Research Article

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Supplementary Cementitious Materials in Construction - An Attempt to Reduce CO_2 Emission

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ABSTRACT

Owing to the growing construction needed for increasing developmental activities massive burden is being posed to the environment in terms of direct products and by-products. Cement is prime construction material and its huge production to meet out the demand is of great concern for environmentalists. During the production of cement, various harmful gases are emitted out of which CO_2 is of prime concern. Several materials, viz. fly ash, rice husk ash, GGBS, silica fume, metakaolin etc., can be used as partial replacement of cement in construction. The use of Supplementary cementitious materials in construction not only improves the mechanical property of cement matrix but also reduce the burden from the environment. In this paper, an attempt is made to explore the possibility of the use of different materials as partial replacement of cement in construction.

Keywords: Compressive strength; Fly ash; Metakaolin; OPC; Pozzolan; Silica fume; Supplementary cementitious materials; Workability.

1. INTRODUCTION

In the fast-growing economy, infrastructural development is key for society. Industrialisation, urbanisation and modernisation are a tool for going ahead. For any developmental activity, new construction or modification of an old one is a prime requirement. This leads to increasing construction activities rapidly. Cement is the prime construction material, and construction activities greatly depend on it. The cement production is about 280 million metric tons in India and 4,100 million metric tons worldwide, which is expected to be increased substantially in the light of growing demand due to the increasing construction activities[(1)]. It is a matter of great concern of environmentalists that the growing production of cement is a great threat to the environment in general and the emission of carbon dioxide (CO_2) in particular. Since it is established that production of cement is liable for the production of approximately the same quantity of CO_2 as such, it is inevitable that consumption of cement is to be reduced to save the environment for our legacy. To reduce the consumption of cementitious materials, the best way is to search for alternative materials which may be used as a partial replacement for cementitious materials as the demand for cement can not be reduced at all. Several materials (natural and byproducts) are available which can be used as partial replacement of cement in concrete making. The materials used as partial replacement of cement and their effect on properties of fresh and hardened concrete are discussed hereinafter.

2. SUPPLEMENTARY CEMENTITIOUS MATERIALS (SCMs)

Supplementary cementitious materials (SCMs) are materials that are added to the cement matrix as part of the total cementing system. They may be used in addition to or as a partial replacement of Portland cement or blended cement in a cement matrix, especially in concrete, depending on the properties of the materials and the desired effect. Basically, all the pozzolanic materials may be used as SCMs. Pozzolana is a siliceous or alumino-siliceous material that, in finely divided form and in the presence of moisture, chemically reacts with the calcium hydroxide released by the hydration of Portland cement to form calcium silicate hydrate and other cementing compounds. Industrial wastes, such as blast furnace slag, fly ash and silica fume, are being used as supplementary cement replacement materials. In addition to these, agricultural wastes such as rice husk ash, wheat straw ash, and sugarcane bagasse ash are also being used pozzolanic materials as partial cement replacement material (Zhang and Malhotra, 1996; Ganesan *et al*. 2007). Depending on the type of SCM, their use as partial cement replacement materials or as mineral additives has different effects on the properties of concrete. This is because they possess different chemical and mineralogical compositions, as well as different particle characteristics, which determine their water requirement, packing ability, as well as reactivity when used as part of a binder for concrete. In general, the use of these materials in concrete has been associated with the refinement of the concrete pore structure. This, in turn, could affect the properties of concrete in the fresh and hardened states, including strength, deformation and durability performance (Bai *et al.* 1999; Guneyisi and Gesoglu, 2008; Brooks and Megat Johari, 2001; Koksal *et al*. 2008; Gesoglu and Ozbay, 2007). Some of the pozzolanic materials which are used as SCMs are discussed as under:

- Fly Ash
- Granulated Ground Blast furnace Slag (GGBS)
- Silica Fume
- Metakaolin

2.1 Fly Ash

Fly ash is a finely divided residue (a powder resembling cement) that results from the combustion of pulverized coal in electric power generating plants. During ignition in the furnace, most of the volatile matter and carbon in the coal is burned off. The fly ash is collected from the exhaust gases by electrostatic precipitators or bag filters.

Class F fly ash is a low-calcium (less than 5% CaO) ash with carbon content less than 5%, but some may be as high as 10%. Class C fly ash generally has a carbon content of less than 2%. Many Class C ashes, when exposed to water, will hydrate and harden in less than 45 minutes. CaO content is more than 10%.

2.2 Granulated Ground Blast Furnace Slag (Ggbs)

Ground granulated blast furnace slag, also called slag, is made from iron blast-furnace slag. It is a non-metallic hydraulic cement consisting essentially of silicates and aluminosilicates of calcium developed in a molten condition simultaneously with iron in a blast furnace.

The molten slag at a temperature of about 1500°C is rapidly cooled by quenching in water to form a glassy sand-like granulated material. The granulated material, which ground to less than 45 microns, has a surface area fineness of about 400 to 600 m2/kg. The relative density is in the range of 2.85 to 2.95. The bulk density varies from 1050 to 1375 kg/m^3. The slag has rough and angular-shaped particles, and in the presence of water and Ca $(OH)_2$ or NaOH supplied by Portland cement, it hydrates and sets in a manner similar to Portland cement.

2.3 Silica Fume

Silica fume, a by-product, is a result of the reduction of high-purity quartz with coal in an electric arc furnace in the manufacture of silicon or ferrosilicon alloy. It rises as an oxidized vapour from the furnaces. When it cools, it condenses and is collected in huge cloth bags. Then it is processed to remove impurities and to control particle size in Nano level.

Fig. 1: Fly ash.

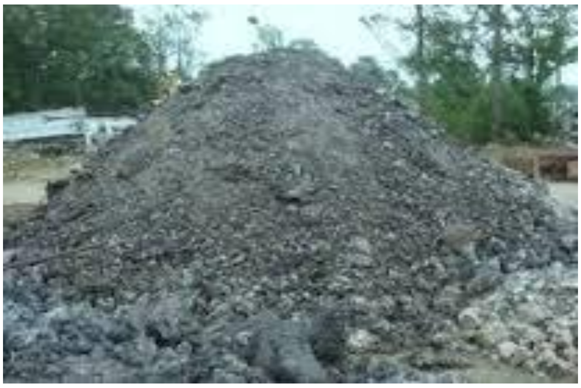

Fig. 2: GGBS.

Fig. 3 Silica fume.

Silica fume is used in amounts between 5% and 10% by mass of the total cementing material. It is used in applications where a high degree of impermeability is needed and in high-strength concrete. Also, in the cases where the concrete must be deicer-scaling resistant. Silica fume is high reactive pozzolana as such, and it can be used as a partial replacement of both for OPC as well as PPC. However, the replacement level may vary accordingly.

2.4 Metakaolin

Metakaolin is a manufactured product from selected kaolins, which refined and calcined under particular condition; it is a highly efficient pozzolona that reacts with Ca(OH)2 produced during the hydration of Cement. Adding gel, i. e. C-S-H gel has a pore-blocking effect and therefore alters the pore structure and strength. It is reported that calcium hydroxide can be virtually eliminated from the cement matrix by using sufficient adapted metakaolin concentrations.

Fig. 4: Metakaolin.

Metakaolin is used in amounts between 5% and 15% by mass of the total cementing material. For high performance and high strength concrete, Metakaolin is a good option. Metakaolin is high reactive pozzolana. As such, it can be used as a partial replacement of both OPC as well as PPC. However, the replacement level may vary accordingly.

3. EFFECT OF SCMs ON FRESH CONCRETE

3.1 Water Requirements

Concrete mixtures containing fly ash generally require less water (1% to 10% less) for a given slump than concrete containing only Portland cement. Similarly, ground slag decreases water demand by 1% to 10%, depending on the dosage. The water demand of concrete containing silica fume increases with increasing amounts of silica fume unless a water reducer or superplasticizer is used. Similarly, metakaolin increases water demand depending on the dosage.

3.2 Workability

Workability is that property of freshly mixed concrete or mortar that determines the ease and homogeneity with which it can be mixed, placed, consolidated and finished. At a given water-cement ratio, the spherical shape of most fly ash particles permits greater workability than conventional concrete (CC). The increased ratio of solid volumes to water volume produces a paste with improved plasticity and more cohesiveness. Fly ash, GGBS, and some natural pozzolans generally improve the workability of concretes of equal slump depending upon doses. While silica fume and metakaolin may reduce the workability and contribute to the stickiness of concrete mix depending upon doses.

3.3 Bleeding and Segregation

In air-entrained as well as non-air entrained concrete mix, the use of fly ash reduces bleeding by providing greater fines volume and lower water content for given workability owing to the spherical particle shape of fly ash. GGBS (with similar fineness as cement) may increase the rate and amount of bleeding with no adverse effect on segregation. GGBS finer than cement reduces bleeding.

3.4 Setting Time

Fly ash, ground slags, and natural pozzolans will generally increase the setting time of concrete. Silica fume and metakaolin may reduce the setting time of concrete.

3.5 Plastic Shrinkage Cracking

Silica fume concrete may exhibit an increase in plastic shrinkage cracking due to the effect of low bleeding characteristics. Proper protection against drying is required during and after finishing. Other supplementary cementing materials that significantly increase setting time can increase the risk of plastic shrinkage.

3.6 Curing

Concrete containing supplementary cementing materials need proper curing. The curing should start immediately after finishing. A seven-day moist curing or membrane curing should be applied. Some organizations specify at least 21 days of curing for all concrete containing pozzolanic materials.

4. EFFECT OF SCMs ON HARDENED CONCRETE STRENGTH

All supplementary materials contribute to the strength gain of concrete. However, the strength of concrete containing these materials can be higher or lower than the referral concrete.

4.1 Compressive Strength

The strength of concrete with SCMs is affected by several factors, viz. type of cement, quality and proportion of SCMs and curing temperature. Concrete containing class F fly ash may develop lower early strength; however, it gives higher ultimate strength if properly cured. Slow gain of strength is due to the relatively slow pozzolanic action of fly ash. The main contribution of silica fume to concrete strength development at normal curing temperature takes place from about 3 to 28 days. Silica fume inclusion increases compressive strength significantly (6-57%). An increase in compressive strength depends upon replacement level. Increased compressive strength by 15-50 % (depending on metakaolin type, w/c and age) as compared to control mixture is reported for concretes produced with metakaolin. The higher surface area metakaolin yielded the highest strength and the fastest rate of strength gain. The positive influence of the metakaolin fineness on compressive strength was more apparent at the later ages (i.e. 7 days or more).

4.2 Tensile Strength

Splitting tensile strength of concrete incorporating silica fume is similar to that observed in concretes without silica fume. As the compressive strength increases, the tensile strength also increases, but at a gradually decreasing rate. At 15% replacement level, the tensile strength of silica fume concrete found to increase in the range of 27 – 34% as compared to concrete without silica fume. Splitting tensile strength of concrete incorporating metakaolin is similar to that observed in concretes without metakaolin. As the compressive strength increases, the tensile strength also increases.

4.3 Flexural Strength

The flexural strength of concrete incorporating silica fume is similar to that observed in concretes without silica fume. At 15% replacement level, the flexural strength of silica fume concrete found to increase in the range of 52 - 65% as compared to concrete without silica fume. The flexural strength of concrete incorporating metakaolin is similar to that observed in concretes without metakaolin. Flexural strength attained by metakaolin concrete at 1 day corresponds to the strength attained by control concrete at 3 days, and flexural strength attained by metakaolin concrete at 3 days corresponds to the strength attained by control concrete at 28 days.

4.4 Drying Shrinkage and Creep

When used in low to moderate contents, the effect of supplementary materials on the drying shrinkage and creep is small and of little practical significance.

4.5 Permeability and Absorption

With adequate curing, the concrete with supplementary materials will reduce the permeability and water absorption. Silica fume and other pozzolanic materials can improve chloride resistance.

4.6 Sulfate Resistance

The damaging effect of sulphate and seawater on concrete can be reduced significantly by using fly ash, ground slag, silica fume and metakaolin. The improvement can be reached by reducing the permeability and reducing the reactive materials such as calcium needed for expansive sulphate reactions.

4.7 Corrosion of Embedded Steel

The improvement in corrosion resistance of concrete can be achieved by reducing the permeability and increasing the electrical resistivity of concrete. Fly ash can reduce the permeability of concrete to water, air, and chloride ions. Silica fume greatly reduces permeability and increases electrical resistivity.

From the above discussion, it may be visualised that the more the use of supplementary cementitious materials less the emission of CO_2. If only 25 % cement could be replaced with different supplementary cementitious materials, about 70 million metric tons of CO_2 may be prevented to be assimilated in an environment in India only.

5. CONCLUSION

From the above study following conclusions may be drawn.

1. The use of supplementary cementitious materials reduces the emission of CO_2 due to a reduction in the production of cement.
2. The use of Supplementary cementitious materials reduces the cost of construction.
3. Partially solves the environmental pollution problems by consuming different wastes.
4. Generally, the waste materials are stabilized in a concrete matrix.
5. The use of supplementary cementitious materials in concrete improves mechanical properties and durability characteristics, and quality of matrix.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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