Supplementary Cementitious Materials for Rural Area

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ABSTRACT
Supplementary cementitious materials are finely divided material that replaces or supplements the use of Portland cement. Its use reduces the cost and /or improves one or more technical properties of concrete. These materials are generally by-product from other processes or natural materials. These materials include fly ash, ground granulated blast furnace slag, condensed silica fume, lime and natural pozzolan [1]. For use in mortar or concrete supplementary cementitious materials need to meet requirements of established standards [2]. Attempt has been made, here, to study the characteristics and behavior of supplementary cementitious materials, especially the lime and fly ash from Vidarbha Region of Central India, which are local resources.

Keywords :
fly ash, pozzolan, lime, ground granulated blast furnace slag, condensed silica fume

1. INTRODUCTION
1.1 Fly ash
Thermal power stations use pulverized coal as fuel. They produce enormous quantities of coal ash as a by-product of combustion. This calls for the development of strategies to encourage and establish technological concepts which will ensure increase in consumption of fly ash in bulk. Among the various uses of fly ash, its major utilization is possible to manufacture alternative cementing material. This necessitates characterization of the fly ash with reference to Lime-fly ash mixture for construction activities.
Coal based thermal power plants all over the world face serious problems of handling and disposal of the ash produced. The high ash content (30-50%) of the coal in India makes this problem complex. At present, about 80 thermal power stations produces nearly 100 million tones of coal ash per annum [3]. Safe disposal of the ash without adversely affecting the environment and the large storage area required are major concerns. Hence attempts are being made to utilize the ash rather than dump it. The coal ash can be utilized in bulk only in construction as mineral admixture in concrete, pozolanic material for lime fly ash mix for mortar as well as for concrete. For this, in-depth understandings of physical and chemical properties are required.
The use of fly ash provides improved workability, increased long term compressive strength, reduced heat of hydration, decreased costs and increased resistance to alkali-silica reaction and sulphate resistance when compared to blended Portland cement [1]. According to research fly ash has proven suitability for variety of application as admixture in cement, concrete and mortar, lime pozzolana mixtures etc. Fly ash as pozzolana reacts chemically with calcium hydroxide (hydrated) in presence of moisture at ordinary temperature to form compounds possessing cementitious properties [4].

1.2 Lime
Limestone functions as a supplementary cementitious material when it is finely ground with clinker in Portland cement. Limestone quality should have at least 75% calcium carbonate by mass, clay content less than 1.2% by mass and organic content less than 0.2% by mass. There are several advantages of using limestone in Portland cement such as reduced energy consumption and reduced CO_2 emissions. Additional cost savings are realized if limestone is available in close proximity to site. In Portland cement with high C_3A contents, the carbonate from limestone will react with the C_3A during hydration and may increase strength again and resistance to sulphate attack [1].
There are two types of lime, Non-hydraulic lime and Hydraulic lime. The former is made from high purity calcium carbonate (limestone or chalk). The calcium carbonate (C_aCO_3) is heated to approximately 900 to 1200 degrees Celsius in a kiln to produce calcium oxide (C_aO), also known as quicklime. When water is added to quicklime, known as slaking, it releases large amount of heat, causing the water to boil and 'pit'. The resulting product is calcium hydroxide $C_a(OH)_2$, or 'hydrated lime', or 'slaked lime' or 'lime putty'.
The lime putty of non-hydraulic lime hardens extremely slowly by drying and by a process named as carbonation in which the lime putty reacts with carbon dioxide in the air to convert it to calcium carbonate [5].
By adding a hydraulic or 'pozzolanic' additive non-hydraulic lime can be converted to hydraulic in nature and sets very fast. These additives include cement, fly ash and brick powder (Surkhi) [5].
Hydraulic lime is made in a very similar process as given above. Quite often the limestone used for the source of calcium carbonate contains impurities, such as small amount of silt or clay. Along with the calcium oxide formed while being burned in the kiln, the silt and/or clay form calcium silicates and aluminates. These compounds will react with water to set and harden regardless of the presence of air. Only enough water is added in hydraulic lime to produce calcium hydroxide in a powder form, not excess to set the calcium silicates and aluminates. This dry material, known as hydrated lime, is mixed with water to produce a mortar that will set very quickly as compared to non-hydraulic lime [5].

1.3 Ground granulated blast furnace slag (GGBFS)
Ground granulated blast furnace slag is produced in a blast furnace where iron ore is converted into iron. This slag forms when the silica and alumina compounds of the iron ore combine with the calcium of the fluxing stone(limestone and dolomite).The newly formed slag floats on the liquid iron and is drawn off from a notch at the top of the hearth while the liquid iron flows from a hole at the bottom of the hearth.
These reactions takes place at temperatures ranging from 1300-1600 degrees Celsius, so the slag is conveyed to a pit where it is

cooled. The conditions of the cooling process determine the type of blast furnace slag: air-cooled, foamed, water granulated, or palletized. Of these types, ground granulated blast furnace slag is both cementitious and pozzolanic. Ground granulated blast furnace slag is a replacement of Portland cement and provides several advantages such as improved workability, reduced heat of hydration, decreased costs, increased resistance to alkali-silica reaction, and sulphate resistance and increased compressive and flexural strength when compared to unblended Portland cement [1].

GGBFS has cementitious properties by itself but these are enhanced when it is used with Portland cement. Slag is used at 20% to 70% by mass of cementitious materials [2].

1.4 Condensed silica fume

Condensed silica fume is a by-product of the smelting process in the silicon metal and ferrosilicon industry. Silica fume is produced when SiO vapors, produced from the reduction of quartz to silicon, condense. Silica fume particles are spherical with an average diameter of 1µm and contain approximately 90% silicon dioxide with traces of iron, magnesium, and alkali oxides. When compared to Portland cement, fly ash, or ground granulated blast furnace slag, silica fume is much finer. The addition of small amounts of silica fume (2-5%) increase workability while large amounts of silica fume (>7%) decrease workability, increase compressive strength, decrease permeability and provide resistance to sulphate attack and alkali-silica reaction. [1] It is generally used at 5 to 12% by mass of cementitious materials for concrete structures that need high strength or significantly reduced permeability [2].

1.5 Natural Pozzolans

Other natural Pozzolans exist such as volcanic ash, rice husk ash, shale, zeolitic trass or tuffs, and diatomaceous earths. These materials originate from volcanic eruptions and have raw or calcined natural material. These natural pozzolans have large internal surface areas and vary depending on the type of magma from which they originate. Calcined Kaolinite is a processed natural pozzolan, which is highly reactive in the presence of lime upon hydration. By including calcined kaolinite in Portland cement, increased compressive strengths and decreased permeability may result. [1].

2 NEED FOR THE SPECIAL STUDY ON SUPPLEMENTARY CEMENTITIOUS MATERIALS

Supplementary cementitious materials can be used for improved concrete performance in its fresh and hardened state. They are primarily used for improved workability, durability and strength. These materials allow the concrete producer to design and modify the concrete mixture to suit the desired application. Concrete mixtures with high Portland cement contents are susceptible to cracking and increased heat generation. These effects can be controlled to a certain degree by using supplementary cementitious materials.

Supplementary cementitious materials such as fly ash, slag and silica fume enable the concrete industry to use hundreds of millions of tons of byproduct materials that would otherwise be land filled as waste. Furthermore, their use reduces the consumption of Portland cement per unit volume of concrete. Portland cement has high energy consumption and emissions associated with its manufacture, which is conserved or reduced when the amount used in concrete is reduced [2].

3. THE EFFECT ON CONCRETE PROPERTIES

Fresh concrete: In general, supplementary cementitious materials improve the consistency and workability of fresh concrete because an additional volume of fines is added to the mixture. Concrete with silica fume is typically used at lower water contents with high range water reducing admixtures and these mixtures tend to be cohesive and stickier than plain concrete. Fly ash and slag generally reduce the water demand for required concrete slump. Concrete setting time may be retarded with some supplementary cementitious materials used at higher percentages. This can be beneficial in hot weather. The retardation is offset in winter by reducing the percentage of supplementary cementitious materials in the concrete. Because of the additional fines, the amount and rate of bleeding of these concretes is often reduced. This is especially significant when silica fume is used. Reduced bleeding, in conjunction with retarded setting, can cause plastic shrinkage cracking and may warrant special precautions during placing and finishing [2].

Strength- Concrete mixtures can be proportioned to produce the required strength and rate of strength gain as required for the application. With supplementary cementitious materials other than silica fume, the rate of strength gain might be lower initially, but strength gain continues for a longer period compared to mixtures with only Portland cement, frequently resulting in higher ultimate strengths. Silica fume is often used to produce concrete compressive strengths in excess of 70 Mpa. Concrete containing supplementary cementitious material generally needs additional consideration for curing of both the test specimens and the structure to ensure that the potential properties are attained [2].

Durability- Supplementary cementitious materials can be used to reduce the heat generation associated with cement hydration and reduce the potential for thermal cracking in massive structural elements. These materials modify the microstructure of concrete and reduce its permeability thereby reducing the penetration of water and water-borne salts into concrete. Watertight concrete will reduce various forms of concrete deterioration, such as corrosion of reinforcing steel and chemical attack. Most supplementary cementitious materials can reduce internal expansion of concrete due to chemical reactions such as alkali aggregate reaction and sulphate attack. Resistance to freezing and thawing cycles requires the use of air entrained concrete. Concrete with a proper air void system and strength will perform well in these conditions [2].

4. EXPERIMENTAL RESULTS

The local materials from Vidarbha region of Maharashtra state of India, which are lime from lime-belt of Yavatmal district, fly ash from thermal power station of Nagpur district and lime-fly ash mix, were tested for Physical and Chemical properties as per the respective codes of Bureau of Indian Standards Institution.

The test results for Physical and Chemical properties of Lime, fly ash and Lime-fly ash mix are shown in Table-1 to Table-6

5. CONCLUSION

The optimum combination of materials will vary for different performance requirements and the type of supplementary cementations materials. The ready mixed concrete producer, with the knowledge of locally available materials, can establish the mixture proportions for the required performance. Prescriptive restrictions on mixture proportions can inhibit optimization and economy. While several enhancements to concrete properties are discussed above, these are not mutually exclusive and the mixture should be proportioned for the most critical performance requirements for the job with the available materials.

Alternative cementing materials can directly replace a portion of Portland cement. These materials can be used alone or blended with other alternative cementing materials to produce cement or concrete with properties different than those resulting from the use of Portland cement. The use of alternative materials affects cement and concrete properties such as workability, hydration, compressive strength, and durability.

Table- 1: Chemical analysis of Hydrated lime sample

SN	Characteristics	Class		Test values	Method of test refer to
		B	C		
1	2	3	4	5	6
1	Calcium and magnesium oxides, percent Min (on ignited basis)	70	85	78.4	IS:6932(Part 1)1973
2	Magnesium oxides; percent, (on ignited basis), Max Min	6 -	6 -	4.5	IS:6932(Part 1)1973
3	Silica,alumina and ferric oxide percent, Min	10	-	7.24	IS:6932(Part 1)1973
4	Insoluble residue in dilute acid and alkali,percent Max	10	2	8.24	IS:6932(Part 1)1973
5	Carbondioxide, percent. Max	5	5	3.66	IS:6932(Part 2)1973
6	Free moisture content; percent. Max	2	2	1.14	IS:1514-1990
7	Available lime as C_aO, percent. Min	-	75(on ignited basis)	74	IS:1514-1990

The Lime and Fly-ash of Vidarbha region shows much positive results for use in construction as cement when used in proper combination. All requirements of Indian Standards have been satisfied by the materials individually and by the combined mix as well.

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Table- 2 : Physical analysis of Hydrated lime sample

Sr. No	**Characteristics**	**Class**		**Test values**	**Method of test refer to**
		B	**C**		
1	**2**	**3**	**4**	**5**	
1	**Fineness** a)Residue on 2.36 mm IS Sieve,percent Max b)Residue on 300 micron IS Sieve,percent, Max c)Residue on 212 micron IS Sieve,percent, Max	Nil 5 -	Nil Nil 10	Nil 4 --	IS:6932(Part 4)1973
2	**Setting time** a) Initial set,Min, h b)Finalset,Max, h	- -	- -	4 hr 2 min 24 hr 10 min	IS:6932(Part 11)1973
3	**Compressive strength** Min, N/mm^2 a) at 14 days b)at 28 days	1.25 1.75	- -	1.28 1.78	IS:6932(Part 7)1973
4	**Transverse strength** at 28 days.N/mm^2,Min	0.7	-	0.85	IS:6932(Part 7)1973
5	**Workability** bumps, Max	-	10	10	IS:6932(Part 8)1973
6	**Soundness**, Le Chaterlier expansion, in mm, Max	5	-	Nil	IS:6932(Part 9)1973
7	Popping and pitting	Free from pop and pits	Free from pop and pits	Free from pop and pits	IS:6932(Part 10)1973

Table 3 : Chemical analysis of fly ash sample

Sr. No.	Characteristic	Requirement for grade 1 pulverized fuel ash	Test Values
i)	Silicon dioxide (SiO_2) plus aluminium oxide (Al_2O_3) plus iron oxide (Fe_2O_3) percent by Mass, Min	70.00	90.07
ii)	Silicon dioxide (SiO_2), percent by mass, Min	35.00	53.38
iii)	Magnesium oxide (MgO), percent by mass, Max	5.0	1.53
iv)	Total sulphur as sulphur trioxide (SO_3), mass, Max	5.0	0.73
v)	Loss on ignition, percent by mass, Max	5.0	0.22

Table 4 : Physical analysis of fly ash sample

Sr. No.	Characteristic	Requirement for grade 1 pulverized fuel ash	Test Values
i)	Fineness-specific surface by Blaine`s Permeability method in m^2/kg, Min	250	260
ii)	Particles retained on 45 micron IS sieve (wet sieving) in percent, Max	40	12
iii)	Lime reactivity-average compressive strength in N/mm^2, Min	3.5	6.55

TABLE 5: Chemical analysis of lime-Pozolana mix Sample

Sr no.	Characteristic	Require ments	Test Val ues	Reference to method of test
i)	Free moisture content, percent, Max	5	2.5	IS:4098-1983 Appendix A
ii)	Free lime, percent, Min	22	34	IS 1514- 1990
iii)	Carbon dioxide, percent Max	5	4.85	IS:6932-1973(Part 2)
iv)	Sulphate content, percent, Max	3	0.5	I S:1727 – 1967
v)	Magnesium oxide, percent, Max	8	1.7	I S:1727 – 1967

Table-6: Physical analysis of lime- Pozzolana mix sample

S N	Characteristic	Requirements types of mixtures		Test values for 50:50 lime pozolana mix	Reference to method of Test
		LP 20	LP 7		
i)	Fineness, percent retained on 150 micron IS Sieve	15	--	14	IS:4031-1988 Part 1
ii)	Setting Time , Hours a) Initial, Min b) Final, Max	2 36	2 48	4Hr20Min 24Hr35Min	IS:4031-1988 Part 5
iii)	Compressive strength, average compressive strength of not less than 3 mortar cubes of size 50 mm composed of one part of lime-pozzolana Mixture and 3 parts of standard sand by weight, N/mm^2 a) At 7 days, Min b) At 28 days, Min.	1 2	0.3 0.7	0.67 1.71	IS:4031-1988 Part 7
iv)	Soundness, mm, Max	10	10	1	IS:4031-1988 Part 3

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