ADVANTAGES OF USING FLY ASH AS SUPPLEMENTARY CEMENTING MATERIAL (SCM) IN FIBRE CEMENT SHEETS

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ABSTRACT

The Supplementary Cementing Materials (SCM) most commonly used includes Fly ash, Silica fume and ground granulated blast furnace slag. Among these Fly ash is most suitable SCM to partially replace cement in fibre cement sheets.

The benefits of SCM's are well known, proper enrichment of fly ash with calcium helps produce stronger and more durable fibre cement sheets. Fly ash is a waste product generated by thermal power stations; it is usually much cheaper than cement in India and hence offers saving in product cost. Most importantly replacing cement with fly ash reduces Green House Gas (GHG) emissions such as carbon dioxide. Production of one tonnage of cement emits one tonnage of CO_2. According to the International Energy Agency, cement production alone accounts for 7 % of total global CO_2 emissions[3]. Replacement of cement with fly ash also reduces the emission of other common air pollutants such as NOx and SOx, associated with cement production by same proportion. Apart from this, cement substitution with fly ash saves natural resources such as limestone and coal, which are used for the manufacturing of cement.

Fly ash in India contains low CaO (less than 10%) and is obtained by burning bituminous coal. Thus such a fly ash containing fibre cement sheets exhibits low early strength even at an optimal dosage of 10-20 %. Two methods can be adopted to increase the dosage of fly ash by calcium – enrichment (1) introducing calcium directly during burning of coal (2) as an additive[4]. The effect of such calcium-enriched fly ash on fibre cement sheet properties was investigated.

In the present investigation, calcium enrichment of fly ash is done by using additives such as hydrated lime and gypsum. A dosage of 30 – 35 % of calcium enriched fly ash can be used as replacement to cement in the production of fibre cement sheets.

KEYWORDS

Fly ash; Cement; Supplementary Cementing Material; Fibre cement sheets; Carbonation.

INTRODUCTION

It is the action of human beings that determines the worth of any material. Materials having potential for gainful utilization remain in the category of waste until its potential is understood and put to right use. Fly ash is one such example, which has been treated as a waste material in India, till a decade back, and has now emerged not only as a resource material, but also as an environment saviour. The Indian market is extremely receptive to clean development mechanism (CDM), with a fair amount of appreciation both by the government and the industry. Developed countries like US account for 30 % of global emissions, while India contributes about 3 % of the global Green House Gases (GHS) against the global average of 5.2 %. Use of fly ash in various products and partly substituting cement at current annual levels in India saves generation of CO_2 by 25 million tonnes, good quality lime by 35 million tonnes and coal by 15 million tonnes a year[5]. The potential that is yet to be tapped is multi-fold of the current levels.

Notwithstanding the above, it is also acknowledged that there are large regional variations in both production (as can be seen from Figure 1) and use of the material, with the perception of fly ash and attitudes to its use, being continually redefined.

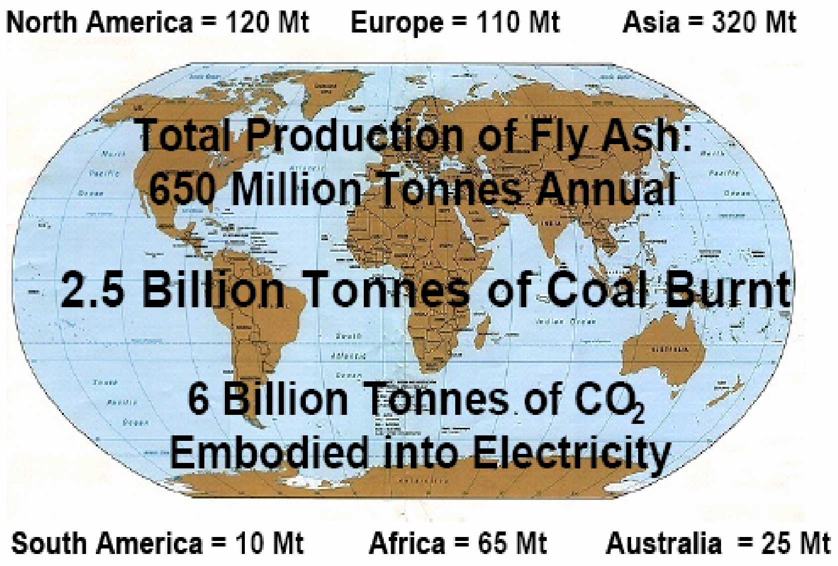

Figure 1 World Scene, 2003

Supplementary cementing materials (SCM) are widely used in India to partly replace cement in concrete. The SCM's most commonly used include fly ash, ground granulated blast furnace slag and silica fume. We have selected fly ash as SCM for the manufacturing of fibre cement sheets due to its availability, cheaper than cement and protection to environment from pollution.

This paper describes in detail how the use of fly ash in fibre cement sheets on a massive scale (35 to 40% in formulation) has been a success story, meeting all the requirements, as specified.

ABOUT FLY ASH

Fly ash is a burnt and powdery derivative of inorganic mineral matter that generates during the combustion of pulverized coal in the thermal power plant. The burnt ash of the coal contains mostly silica, alumina, calcium and iron as the major chemical constituents. Depending on the burning temperature of coal, the mineral phases in crystalline to non-crystalline structures such as quartz (SiO_2), mullite ($3Al_2O_3$ 2 H_2O), hematite (Fe_2O_3), magnetite (Fe_3O_4), wustite (FeO), metallic iron, orthoclase (K_2O $Al_2O_3$6 SiO_2) and fused silicates usually occur in the burnt coal ash[2]. Silica and alumina account for about 75 to 95 % in the ash. The classification of thermal plant fly ash is considered based on reactive calcium oxide content as class-F (less than 10 %) and class-C (more than 10 %). Indian fly ash belongs to class-F. The calcium bearing silica and silicate minerals of ash occur either in crystalline or non-crystalline structures and are hydraulic in nature; they easily reacts with water or hydrated lime and develop pozzolanic property. But the crystalline mineral phases of quartz and mullite present in the ash are stable structures of silica and silicates, and are non-hydraulic in nature. Usually the fly ash contains these two mineral phases as the major constituents. Therefore, the utilisation of fly ash in making building materials like fibre cement sheets largely depends on the mineral structure and pozzolanic property.

Fly ash is broadly an aluminium-silicate type of mineral rich in alumina and silica. The conversion of these oxides of fly ash to hydrous silico-aluminate structures by chemical activation has been made under alkaline condition with lime. The effect of chemical transformation of ash in the development of binding property has been observed to find their suitability in manufacturing of fibre cement sheets. Further, it has been attempted to use high volume fly ash (35 to 40 % in formulation) in development of corrugated and flat fibre cement sheets with asbestos and non-asbestos fibres.

THE MANUFACTURING PROCESS OF FIBRE CEMENT SHEETS

L.Hatschek invented a process for the manufacturing of fibre cement sheets. Essentially this invention consisted of manufacturing a sheet material on a rotating sieve machine using a highly diluted suspension of Portland cement and reinforcing fibres. Fibre cement sheet is understood to be a composite material with mechanical properties that largely depends on the interaction between the reinforcing fibre and the matrix (cement).

EXPERIMENTS

1. Materials

1.1 Fly ash: In experiments fly ash with specific surface area of 338 $m^2.kg^{-1}$, Lime reactivity of 6.2 N/mm^2 and a compressive strength that is 83 % of corresponding plain cement mortar cubes was used. The typical chemical composition of Fly ash (source Vijayawada Thermal Power Station) is presented in table-1.

1.2. Cement: In experiments normal Portland cement with specific surface area of 306 $m^2.kg^{-1}$ and minimum 28 days strength of 53 N/mm^2 was used. Its chemical composition is presented in table-2.

Table 1 - Chemical composition of fly ash

Content of the component, %							
SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	$K_2O + Na_2O$	LOI
60.5	30.8	3.6	1.4	0.91	0.14	1.1	0.8

LOI – Loss of ignition

Table 2 - Chemical composition of Portland cement

Content of the component, %								
IR	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	LOI	Free Lime
1.32	21.53	5.20	4.15	62.09	1.21	1.58	1.54	1.53

IR- Insoluble residue

1.3. Fibres: Blend of white Chrysotile asbestos fibre (IV, V and IV groups in the ratio of 1: 1: 1) were used as reinforcement.

2. Process.

Fibre cement sheets made on Hatschek machine with low calcium fly ash at dosages ranging from 10 – 40 % (as a replacement of cement) are steam cured at 80 ^{0} C $\pm$ 5 ^{0} C for 10 hours and tested after 10 days .

RESULTS AND DISCUSSION

Test result presented in table –3 shows that the Load Bearing Capacity of the sheets decreases with increasing dosage of fly ash. Strength of sheet at a dosage of 10 % decreases by 5 –10 % and at 20 % it decreases by 10 – 20 %, but meets the requirement of Min. 5000 N/m as per Indian Standard IS 459: 1992, when tested in accordance with IS 5913: 1989. Strength of sheet at a dosage of 30 % and 40 % are below the required standard value of 5000 N/m.

Table – 3

S.No	Material	% used in mix				
1	Cement	91.0	81.9	72.8	63.7	54.6
2	Fly ash	0.0	9.1	18.2	27.3	36.4
3	Asbestos fibre blend	9.0	9.0	9.0	9.0	9.0
Properties Observed						
1	Density (g/cc)	1.43	1.42	1.44	1.42	1.41
2	Load Bearing (N/m)	6500	6032	5500	4840	4225

Thus, there is a need to increase dosage of fly ash, economize on cement and improve strength of fibre cement sheets. Effect of calcium enrichment on fly ash dosage as well as strength development and other properties of fibre cement sheets are reported in this paper.

The calcium-enriched fly ash was obtained by introducing a certain amount of hydrated lime and gypsum powder as additives into low calcium fly ash (Vijayawada Thermal power Station).

Further experiments were conducted partly replacing cement with calcium-enriched fly ash. Fibre cement sheets made on Hatschek machine with low calcium fly ash and calcium-enriched fly ash were steam cured at $80\,^{0}C \pm 5\,^{0}C$ for 10 hours and tested after 10, 30, 60 and 90days respectively. Test results are presented in table - 4.

Table - 4

S.No	Material	% used in mix			
1	Cement	56.0	56.0	51.0	46.0
2	Fly ash	35.0	--	--	--
3	Calcium enriched fly ash (Fly ash 87 % + H.lime 10 % + gypsum 3 %)	--	35.0	40.0	45.0
4	Asbestos fibre blend	9.0	9.0	9.0	9.0
Properties observed					
1	Density (g/cc)	1.39	1.41	1.42	1.42
2	Load Bearing (N/m) - 10 days	4580	6110	5500	4800
	30 days	4809	6446	5840	4890
	60 days	4855	6508	6125	4933
	90 days	4878	6550	6236	4956

Results show that fibre cement sheets made with up to 40% calcium enriched fly ash replacing cement are meeting the minimum load bearing strength of 5000 N/m after 10 days. Strength increase with higher dosage of calcium enriched fly ash is attributed to the self-hardening effect of the fly ash and the presence of C_2S, calcium aluminate and free CaO. Thus, calcium enrichment of fly ash results in increased activity due to formation of Si-Ca phase from ash and CaO; this can increase dosage of fly ash in fibre cement sheet and improve early and long-term strength. It is also observed that after 60, 90 days strength of sheets made with 35-40 % calcium enriched fly ash (replacing cement) surpasses or approaches those of reference sheets made with out fly ash at the corresponding ages.

Experiments also conducted with calcium enriched fly ash in fibre cement sheets that are made of non-asbestos fibres such as pulp and synthetic fibres. Test results are presented in table-5

Table - 5

S.No	Material	% used in mix			
1	Cement	57.0	57.0	52.0	47.0
2	Fly ash	35.0	--	--	--
3	Calcium enriched fly ash (Fly ash 87 % + H.lime 10 % + gypsum 3 %)	--	35	40	45
4	Soft wood pulp and synthetic fibre blend	8.0	8.0	8.0	8.0
Properties observed					
1	Density (g/cc)	1.31	1.29	1.26	1.24
2	Load Bearing (N/m) 10 days	3560	3885	3730	3610
	30 days	3739	4087	3868	3728
	60 days	3766	4118	3971	3793
	90 days	3798	4150	4036	3826

In general, the mechanism by which fly ash influences the properties of fibre cement sheets are dependent more on the size, shape, and texture of the particles than on the chemical composition. For instance, the water demand and filterability are controlled by particle size distribution, particles packing effect and smoothness of sheet surface texture. The pozzolanic and cementitious properties, that govern the strength development and permeability of the product, are controlled both by the mineralogical characteristics and particle size of the fly ash.

1. Effect of Additives on Calcium compounds.

By adding calcium-based additives to fly ash, strength and other properties of the fibre cement sheets improve and meet the requirement at higher dosages. Steam curing favours the reaction between fly ash and $Ca(OH)_2$ formed by hydration of cement and also more CSH hydrate is formed by reaction between fly ash with H.lime and gypsum. These effects compensate for decrease in strength and deterioration of properties of the fibre cement sheets due to decrease in cement basicity and inadequate amount of binder at higher dosages of fly ash.

2. Properties of calcium enriched fly ash fibre cement sheets.

For the assessment of the durability of fibre cement sheets made with calcium enriched fly ash, Type tests such as a) Mechanical characteristics (deflection), b) Impermeability, c) Frost resistance, d) Warm water and e) Heat-Rain are also conducted. The results of the tests are given below.

i. In water impermiability test, there was no formation of water droplets under side the sheet.

ii. In frost resistance test, after 50 freeze-thaw cycles, the limit 'L' of the average ratio 'r' is 0.92.

iii. In warm water test, the limit 'L' of the average ratio 'r' is 0.98.

iv. After Heat–Rain test no visible cracks, delamination or other defects were observed in sheets.

In all aspects, the test results are incompliance with the standards. It is observed that with increase in fly ash content, frost resistance and shrinkage properties of sheets are improved when compared with reference sheets that are made with cement. After 28 days of carbonation, the carbonation depth of fibre cement sheet made with 35% dosage of calcium enriched fly ash is 5.8 mm, compared with 6.3 mm for reference fibre cement sheet. Carbonation resistance in fibre cement sheets increases with calcium enriched fly ash. As seen from X-ray diffraction curves of 3 months old specimen made with cement and low calcium fly ash, a small peak for $Ca(OH)_2$ appears; but for samples made with cement and calcium enriched fly ash, intense $Ca(OH)_2$ peak is observed. Thus, basicity in fly ash cement products seems to be an important factor that controls strength and other properties[1].

3. The advantage of utilising fly ash as supplementary cementing material for environmental protection.

The technology of replacing Portland cement with fly ash in fibre cement sheets offers numerous benefits such as increased strength, durability and resistance to chemical attacks. Fibre cement sheets are widely used for shelters and are a versatile building material. Cement which is a main component of the sheet is produced around 2 billion tons annually, consequently 2 billion tons of CO_2 is emitted in to the atmosphere from cement manufacturing industries. A successful process which is described in the paper reduces the consumption of cement by partly replacing it with fly ash. The current generation of fly ash per annum is about 650 million tones across the world. Indian fly ash generation is about 120 million tons annually. Hence there is large potential for the use of fly ash in building products and in turn protect the environment by reducing Green House Gas (GHS) emission (According to the International Energy Agency, cement production accounts for 7 % of total global CO_2 emission) and global warming[3]. Replacement of cement with calcium enriched fly ash (excluding the amount of lime used which emits CO_2) reduces the emission of CO_2 and other common air pollutants such as NOx and SOx associated with cement production by the same proportion. Use of fly ash in cement, mortar and concrete as a pozzolanic material, saves the equal amount of cement, which otherwise would have been consumed. The production of cement apart from being quite energy intensive also uses about 1600 kg of limestone and 400 kg of coal per tone of clinker. Replacement of cement by fly ash also saves the corresponding amount of these natural mineral resources, which are already scarce. As per the estimates, India is left with limestone reserves, which are expected to last only for next 40 years[5]. Further, reduction in usage of these minerals would also decrease the associated mining activity to the corresponding extent, hence the related environmental benefits.

CONCLUSIONS

1. Fibre cement sheets made by part replacement of cement with low calcium fly ash shows low strength; strengths decrease with higher fly ash dosage.
2. Dosage of fly ash in fibre cement sheets can be increased up to 35% after enriching it with additives such as H.lime and gypsum.
3. Calcium enriched fly ash improves frost and carbonation resistance of fibre cement sheets.
4. Strength of fibre cement sheet made with calcium enriched fly ash increases with aging and indicates better durability.
5. Utilization of fly ash reduces the cost of the product where fly ash is cheaper than cement.
6. Utilization of fly ash as SCM prevents pollution, conserves natural resources and protects the environment.

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