Journal of Civil Engineering Research 2014, 4(2A): 7-11
DOI: 10.5923/c.jce.201401.02

Durabilty and Strength Properties of High Volume Fly Ash Concrete

T. Ch. Madhavi[1,*], L. Swamy Raju[2], Deepak Mathur[3]

[1]Professor & Head, Department of Civil Engineering, SRM University, Ramapuram Campus, Chennai, India
[2]Additional Chief Engineer (Civil), BHAVINI, kalpakkam, India
[3]Scietific Officer (Civil), BHAVINI, Kalpakkam, India

Abstract Use of High Volumes of Fly Ash in concrete is gaining significance and is considered as a sustainable option for many concrete constructions. Experimental results show that, HVFAC has lower strength at early ages but at later age HVFAC shows continuous increase in strength properties. Significantly both the crack width and drying shrinkage reduce and thus contribute to the long term durability of concrete. HVFA Concrete exhibits comparable costs, increased strengths and enhanced durability. Thus, the HVFA concrete is more suitable for warm weathers and where early strength is not essential. This paper reviews the durability and strength properties of High Volume Fly Ash Concrete.

Keywords Fly ash, High Volume, Concrete, Durability, Strength

1. Introduction

Fly ash, is one of the residues generated during combustion of coal and comprises of the fine particles that rise with the flue gases. Major components of Fly ash include, silicon dioxide (SiO_2) and calcium oxide(CaO), Al_2O_3, Fe_2O_3. However, the components of fly ash vary considerably, depending upon the coal being burned. The heavier unburnt material drops to the bottom of the furnace and is termed as bottom ash. Bottom ash is not suitable for structural concrete but is used for concrete masonry blocks. Fly ash acts as a pozzolona when used as a supplementary cementitious material in concrete. Pozzolonas are those materials which in itself do not possess any cementitious value but in its finely divided form exhibits cementitious properties when combined with Calcium Hydroxide in the presence of moisture. The pozzolonas chemically react with Calcium Hydroxide at room temperature to form cementetious compounds. Similar to OPC, pozzolonas hydrate in water but do not produce the required strength as OPC and gains strength over a much longer period of time. Fly ash which is a finely divided amorphous alumino-silicate powder, reacts with the calcium hydroxide released by hydration of cement and produces various calcium-silicate hydrates (C-S-H) and calcium aluminum hydrates. In High Volume Fly Ash Concrete (HVFAC), increase in the quantity of cementitious C-S-H phase and calcium aluminum hydrates improves the long term strengths and reduces the permeability. Thus improves the durability properties [1].

Concrete containing more than 50% of fly ash content by mass of the total cementitious materials is considered as High Volume Fly ash Concrete (HVFAC). Fly ash is considered as a hazardous waste due to leaching of toxic substances into the ground water and soil when it is disposed into ponds, lagoons etc or used as a land fill. In India only 25% of the total fly ash produced is being utilized [2]. Production of Portland cement produces large amounts of carbon di oxide. About one ton of carbon dioxide is released into the environment during the production of 1 ton of clinker besides SO_2 and NO_2 emissions. Cement industry contribute about 7% of global man made CO_2 emissions, of which 50% is released due to chemical reactions while 40% is from burning of coal. Hence, there is a need to reduce Carbon dioxide emissions, by lowering the consumption of cement. This can be achieved by replacing cement with high volumes of supplementary cementitious materials like Fly ash. Utilization of fly ash as a low cost mineral admixture in concrete instead of dumping and polluting the environment seems to be the best solution. Less than 20% of the total fly ash produced is being used in construction industry. While concrete with fly ash content of upto 25% is routinely used, high volumes of fly ash content are not common due to lower early age strengths.

Fly ash is the by-product of incineration of coal. Fly ash is commonly used by replacing cement up to 30% of total mass of cementitious material. ACI 211[3] recommends Fly Ash replacement ranging from 15% to 35%. However, of late, researchers observed that replacement of cement by fly ash can go up to 50% with a wide range of benefits. However,

* Corresponding author:
tcmadhvi@gmail.com (T. Ch. Madhavi)
Published online at http://journal.sapub.org/jce

the strength development is slower in HVFA concrete when compared to PCC but the pozzolanic properties of fly ash result in long term strengths comparable to or better than the conventional concrete. Thus, though it may seem that the HVFA mixture would have lower strengths at early stages due to decreased cement content, low water cement ratio and high admixture content overcome the adverse effects. Application of fly ash in concrete will enable concrete to be more sustainable.

2. Class C and Class F Fly ash

There are two classes of fly ash as defined by ASTM C618: Class F fly ash and Class C. Class F fly ash is produced by burning harder, older anthracite and bituminous coal while Class C fly ash is obtained by burning, younger lignite or subbituminous coal. Class F fly ash is less pozzolonic in nature, while Class C fly ash has pozzolonic properties in addition to some self cementitious properties. Hence, Class F fly ash concrete need cementing agents like Class Cement, Lime etc while Class C fly ash do not need any activator. Class F Fly ash has less that 20% lime (CaO), while Class C fly ash has more than 20% of Lime. Class C fly ash generally has higher quantities of Alkalis and Sulphates. Unlike the Class C fly ash, the early age strengths of the HVFA mixture with Class F fly ash will be slightly lower. This is because Class F fly ash possesses good pozzolonic properties and low cementitious properties. Class F fly ash is used for high volume fly ash concrete, while Class C is used for low volume fly ash concrete mixes. Class C fly ash produces more heat of hydration than Class F fly ash. Class F Fly ash is used for structural Concrete, high performance concrete and high sulphate exposure concretes while Class C fly ash is used for residential constructions and is prohibited for high sulphate exposure environments. Class C fly ash mixes develop more early age strength than Class F Fly ash mixes.

Low Calcium fly ash (Class F), is composed of Aluminium Silicate glass crystalline quartz, hematite magnetite and mullite. These crystalline phases are generally inert in concrete and requires a source of alkali or lime $Ca(OH)_2$ to react and form cementitious hydrates. Such fly ashes are pozzolanic and display no significant hydraulic behaviour. Whereas, high calcium fly ash (class C), is composed of calcium-alumino-silicate glass in addition to those found in low calcium fly ash.

Some of these crystalline phases will react with water and together with the more reactive nature of the calcium-bearing glass, makes these fly ashes react more rapidly than low-calcium fly ashes and renders the fly ash both pozzolanic and hydraulic in nature. These fly ashes will react and harden when mixed with water due to the formation of cementitious hydration products. If the calcium content of the fly ash is high enough, it is possible to make geopolymer concrete with moderate strength. [4]

3. Properties of HVFA Concrete

Because of lower water cement ratio, application of superplasticizer or water reducing admixture is essential to ensure workability. Air entraining admixtures can be used when frost resistance is required. The effectiveness of air entraining admixtures decreases with increase in fly ash content to cementitious content ratio. Higher content of air entraining admixture has to be used when the carbon content in the fly ash is higher.

3.1. Properties of Fresh HVFA Concrete

3.1.1. Workability -Slump Cone

Addition of Fly ash increases workability when compared with conventional concrete with the same water content. The spherical shape and particle size distribution of fly ash improves the fluidity of concrete and thus the demand for water reduces, contributing to long term strength.To achieve early strengths, generally low water cement ratio of about 0.3 is used. Hence a super plasticizer is commonly used in HVFAC to achieve workability. The workability improves in a well- proportioned fly ash concrete.

Fly ash is less expensive and improves workability by “ball bearing action” of spherical fly ash particles and also reduces internal temperatures. Fly ash also improves grading of the mixture by smoothing out of fine particle distribution. Fly ash reduces the amount of water required by about 15 to 20% [5]. The approximation is that for every 10% of fly ash added the water reduction is about 3%. For HVFA concrete the water content is about 100 to 130 kg/m^3 by using a super plasticizer. The water cement ratio is generally adopted to be less than 0.35. HVFA concrete requires a minimum curing period of 7 days. The most attractive property of HVFA is improvement in durability due to the reduction of Calcium Hydroxide, which is the most soluble of hydration products. The water permeability is lower in HVFA concrete than PCC.

Jo Jacob Raju and Jino John [5] reported from their experimental investigations on HVFAC with polypropylene fibers that the workability of fly ash concrete decreased with addition of fibers.

3.1.2. Workability -Compaction Factor

In HVFAC, the compaction factor decreases with addition of fibers.

3.1.3. Bleeding of Concrete

HVFAC is typically made with a very low water to cementitious materials ratio. Hence, bleeding is usually reduced and is usually not a problem [6].

3.1.4. Setting Time

Because of low cement content in HCFAC and slow reaction of fly ash, the setting time of concrete increases. Because of sufficient air voids, freezing and thawing resistance is adequate. Hence the setting time for the HVFA concrete is higher than PCC by about 2 hrs. This increased setting time is understandable as the cement content is reduced and the reaction happen at a slower rate.

3.2. Durability

The long term permeability of HVFAC is very low. Vengata [7] has reported that the permeability of HVFA decreases considerably, even though the strength of fly ash concrete at 28 days is not encouraging.

Suvimol Sujjavanich [8] concluded that HVFA concrete has lower chloride permeability and minimizes corrosion risk.

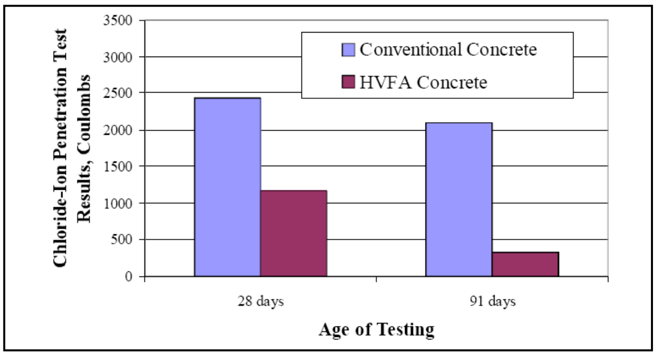

Figure 1. Comparison of Chloride-ion penetration in HVFAC and Conventional Concrete of same strength (CII and CANMENT, 2005)

Mehta [9] has reported the mechanisms for reducing water content in concrete mixture with more than 50% fly ash thus causing improvement in workability, minimizing thermal and drying shrinkage and enhancing durability Increase of fly ash content from 30% to 45% increases the durability of concrete without loss of compressive and flexural strength [10]. Malhotra and Mehta [11] concluded that HVFAC is sustainable, durable and economic Concrete.

3.3. Properties of Hardened HVFA Concrete

3.3.1. Heat of Hydration

Replacement of cement with fly ash reduces the heat of hydration. Replacing cement by 50% fly ash reduces the peak temperatures by 23% while 70% replacement by fly ash reduces the peak temperatures by 45%.

3.3.2. Drying Shrinkage

The lower water cement ratio and low cement paste content in HVFAC reduces the drying shrinkage. Studies reveal that the drying shrinkage in HVFAC is less than that in conventional concrete. Also, HVFA reduces the shrinkage cracks, due to the reduced water content and also due to the decrease in the total volume of the cement paste. The lower heat of hydration reduces the cracking due to thermal shrinkage.

3.3.3. Creep Strains

Creep strains are higher in the early ages as the strength gain is slow in HVFAC. The quality of fly ash also influences the strength gain and hence the creep strain.

3.3.4. Compressive Strength

The increase in compressive strength is dependent on the volume of cement replaced, the age of concrete and type of flyash. The early age strength gain is higher with class C fly ash than Class F fly ash. The long term compressive strength is higher when class F fly ash is used due to its long term pozzolanic strength contribution. The higher long term strength is also due to the smaller capillary pores and dense microstructure resulting from the pozzolanic reactions. Hence adequate curing to a minimum of 7 days is essential to ensure that the later age strength development takes place. To attain early age strength, low water cement ratio is essential. Early compressive strength is a function of the coarseness and content of the fly ash used. Long term compressive strength of HVFAC normally exceeds that of conventional concrete. 56 day compressive strength is often specified.

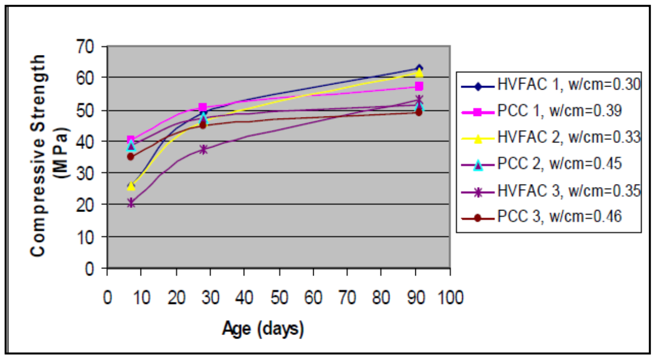

Figure 2. Comparision of Compressive strength of Concrete with 55% class F fly ash (Langley, Carette and Malhotra 1989)

Raju et al. [12] 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.

Early age compressive strength of fly ash concrete reduces but there is a drastic increase at later age because of decreased water cement ratio for high volumes of fly ash content beyond 40%. Concrete with fly ash content of more than 40% shows lesser 28 days strength but gains better strength at 90 days. But for concretes with less than 40% of fly ash content the compressive strength is higher at 28 days. This is because the strength of the concrete is a function of water/binder ratio, quality of fly ash and cement and age of curing [13].

Ozkan Sengul [14] reported that HVFAC upto 70% replacement has lower compressive strength at 28 days but gains better strength at later ages of 56 days and 120 days.

3.3.5. Split Tensile Strength

Rafat Siddique [15] used 40%, 45% and 50%. of class F fly ash in concrete and he concluded that Split tensile strength decrease with increase in fly ash content at 28 days. He also reported that compressive strength, modulus of elasticity and abrasion resistance decrease at 28 days of age.

3.3.6. Flexural Strength

The flexural test is one measure of the tensile strength of unreinforced concrete to resist failure in bending. Manish Rohit et al [16] used polyester fibers in Fly ash concrete and reported that gain of flexural strength from 28 days to 56 days for 50%, 55% and 60% of fly ash is up to 21.32%, 29.02% and 42.26% respectively. Addition fibers Improves the flexural strength.

4. Applications

With an optimum replacement level of 40% to 60% fly ash, the concrete can be used in massive concrete structures to reduce the heat of hydration and thermal cracking. If the elements such as footings, walls, columns and beams do not require early age strengths, then HVFAC can be used with a minimum of 7 days curing. If 7 days curing cannot be provided, lower quantity of fly ash has to be used.

Fly ash contents of 40% to 50% are suitable for slabs that require a mere broom finish, but that for slabs that require trowel finishing the fly ash content has to be reduced to about 25% to 50%, so as to avoid unwanted delays in finishing [17, 18].

5. Disadvantages of HVFAC

Some of the short comings of HVFAC are

- ➢ Extended setting times
- ➢ Slow development of strength
- ➢ Low early age strength.
- ➢ Delay in Construction.
- ➢ Difficult to use in cold weather concreting.
- ➢ Low resistance to deicer-salt scaling and carbonation.

6. Conclusions

- ✓ High Volume Fly ash Concrete is more sustainable concrete compared to conventional concrete as it reduces the usage of cement and also reduces environment pollution.
- ✓ HVFAC performs well at a later stage than at an early age.
- ✓ Low water cement ratio and adequate curing are essential for strength gain.
- ✓ Long term permeability of HVFAC is very low.
- ✓ HVFAC is effective in controlling temperature effects in mass concrete applications.
- ✓ HVFAC can be safely used in Concrete in Pavements for economic & ecological benefits.
- ✓ Fly ash contents of up to 50% may be suitable for most elements provided the early-age strength requirements of the project can be met and provided that adequate moist-curing can be ensured.

ACKNOWLEDGEMENTS

The authors thank BHAVINI, DAE, Kalpakkam, India for supporting the R & D work on fly ash concrete.

REFERENCES

[1] ACI Committee 232, Use of Fly Ash in Concrete, ACI 232.2R- 03, American Concrete Institute, Farmington Hills, Michigan, 1996, 41 pages.

[2] Bhattacharjee Ujjwal, Kandpal T C., ‘Potential of fly ash utilization in India’, Energy Vol..27, 2002, pp.151-166.

[3] ACI 211.4R-93,1996 “Guide for Selecting Properties for High-Strength Concrete with Portland Cement and Fly Ash”, ACI Manual of Concrete Practice, Part 1, American Concrete Institute, Detroit, Michigan.

[4] Cross, D., Stephens, J. and Vollmer, J., “Field Trials of 100% Fly Ash Concrete,” Concrete International, September, 2005, pp. 47-51.

[5] Jo Jacob Raju, jino John, “Strength study of High Volume Fly Ash Concrete with Fibers”, Intl. Journal of Advanced Structures and Geotechnical Engineering”, Vol.3, No.1, Jan. 2014.

[6] Gebler, S.H. and Klieger, P., “Effect of Fly Ash on the Durability of Air-Entrained Concrete,” Proceedings of the 2nd International Conference on Fly Ash, Silica Fume, Slag, and Natural Pozzolans in Concrete, ACI SP-91, Vol. 1, American Concrete Institute, Farmington Hills, MI, 1986, pp 483-519.

[7] Vengata G. K.B., 2009, ‘High volume fly ash concrete for pavements’, M.E. Dissertation, Department of Civil Engineering, Anna University, Chennai, India.

[8] Sujjavanich S., Sida V. and Suwanvitaya P., 2005, ‘Chloride permeability and corrosion risk of high volume fly ash concrete with mid range water reducer’, ACI Materials Journal, Vol.102, No.3,pp. 243-247.

[9] Mehta, P. K., 2004, ‘High –Performance, High–Volume Fly Ash Concrete for Sustainable Development’, International Workshop on Sustainable Development and concrete Technology.

[10] Vanita Aggarwal, S.M. Gupta, S.N. Sachdeva, ‘Concrete Durability Through High Volume Fly ash Concrete (HVFC) A Literature review’ International Journal of Engineering Science and Technology, Vol. 2(9), 2010, 4473-4477.

[11] Malhotra, V.M., and P.K. Mehta, ‘High-Performance, High-Volume Fly Ash Concrete’, Supplementary Cementing Materials for Sustainable Development, Inc., Ottawa, Canada, 2002, 101 pp.

[12] Raju. N.k., 1991, ‘Production and Properties of High Strength Concrete Using Superplasticizers’, National Seminar on High Strength Structural Concrete, 1991, Indian Concrete Institute, Banglore, pp. 11.32-11.53.

[13] Rao, B.K. and Kumar Vimal, 1996, ‘Fly ash in high strength Concrete’, Recent Advances in Civil Engineering, National Seminar, September 28, pp.115-121.

[14] Sengul O., Tasdemir C. and Tasdemir M. A, ‘Mechanical properties and rapid chloride permeability of concretes with Ground fly ash’, ACI Materials Journal, Vol.102, No.6, 2005, pp.474-482.

[15] Siddique R., 2004, ‘Performance characteristics of high volume class F fly ash concrete’, Cement and Concrete Research, Vol. 34, pp.487-493.

[16] Manish Rohit, Indrajit Patel, C D Modhera, “Comparative Study on Flexural Strength of Plain and Fibre Reinforced HVFA Concrete by Destructive and Non Destructive Techniques” International Journal of Engineering and Science, Vol. 1, Issue 2 (Sept 2012), PP 42-48.

[17] Obla, K.H, Hill, R.L. and Martin, R.S., “HVFA Concrete—an Industry Perspective.” Concrete International, August, 2003, pp 29 -33.

[18] Haque, M Langan, B., Ward, M. “High fly ash concretes”, ACI materials Journal, Jan-Feb 1984, pp 54-60.