantly while the strength of sand mixes remained fairly constant beyond 28 days, those of fly ash foamed concrete at 56 and 180 days were up to 1.7 to 2.5 times higher than 28 days values respectively.

(Rebeiz, Serhal & Craft, 2004) reported investigation on the use of fly ash as replacement of sand in polymer concrete. In the weight mix design 15% sand was replaced by fly ash. This replacement of 15% sand with fly ash by weight increased compressive strength by about 30%. Also there was improvement in the stress strain curve.

They also reported good surface finish due to addition of fly ash as replacement of sand which also reduce permeability and have an attractive dark colour. Flexural strength of steel reinforced polymer concrete beams was increased by 15%. When subjected to 80 thermal cycles polymer concrete with fly ash exhibits slightly better thermal cycling resistance (about 7% improvement) than polymer concrete without fly ash.

(Rao, 2004) discussed the need to use about 650 kg/cu.m of fine material to make self compacting concrete. This also requires fine aggregates more than 50% of total aggregate so that coarse aggregate can float in the fine material. This requirement of fine materials can be easily fulfilled by use of fly ash.

(Papadakis, 1999) used a typical low calcium fly ash as additive in mortar replacing, part of volume either of Portland cement or aggregate. In both cases 10, 20 and 30% addition to the cement weight was done. A very important finding was that when the compressive strength of mix in which aggregate was replaced by fly ash were similar to that of control mix at 3 and 14 days, but were higher from 28 days and later.

The strength increase is due to higher content of calcium silicate hydrate. There is reasonable distribution of the strength increase according to fly ash content but after 91 days there is no difference between 20% and 30% replacement.

When fly ash replaces cement the strength is reduced, at first due to lower activity of the fly ash, but as time precedes this gap is gradually eliminated.

(Neville, 2009) In general, the aggregate cement ratio is only a secondary factor in the strength of concrete but it is found that, for a constant water cement ratio, a leaner mix leads to higher strength for higher aggregate cement ratio. A large amount of aggregate absorbs a greater quantity of water. It reduces the effective water cement ratio increasing the strength. The most likely explanation, however, lies in the fact that the total water content per cubic meter of concrete is lower in a leaner concrete. As a result, in a leaner mix, voids form a smaller fraction of total volume of concrete, and it is these voids that have an adverse effect on strength.

(Pofale, & Deo, 2010) with their study indicated about 20% increase in compressive strength and about 15% increase in flexural strength of concrete over control concrete by replacing 27% of sand with low lime fly ash. In study fly ash based Portland pozzolana cement was used. They had also reported about 25% increase in workability of the fly ash based concrete over control concrete.

Out of large number of papers studied papers only found very relevant are included for putting forward present objectives. Literature discussed has shown partial replacement of scarce sand with fly ash had shown higher strength from 3rd day as compared to control concrete. Long term strength was about 20% higher than the control concrete. Along with increase in strength, increase in workability and durability of concrete by partial replacement of sand with fly ash is very encouraging.

Analysing the results it may be seen that due to ball bearing and pore filling effect, dispersion of cement particles and pozzolanic reactivity of fly ash as partial replacement of sand workability and strength also increased. This additional strength and workability offered by partial replacement of sand with fly ash could offset loss of 28days strength of high volume fly ash concrete.

IV. High Volume Fly Ash Concrete Scenario in World

(Malhotra & Ramezanianpour, 1994) after their extensive research noted in the report about pozzolanic activity of fly ash for increasing long term concrete strength and durability. They also reported that addition of fly ash to concrete makes concrete more workable at same water cement ratio or can effectively reduce water cement ratio for same workability. This reduction in water cement ratio can increase strength of concrete and also make it more durable. The pozzolanic activity of fly ash also allows to reduce the quantity of cement required to archive the same strength. Other specific recommendations of the authors were as given below

1. Workability was reported to increase and water requirement was reported to decrease
2. Temperature rise in fresh concrete was reported to be lower by partial replacement of cement with fly ash
3. Strength was reported to be marginally lower at up to 28 days but may even be more at higher age. Factors reported to have influence on strength developed are properties of fly ash, Chemical composition of fly ash, Particle size, Reactivity, Temperature and other curing conditions.
4. Modulus of elasticity of concrete was reported to increase
5. Creep was found to be negligible with less than or equal to 15% replacement of cement with fly ash. However, slightly higher creep was reported for fly ash replacement higher than 15%.
6. The drying shrinkage for structures like roads, slabs, walls etc. at the exposed surfaces of concrete up to the age of one year for fly ash cements was reported

to be less than, that for corresponding Portland cements.

7. Permeability of fly ash concrete was reported to be higher at 28 days but was reported to be one fifth of the concrete without fly ash after six months.
8. Durability of concrete with fly ash was reported to increase due to reduction of permeability and lesser availability of calcium hydroxide for leaching due to formation of CSH gel by reacting with fly ash.

With their studies on high volume fly ash low lime fly ash concrete they reported that with about 57% cement replacement with fly ash 1 day strength was about 20% of that achieved by only cement concrete. Though difference was reduced at 28 days still fly ash concrete strength was only about 77% of cement concrete.

(Thomas, Shehata, Shashiprakash, Hopkins & Cail, 1999) reported the results from laboratory studies on the durability of concrete that contains ternary blends of portland cement, silica fume, and a wide range of fly ashes. Previous work had shown that high CaO fly ashes are generally less effective in controlling alkali silica reactivity (ASR) and sulfate attack compared with Class F or low lime fly ashes. Contrary to this, in this study it was shown that replacement levels of up to 60% were required to control expansion due to ASR with some fly ashes. However, combinations of relatively small levels of silica fume (e.g., 3 to 6%) and moderate levels of high CaO fly ash (20 to 30%) were very effective in reducing expansion due to ASR and also produced a high level of sulphate resistance.

Authors also reported that concretes made with these proportions generally show excellent fresh and hardened properties since the combination of silica fume and fly ash is somewhat synergistic. The reason for this synergy was fly ash appears to compensate for some of the workability problems often associated with the use of higher levels of silica fume, whereas the silica fume appears to compensate for the relatively low early strength of fly ash concrete. Diffusion testing indicated that concrete produced with ternary cementations blends has a very high resistance to the penetration of chloride ions. Furthermore, these data indicate that the diffusivity of the concrete that contains ternary blends continues to decrease with age. The reductions are very significant and have a considerable effect on the predicted service life of reinforced concrete elements exposed to chloride environments. Authors concluded that it was possible that much of these benefits are attributed to reductions in permeability and ionic diffusivity in the system.

(Camoes, Aguilar & Jolali, 2003) used fly ash as replacement for cement to reduce cost of high performance concrete and increase the durability of concrete. They reported that addition of fly ash is beneficial, leading to more durable concrete. The authors also reported that adding up to 60% fly ash makes concrete more workable as compared to control concrete mix.

(Mehta, 2009) with his research on high volume fly ash concrete with low lime fly ash compared only cement concrete with water cement ratio of 0.58 and 50% cement replaced by fly ash concrete with water cement of 0.39. In case of high volume fly ash concrete author reported much strength gain between 28 and 90 days.

(Ravina & Mehta, 1988) by replacing cement with class F and class C found that i) the compressive strength decrease with increase in fly ash percentage, ii) the compressive strength is more with class C fly ash than class F fly ash.

(Zang, Sun & Shang, 1997) used high calcium fly ash with fly ash content 50% and 60% by weight. They observed that the strength at 28 days was about 84% to 91% than control concrete however at 90 days strength surpassed that of control concrete.

(Camoes, Aguilar & Jolali, 2003) indicated that optimum compressive strength was obtained at 20% cement replacement with fly ash and the strength is more than that of control concrete after 28 days. They also reported that with 60% replacement durability was better than control concrete. (Siddique, 2004) made an experimental investigation to study effect of 55% replacement of cement with fly ash. He reported that workability increased but there was 48% decrease in compressive strength, 49% decrease in splitting tensile strength of concrete and flexural strength reduced by 56%.

(Siddique, 2004) with his study by replacing cement with class F fly ash and reported lower strength at 28 days than control concrete. He also reported less strength than control concrete even beyond 28 days.

(Jiang, Liu & Ye, 2004) with their study on concrete taking 40% and 60% replacement of cement with fly ash reported that compressive and flexural strength of fly ash concrete were more than control concrete after 118 days. They also reported higher corrosion resistance with fly ash concrete with hydra head activator over control concrete.

(Oner, Akyuz & Yeldiz, 2005) found that the compressive strength increases with increase in amount of fly ash up to about 40% of cement, beyond which strength starts to decrease with further addition of fly ash.

(Barryman, Zhu, Jensen & Tadros, 2005) compared results of class C and class F fly ash replacing cement up to 75% with fly ash. Their experimental findings revealed that the maximum compressive strength 41.5 Mpa was found with 35% cement replacement with class C fly ash; however with class F fly ash at about 25% replacement level achieved only 36.0 MPa.

From the above sited papers it is clear that with higher volumes of replacement of cement with fly ash strength even at 28 days is less than control concrete without fly ash, though equal or even higher strength is reported at beyond 118. However practically curing up to 118 days is not possible. Strength with low lime fly ash is reported to be even less than high lime fly ash. Few researchers had also tried activation of fly ash for higher strength. The cost needed for activation of fly ash may make it uneconomical as compared to cement. However increased slump and durability shown by the researchers is needed today to increase life of structures.

Low lime fly ash concrete gains strength due to reaction between lime in cement and silica and alumina in fly ash. However in case of high lime fly ash part of silica and alumina in fly ash reacts with lime in fly ash and remaining with lime in cement. Major studies on HVFAC were based on high lime fly ashes. Low lime fly ash in concrete is totally dependent on lime from cement for the formation of C-S-H gel. This limits the percentage replacement of cement with low lime fly ash. Hence further studies with HVFA concrete are needed to achieve higher strengths at 28 days with low lime fly ash. Low lime fly ash available in India, being low reactive could not achieve the today's requirement of 3 hr or 1 day strength required by the construction industry.

V. Conclusion

HVFAC is most important building material for the sustainable construction and consumption of large volumes of fly ash. Literature discussed in the present paper has given an overview of advantages of HVFAC to increase workability and durability of concrete. The literature surveyed has also listed the slower strength gain at early ages as major problem in making HVFAC very popular in the Indian construction industry which is only focused on short term strength gain. A detailed mix design procedure along with conformation of results for designing HVFAC to achieve required strength at 28 days is urgently needed. It is must to shift contractors focus on economical and durable HVFAC even if higher days of curing are required. A separate codal provision for higher days of curing of HVFAC should be proposed to eliminate the risk of lower strength of concrete at 28 days.

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