
Fly ash: The resource for construction industry

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The utilisation of fly ash in cement and concrete is gaining immense importance today, mainly on account of the ecological benefits and the improvements in the long-term durability of concrete. The authors, while explaining the production process and characteristics of fly ash, have highlighted the use of fly ash in bricks, concrete, high volume flyash concrete, roads and embankments, etc. An overview of the Indian scenario as well as the role of the fly ash in the clean development mechanism are also presented.

India is a resourceful country for fly ash generation with an annual output of over 100 million tonnes, registering almost 50 percent escalation over the last decade. Though utilisation of fly ash has been a subject of great concern in India for the past two and half decades, its use has picked up during the last five to six years, recording 15 to 18 percent use. Nevertheless, targets are very high against the generation that may touch 120 million tonnes per annum in the coming decade.

Of all the applications, the role of fly ash as a value-added complement to cement is the holistic approach and more tangible for durability enhancement of structures, leading to a voluminous consumption. This feature is tapped by FaL-G (Fly ash-lime-gypsum) technology for the proliferation of fly ash brick plants all over the country. The success lies in realising that Indian fly ashes are one of the best lots in the world to manufacture high strength concretes.

Technologically, the performance of fly ash has been established way back in 1948 in the construction of Hungry Horse dam in the United States. Utilisation was upto 32 percent and fly ash was used for two phenomena, namely, reduced water demand to achieve the required workability

and reduced heat of hydration of the concrete. Thereafter, these intricate properties were availed to address the durability problems of concrete which resulted out of high early strength cements, developed and used during post-II World War period. Fly ash has become an imminent input of concrete in many high-profile structures.

When fly ash utilisation in India is analysed, an altogether different scenario emerges for the peculiar conditions prevailing in India, such as:

- brick market is traditionally attached to the age-old clay bricks, vetoing chances for any alternate walling materials to penetrate on price logistics
- till the advent of FaL-G technology, autoclaved curing being the predominantly known art, no approach was economical to manufacture walling material with fly ash
- the poor quality of fly ash during the 70's and the unscientific use of such fly ash in a few pockets of cement industry had affected the credibility of pozzolanic cements with regard to durability that is haunting the confidence level in certain segments even today
- the ban on the use of pozzolana cement for structural applications, imposed by the Central Public Works Departments (CPWD) during the fall of 80's, and reiterated in 1999, has given more room for consumers' apprehensions, making the task tough for the cement and concrete industry in promoting the product.

Since the beginning of the 90's utilisation of fly ash attained new thrust from all segments of the country buttressed by

many positive developments. Though India has to go a long way, the stage, set in the country, is poised to accomplish the target of putting to use over 100 million tonnes in the near future.

Upgradation in thermal plant operations

Use of pulverised coal

The installation of pulverised coal boilers (PCB) and fluidised bed combustion (FBC) systems rapidly since the 80's in Indian thermal plant operations has contributed to a dramatic change in the quality of fly ash. The high fineness of coal at 75 micron (70 percent passed) facilitates maximum combustion within short residential time and also the effective phase transformation of the mineral matter of the coal. Fineness causes to reduce coarse fly ash, and also limit the unburnt carbon to less than 1 percent.

Economiser and electrostatic precipitator

The fly ash travels together with the flues and undergoes quenching with sudden temperature drop in economiser attaining more reactivity. Then the fly ash is segregated from the flue gas and collected in electrostatic precipitators (ESPs) or bag filters. The fineness of fly ash improves as it passes through a series of fields; the field at the boiler-end collecting the coarsest fly ash and the field at the chimney-end collecting the finest. This segregation facilitates the choice for required quality of fly ash by the consumers.

It is beyond dispute that, the optimisation of thermal plant operations, with heat recovery systems such as economisers, helped to generate the most qualified fly ash in India. Following data show the difference in pozzolanic activity index (PAI) of two fly ashes, collected from the same field, with reference to the impact of economiser:

	Soluble fraction percent	PAI, percent
Fly ash not subjected through economiser:	4.30	94.00
Fly ash subjected through economiser:	8.80	103.00

The data in Table 1 show the improvement in fineness, soluble fraction and PAI of the fly ash of a typical super thermal plant, as the field progresses.

In other words performance of fly ash blended OPC excels as age progresses, provided the correct grade of fly ash is selected. Wherever optimum operating environment is maintained in the power plant, may be in the interest of cost-effective power generation, high quality fly ash is an incidental bonus, utilisation of which is more attractive to the user industries.

Characterisation of fly ash

Classification

ASTM C618 specified two categories of fly ashes depending on the type of coal and the resultant chemical analyses.

Table 1: Improvement in the fineness, soluble fraction and PAI of fly ash

Field No.	Fineness cm ² /g	<25 micron, percent	SiO ₂ , percent	Al ₂ O ₃ , percent	soluble fraction, percent	PAI, percent 7-day	PAI, percent 28-day
I	2633	46.45	63.38	29.02	5.60	70	90
II	3403	54.20	62.52	30.99	6.91	77	92
III	4325	78.29	60.15	33.18	9.92	86	106

Class C fly ash, normally produced from the combustion of lignite or sub-bituminous coals, contains CaO higher than 10 percent and possesses cementitious properties in addition to pozzolanic properties.

Class F fly ash, normally produced from the combustion of bituminous or anthracite coals, contains CaO below 10 percent and possesses pozzolanic properties.

Notwithstanding the ASTM classification, based on the boiler operations, the authors have further classified fly ash with two distinct identities:

Low temperature (LT) fly ash: Generated out of combustion temperature below 900 °C

High temperature (HT) fly ash: Generated out of combustion temperature above 1000 °C.

This threshold temperature demarcates the development of metakaolinite phases in the case of LT and, the same constituents form as reactive glassy phases in the case of HT fly ash. LT fly ash is more reactive at early ages hence preferred for precast building materials such as bricks/blocks. However, the higher ignition loss, of the order of 4-8 percent makes the fly ash less desirable for cement and concrete applications. In

contrast, the initial pozzolanic reaction is slow in HT fly ash, which is accelerated with age. This property together with a relatively low ignition loss makes HT fly ash more suitable for use in cement and concrete industries.

Chemical characteristics

The chemical composition of fly ash depends on the source of coal and also on operating parameters of the boilers, thus the quality varies from source to source and within the same source also. With use of pulverised coal and efficient combustion systems, loss on ignition (LOI) is very much controlled in most of the fly ashes. High-unburnt carbon is a point of concern in principle, which increases demand for air entraining agents and plasticisers in the production of concrete. Though a fly ash complies codal specification for chemical characteristics, it cannot be correlated with the performance in concrete. As per Mehta¹:

“Since it is the mineralogical composition, and not the chemical composition, which would govern the pozzolanic and cementitious behaviour of a mineral admixture, classifications and specifications emphasising the chemical composition are more of a hindrance than a help in promoting the use of mineral

admixtures in cement and concrete industries. New classifications, specifications and accelerated tests...that are capable of relating the desired performance criteria to the microstructure of the hydrated cement paste containing the admixture are urgently needed."

Mineralogical characteristics

Fly ash is constituted of crystalline and amorphous/glassy phases. These phases of ASTM type Class C fly ash are highly reactive as they are formulated in association with CaO. Due to its higher reactivity, Class C fly ash is less preferable for concrete over that of Class F from its durability point of view.

The development of amorphous phase in ASTM type Class F fly ash depends on the basic clay composition of coal and then, on the operating parameters of the power plants with special emphasis on combustion temperature, fineness and quenching in economiser.

Reactivity

It is generally agreed that the glass or non-crystalline constituent of Class F fly ash goes into reaction with Ca(OH)_2 , which is added as lime or released from the hydration of portland cement. However, there are many other factors that influence the reactivity and relative rates of hydration such as fineness, particle shape, particle size distribution.

Fly ash is generally judged for its quality in terms of strength behaviour. This is studied for pozzolanic characteristics in two approaches; lime reactivity strength (LRS) and pozzolanic activity index (PAI). IS:3812-1981, accords two grades to fly ash based on LRS². Grade I is identified with a minimum 4 MPa LRS whereas fly ash with lower strength at 3 MPa is categorised as Grade II. The same code has also specified replacement compressive strength (PAI) at 80 percent as another yardstick. The LRS given for these grades generally does not correlate with pozzolanic activity index. It is observed that certain fly ashes registering low LRS prove better for PAI and certain other fly ashes recording good LRS have shown lower PAI. Hence to ascertain the suitability of fly ash as supplement to cement, the reactivity study in terms of PAI is desirable.

Technological scenario

Fly ash in brick

Autoclaved technology

Bricks made of lime and sand, popularly known as calcium silicate bricks and hardened by high pressure steam curing, were commercially manufactured first in Germany in 1898. The process requires finely ground sand. Fly ash, which is already fine, replaces ground sand partially or totally, thus conserving on grinding costs. Being a pozzolan, fly ash also reacts with lime resulting in bricks of superior quality. Generally fly ash-lime bricks are classified into high density and low density (aerated autoclaved concrete-AAC) bricks. Fly ash-lime reactions are known for their slow chemistry resulting in feeble strengths at early age. Hence, autoclave is an indispensable production unit wherein, at a high

Table 2: Seven and 28-days strengths of fly ash-lime and FaL-G

Source	Strength, N/mm ²			
	Fly ash + Lime		FaL-G	
	7-day	28-day	7-day	28-day
LT fly ash 1	9.0	17.9	25.0	32.0
LT fly ash 2	11.0	15.8	20.0	25.8
HT fly ash 1	2.6	7.8	8.4	24.0
HT fly ash 2	3.3	4.9	6.5	24.8

temperature of around 180 °C and pressure of about 8-12 bar, the chemistry is augmented. The reactions between fly ash and lime effectively progress under induced hydrothermal conditions to form calcium silicate hydrates, which impart strength to the matrix. While AAC is extensively marketed in other parts of the world, it could not make enough penetration in Indian market due to the tendency to compare the price of the bricks with that of clay bricks regardless of technical virtues.

By integrating the principles of FaL-G technology with parameters of age-old aeration process, the authors have developed alternate technology called non-autoclaved aerated concrete that dispenses away autoclaving. By doing so, the energy consumption could be slashed down from 250 kcal/kg to 75 kcal/kg, simultaneously bringing down the plant cost by about 25 percent.

FaL-G technology

FaL-G is the product name given to a cementitious mixture composed of fly ash (Fa), lime (L) and gypsum (G). FaL-G technology, developed by the authors, is based on two principles namely, that the fly ash-lime pozzolanic reaction does not need external heat under tropical temperature condition, and that the rheology and strength of fly ash-lime mixtures can be greatly augmented in the presence of gypsum. This has dispensed with the need for heavy-duty press and autoclave, and also made the process energy-efficient, bringing the activity within the reach of tiny sector entrepreneurs.

FaL-G is the extension of work based on the theory of crystallo-mineral combination of setting behaviour, postulated and presented by the authors in 1986, which says³

"A weak crystal formation of the hydrated reactions of a cementitious material can be made good for attaining healthy cohesive bond if compensatory mineralogical formation is initiated through conducive stoichiometry".

Thereby the weak phases of calcium aluminate hydrates of fly ash-lime mixtures have been tapped of their potential towards calcium sulpho aluminate hydrates, resulting in the

Table 3: Comparison of mixes using lime and using OPC in place of lime

Source	Strength, N/mm ²					
	Lime route			OPC route		
	3-day	7-day	28-day	3-day	7-day	28-day
LT fly ash	12.4	16.0	22.8	14.0	17.4	20.0
HT fly ash	2.5	7.8	22.0	6.4	18.4	33.8

mixture of FaL-G. Table 2 shows the enhanced strengths of fly ash-lime mixes in the presence of gypsum.

FaL-G technology has been successfully used with even low quality of lime and gypsum that are obtained as by-products from other industries. In the modified version of FaL-G technology, OPC is used as a substitute for lime at parallel cost. It was observed that, for FaL-G production, LT fly ash proves good in lime route and HT fly ash proves good in OPC route as shown in Table 3.

Also, some fly ashes, which did not meet Indian Standard specifications, have been successfully used to make FaL-G products. This has prompted Mehta to make the following observation⁴ on FaL-G technology,

“By disregarding the standard chemical and physical requirements for use of fly ash in the cement and concrete industries, it is found that tailor-made blends of even non-standard fly ashes with lime and gypsum or with portland cement produced adequate strength on normal curing.”

Due to above flexibilities, FaL-G bricks/blocks offer plausible terms of techno-economic logistics as follows:

- (i) FaL-G bricks can be produced with compressive strength of 10-35 N/mm², water absorption of 8-15 percent and coefficient of softening at 0.85 to 0.95.
- (ii) It is feasible to produce FaL-G bricks at places where the prevailing brick price is around Rs. 1 or more such as at Hyderabad, Madras, Bangalore, Calcutta etc. It is possible to produce bricks even by procuring fly ash from distances of 300-400 km.
- (iii) It is easy to manoeuvre the production cost of FaL-G bricks by playing with FaL-G to sand/crusher dust ratio whereby strength can be diluted from as high as 25-30 N/mm² to 8-15 N/mm² so much so the production costs.
- (iv) FaL-G process is simple with production steps of casting and curing, without dependence on thermal energy. Thereby, the total production cycle spans to 7-10 days with minimum capital deployment in comparison to clay brick that has a production cycle of 40-45 days.

With the above features FaL-G technology changed the scenario over the last 11 years. As against a handful of autoclaved plants in India, there are over 800 FaL-G brick plants, manufacturing more than one billion bricks or 2 million m³ of blocks annually. The product is well accepted for rendering two to four fold strength; all this is at parallel price to that of clay brick.

FaL-G for infrastructure applications

The clay bricks of yester years were produced out of fertile soil with absolute water repellency and strengths of the order

Table 4: Comparative properties of concrete made with NSA and FMA (Mix design : 1:2:4 by volume at zero slump)

Property	Strength, N/mm ²	
	With NSA	With FMA
Compressive strengths		
3 day	25.6	22.6
7 day	32.8	28.5
28 day	40.6	37.4
Modulus of rupture		
28 day	5.4	5.4
Young's modulus		
28 day	0.25x10 ⁵	0.25x10 ⁵

of 30-50 N/mm². Earlier to the advent of OPC into construction arena with its history of 179 years, sintered clay products used to be the popular structural media. Canal linings and *khadanza* roads were some popular infrastructure avenues where the quality of bricks used to be aptly tapped to serve the technical requirements.

With deterioration in quality of clay, undue reduction in sintering practices (on account of spiraling fuel costs) and fall in production standards, the practice of using bricks in infrastructure applications faded away and has been replaced by the use of cement.

FaL-G is poised to revive this trend with its superior technical virtues and modest cost factors. Such opening up of applicational avenue creates market for hundreds of billions of bricks summoning for additional production capacities in huge quantities, notwithstanding its demand in housing sector.

There are over 800 FaL-G brick plants, manufacturing more than one billion bricks or 2 million m³ of blocks annually

Fly ash (FaL-G) as the coarse aggregate

Though there were technologies to use fly ash as sintered lightweight aggregate (SLA), they have not caught up in India on account of economic logistics. SLA is energy intensive that needs around 800 kcal/kg of thermal energy. While attempting to break the stone-like hardened FaL-G blocks into workable pieces, ideas have emerged to avail the broken pieces as coarse aggregate. Having achieved positive results, the outcome is viewed as an approach to agglomerate quarry dust that has missed its journey to concrete.

The behaviour of concretes made with normal strength aggregate (NSA) and FaL-G mortar aggregate (FMA) was almost similar. Table 4 shows that the modulus of rupture and Young's modulus values of both concretes are similar, inspite of slightly lower values of compressive strengths of concrete with FMA. This is attributed to the strong bonding of cement paste with FMA in the transition zone on account of cementitious nature of the latter product.

Fly ash in concrete

Hydration chemistry

OPC consists of mainly four mineralogical phases, which undergo various stoichiometric reactions upon hydration. While the hydration of C₃A and C₄AF does not contribute

Table 5: Improvement in workability with fly ash addition

OPC, percent	Fly ash, percent	Water(OPC + fly ash)	Slump, mm
100	—	0.60	14
65	35	0.60	80
55	45	0.60	120

surplus Ca(OH)_2 , that of C_3S and C_2S invariably release surplus Ca(OH)_2 to the tune of 39 percent and 18 percent respectively upon complete hydration, which is identified as the possible cause for deleterious reactions, ultimately leading to distress of concrete.

As per the established data, the hydration of OPC yields approximately 75 percent strength rendering mineralogical phases. The balance 25 percent is Ca(OH)_2 that is vulnerable for deleterious effects rather than contributing for the strength. Nevertheless the same Ca(OH)_2 is a resource for pozzolanic reactions of fly ash to form secondary mineralogical phases, contributing additional strength, more so at later ages. Strength and durability are two important features for concrete performance, which can be addressed by fly ash through this mechanism.

Influence of fly ash on concrete

The role of fly ash is positively significant both on rheological properties of freshly mixed concrete and engineering characteristics of hardened concrete.

Workability

It is generally agreed that the workability of mortars and concrete increases over that of control concrete for the given water to cementitious material ratio, provided fly ash of proper quality is used. Table 5 shows the improvement of slump for a concrete of typical mix design.

Strength

The earlier apprehensions that fly ash reduces strength is no more valid. Strength development in fly ash-blended concretes is indispensable and depends on the type of fly ash, particle size, reactivity and temperature of curing.

When ASTM type Class F fly ashes are used, there is a general trend that rate of initial strength gain is slow. However, ultimate compressive strength surpasses that of control concrete depending on the input and quality of fly ash. Finer the particle size, higher the surface area. As hydration activity occurs on the surface of solid phase through diffusion and dissolution of materials in concentrated paste, surface area plays considerable role in determining the kinetics of such processes. Mehta's work confirmed a linear relation between percentage of particles of $< 10 \mu\text{m}$ and strength of mortars⁵.

Effect of fly ash in concretes is more pronounced in flexural strength than on compressive strength. Improved bond at the transition zone may be attributed as one of the significant contributions for this phenomenon.

Modulus of elasticity is low at early ages and high at later ages for fly ash-blended concrete. On the contrary, creep strains are high at early ages that decrease progressively at later ages. For concretes without fly ash, modulus of elasticity is high and creep is low that results in restrained extensibility of concrete, leading to cracks owing to drying shrinkage and thermal shrinkage. This phenomenon is more evident in concretes when large inputs of high grade cements are used.

Durability

Permeability is the prime cause for the problems of concrete associated with several types of chemical attacks. Surplus Ca(OH)_2 released out of cement plays as the host to initiate and invigorate chemical reactions when reactive chemicals such as SO_2 , CO_2 , O_2 , Cl^- ingress into permeable concrete. Transition zone is the crucial area in concrete, which influences the micro-cracking and durability of concrete. Incidentally, for a variety of reasons, transition zone is the weakest link in general and it is more so in permeable concretes. The thickness of transition zone produced on aggregate is proportional to the quantity of surplus Ca(OH)_2 produced at early age of hydration. Hence, where cements with high C_3S and fineness are used, obviously transition zone gets thickened.

This is where the addition of fly ash becomes significant. Pozzolanic reactions with hydrated lime in transition zone are associated with two physical effects namely, pore-size refinement and grain-size refinement. While pore-size refinement contributes to impermeability of concrete, grain-size refinement influences the transition-zone towards densification thereby minimising chances for micro-cracking. Such

improved microstructure of cement paste mitigates various chemical attacks and contributes towards improved durability of concrete.

Holistic performance for durability

Pozzolanic chemistry with fly ash is the holistic performance towards durability enhancement of a concrete in multiple ways:

- reduction in heat of hydration and minimisation of thermal cracks
- absorption of surplus lime released out of OPC to form the secondary hydrated mineralogy
- pore refinement and grain refinement due to the secondary hydrated mineralogy, thus, contributing for impermeability and enrichment of transition zone
- improved impermeability of the concrete, resulting in increased resistance against the ingress of moisture and gases, thus ultimately leading to durability enhancement.

This holistic performance addresses the issues of multiple needs in a single go, which otherwise need various inputs, as shown in Fig 1⁶.

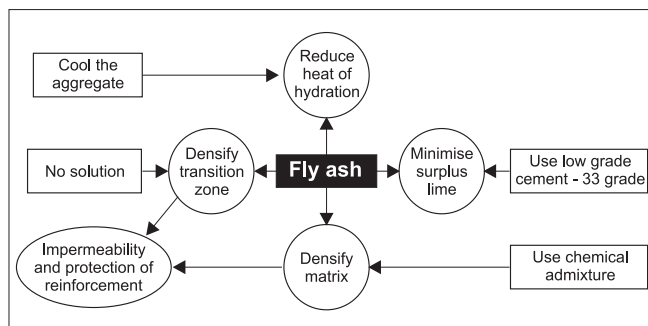


Fig 1 Holistic performance of fly ash for concrete durability advocated by INSWAREB

There is no product comparable to fly ash to render such holistic performance towards durability of concrete. Particularly on the aspect of enriching the transition zone between aggregate and cement paste, fly ash is the unique and cost-effective solution. ASTM has included C1202, the method for rapid chloride ion permeability, as one of its specifications to rate the performance of concrete in qualitative terms.

Chloride permeability and electric resistivity

Table 6 shows fall in permeability for fly ash blended concrete in comparison to that of control. The data clearly delink durability from strength, which is a performance of increase in fineness of fly ash and its quantity.

This data also highlight the resistivity of the concrete to electric charge manifested in coulombs, which means that lesser the coulombs more the resistivity. Electric charge is the basic activity, in the presence of moisture and oxygen, to initiate corrosion of the reinforcement. Needless to point out that a concrete resistive to electric charge is also resistive to corrosion. Can there be a more tangible data to prove that fly ash blended concrete is more resistive to corrosion in comparison to OPC concrete!

But surprisingly, none of the codes in the world set specifications nor pronounced parameters for durability in categorical terms. This has happened because, till the premature failure of structures built with high grade cements, no attention was focused on durability issues.

Codal revision

The codes have remained as the major stumbling block for quite a long time to promote fly ash. For considerable time,

Table 6: Fall in permeability with fly ash blended concretes (M20 grade, cementitious content = 300 kg/m³)

OPC, percent	Fly ash, percent	Strength, N/mm ²			Chloride permeability, coulombs		
		28d	90d	180d	28d	90d	180d
100	—	43.3	47.2	51.4	3852	2451	2251
65	35 (C)	28.8	41.1	44.2	2361	503	303
65	35 (F)	35.1	53.7	58.4	2529	313	166
55	45 (C)	24.9	35.3	41.9	2378	333	195
55	45 (F)	28.7	51.0	54.3	2358	230	92

Note : (C) Coarse composite fly ash with a Blaine of 2800 cm²/g.
(F) Fine fly ash from the same source with a Blaine of 6300 cm²/g.

the code allowed use of fly ash with 12 percent LOI, which caused enough damage to the efficacy of fly ash. This code is under revision now to bring down the LOI to maximum 5 percent. IS 1489, the code for PPC has confined the input of fly ash to 25 percent that has been revised to 35 percent very recently⁷.

IS 456, *The code of practice for plain and reinforced concrete*, was formulated in 1953 giving thrust on structural factors, disregarding the importance of material science. However, pursuant to various government notifications and demand from the industry, a lot of thrust has been given to the application of blended cements on the plank of durability in the fourth revision of the code in 2000, identifying the role of fly ash on the same count⁸.

High-volume fly ash concrete

Malhotra has achieved the distinction of developing high-volume fly ash concrete (HVFC) technology consisting of about 55 percent fly ash by weight in the cementitious system, at CANMET, Canada⁹. HVFC is an approach to maximise the fly ash input in concrete. The first batch of HVFC was developed in 1986. The fall of strength and belated rheology on account of fly ash are counteracted through efficient control of water-cement ratio and effective role of superplasticisers. The HVFC so developed has all the attributes of high performance concrete namely, excellent mechanical properties, low permeability and superior durability. Because of high input of fly ash, the autogenous temperature is very much controlled. In one of the field level studies it was recorded that the temperature rise for HVFC was 35 °C as against 65 °C for control concrete⁸.

Controlling the water-to-cement ratio with the aid of chemical admixtures helps HVFC to gain more strength⁹. However, it is reported that HVFC yields to surface erosion with rampant exposure to de-icing chemicals. It is desirable that HVFC be manufactured with additional gypsum input in order to engage the alumina phase of fly ash into strength rendering mineralogy. This would not only increase early strength and surface hardness, but shows improvement in impermeability as proved by various studies.

Fal-G in cement route is a parallel approach to HVFC; the addition of gypsum commensurate to fly ash being an additional aspect. A concrete road along these lines was laid at Ropar (Punjab), Fig 2. Blending OPC to Fal-G (Portland: Fal-G)¹⁰ is another diversification for high early strength to Fal-G. Some works have been executed in India; a couple of buildings and roads in Andhra Pradesh; a few high capacity ground and overhead water tanks (40 to 200 thousand litres) in rural water works (RWS) of Panchayat Raj Department, Andhra Pradesh, Fig 3.

Fly ash in prestressed concrete

A study was undertaken by the authors to manufacture prestressed railway concrete sleepers, replacing 25 percent cement by fly ash. While the compressive strength is almost parallel, the flexural strength has exceeded by 10-18 percent, as shown in the Table 7.



Fig 2 HVFC road in Ropar

This work establishes the scope of fly ash blends for prestressed concrete also with superior engineering performance, which is considered as critical application to demonstrate efficacy of concrete.

Fly ash for roads and embankments

Fly ash proves as the best soil substitute with superior shear strength and engineering properties. These properties can be augmented through stabilisation with lime or OPC. Thus fly ash can find place for embankments and as sub-grade in roads. For such a potential associated with fly ash, the attention paid in India is decimal in the background of 100-million tons of generation annually, and massive infrastructure needs throughout the country.

As per the Australian guide, strength and compressive properties of fly ash resemble a medium to dense sand, but with a compacted mass of only 60 percent to that of dense sand¹¹. Hence, the guide recommends the use of fly ash for backfilling retaining walls or for constructing embankments, enlisting the following characteristics:

- high internal angle of friction
- low unit mass
- low compressibility
- reduced settlement when used as fill material
- ease of compaction
- its self-hardening properties, resulting in a possible reduction in fill pressures on structures.

Indian scenario

Guidelines for use of waste and byproduct materials in pavement construction (FHWA-RD97-148) covers fly ash with

Table 7: Data on railway concrete sleepers

Railway concrete sleepers	Strength, tonnes		
	RS1	RS2	Centre top
With control concrete	22.6	22.0	6.5
With PPC concrete containing 25 percent fly ash	25.0	26.0	6.6



Fig 3 Water tanks RWS — Panchayat Raj Department, Andhra Pradesh, in Portland: Fal-G

regard to origin, sources, properties, application, past performance, cost issues, design and construction. The following are some of the codal references of the Indian Rule Congress, New Delhi.

- IRC:60-1976 Tentative guidelines for the use of lime-fly ash concrete as pavement base or sub-base.
- IRC:68-1976 Tentative guidelines on cement fly ash concrete for rigid pavement construction.
- IRC:74-1979 Tentative guidelines for lean cement concrete and lean cement fly ash concrete as a pavement base or sub-base.
- IRC:88-1985 Recommended practice for lime fly ash stabilised soil base and sub base in pavement construction.

Fly ash is used as a filler in asphalt production, providing improvement in the physical properties of asphalt for roads. Alternately, fly ash can be mixed into the bitumen along with sand and stone. The impermeability of bitumen top increases and, thus, its weakness against water attack is mitigated, to offer longer service life.

It is observed that fly ash fills are amenable for quick consolidation. However, the non-cohesive fine-grained fly ash has the weakness to erode when exposed to surface run-off. Stabilisation with lime or cement gives resistance to fly ash against this weakness. The geotechnical characteristics of fly ash, that is, grain distribution pattern, compaction coefficient, shear strength and impermeability are superior with HT fly ash over that of LT fly ash. The high level of unburnt carbon in the latter affects the geotechnical parameters.

It is reported that in the embankments of second Nizamuddin bridge at Delhi across river Yamuna on national highway 24, 1.50 lakh m³ of fly ash has been used. The project is unique because this is the first fly ash embankment in the country that has been constructed in a flood zone without any reinforcement except soil cover and stone pitching. To facilitate compaction and additional stability, fly ash and soil

were laid in alternate layers duly compacted by vibratory rollers. The thickness of fly ash layer is 2 m, over which 0.40 m thick soil layer has been constructed.

Vishveshvaraya Sethu (Okhla flyover) is another project where reinforced fly ash retaining wall is constructed. The length of the approach embankment is 59 m with variable height of 7.3 to 5.3 m. The substructure was filled with bottom ash and reinforced with bi-oriented geogrids.

The American Concrete Institute (ACI) described roller-compacted concrete (RCC) as a dry concrete material that is consolidated by external vibration by vibratory rollers. It differs from conventional concrete in its required consistency; RCC must be dry enough, for effective consolidation, to support the weight of the placement equipment; but workable enough to permit distribution of the paste throughout the mass during mixing and compaction. Platanovyssi Dam on Nasto river in Greece, is the best reference structure for roller compacted concrete, having used as high as 82 percent class C fly ash as complement to OPC in the concrete.

Fly ash – clean development mechanism (CDM)

The Kyoto Protocol is enshrined with clean development mechanism (CDM) in order to ensure the participation of second and third world countries towards the minimisation of green house gases. INSWAREB has conducted base-line studies to define the fly ash based brick and cement plants as qualified CDM projects. In one of the studies they have projected the scope of earning over 60-80 million tonnes of CO₂ credits every year if the potential of fly ash in the country is suitably tapped. One can be quite sure and optimistic of interfacing the incentive of carbon credits to the fly ash utilisation program, thus making it more lucrative and sustainable to the industry and exchequer with impact on GDP (gross domestic product).

Conclusions

It is beyond doubt that a distinct shift is evident in the Indian scenario of fly ash utilisation from pessimism to optimism if the increased production of PPC is any indication. However the mind set in government construction agencies has to be necessarily changed for the furtherance of the trend. There is a need to converge the commitments and actions of various state governments into action.

Maximum sources of Indian fly ash are some of the best lots in the world. Without giving credence to this fact, any interpretation to discourage the utilisation through reduction-approach is unfair and dis-service to the nation.

Fly ash-based brick and cement are far superior in engineering properties over their conventional competitors. This knowledge needs to be disseminated globally, more so in second and third world countries, through tangible technical explanations.

The opportunity to abate CO₂ is 35 million tonnes in cement and 45 million tons in brick by using fly ash in both the segments in India. When Kyoto Protocol comes into effect, fly ash utilisation proves as the money-spinner in 'green trading' point of view, for achieving CO₂ abatement.

Very few technologies can assimilate economy, value addition and eco-service; all in a single go. Fly ash utilisation is the unique opportunity to serve these multiple indicators collectively.

Acknowledgements

The authors thankfully acknowledge the various articles of Prof P.K. Mehta, Professor Emeritus of Civil & Environmental Engineering, University of California, Berkeley. HUDCO deserves special mention for funding the R&D laboratories of INSWAREB.

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