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Pozzolanas- Role of utilization of Ground granulated blast-furnace slag in 21st century

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Abstract:IS 456 recommends the use of blended cements like PPC and PSC, or mineral admixtures like fly ash, granulated slag and silica fume, for improving durability of concrete. Recent constructions in many prestigious projects like Delhi Metro, atomic power projects and others have used concrete containing fly ash or granulated slag. In this paper the evaluation of Ground granulated blast- furnace slag for use in Concrete is done.

Keywords-
Supplementary cementing material, Engineering properties, Physical properties, Durability properties

INTRODUCTION

Greeks, pre 400 B.C, followed by the Romans, were the first civilizations to use the pozzolanas in lime mortars. Romans used not only crushed pottery, bricks and tiles which formed the first artificial pozzolanas, but also found that some of volcanic soils were excellent for producing a hydraulic mortar when mixed with lime. The development of hydraulic cements based on lime-pozzolana mixtures led to radical changes in building during Roman era. The increased strength of lime pozzolana mixtures, their hydraulic properties and good resistance to seawater, permitted the construction of not only arches and vaults but also marine structures. Lime-pozzolana mortars were also used as water proofing renders in the lining of baths, tanks and aqueducts. The many remains of Roman structures attest to the durability of the material, still in evidence today.

More recently, over 100,000 tones of pozzolana were used in the construction of the Los Angeles aqueduct from 1910 to 1912. Since then, pozzolanas have been used in the construction of many mass concrete and marine structures such as dams and harbors, particularly in Europe, North America, and Japan.

Pozzolanic materials are siliceous or siliceous and aluminous materials, which in themselves posses little or no cementitious value, but will, in finely divided form and in the presence of moisture, chemically react with calcium hydroxide liberated on hydration, at ordinary temperature, to form compounds possessing cementitious properties.

Pozzolanic materials can be divided into two groups

1. Natural pozzolana and
2. Artificial pozzolana

Following are some of the natural pozzolanas:

- Clay and shale
- Opalinic cherts
- Diatomaceous earth
- Volcanic tuffs and pumicities.

Following are some of artificial pozzolanas:

- Fly ash
- Blast furnace slag
- Silica fume
- Metakaolin
- Rice husk ash

Ground granulated blast- furnace slag (GGBFS)

Ground Granulated Blast Furnace Slag (GGBFS) is a by-product of the manufacturing of iron in a blast furnace where iron ore, limestone and coke are heated up to 1500°C. When these materials melt in the blast furnace, two products are produced -molten iron, and molten slag. The molten slag is lighter and floats on the top of the molten iron. The molten slag comprises mostly silicates and alumina from the original iron ore, combined with some oxides from the limestone. This molten slag is instantaneously tapped and quenched by water. The rapid quenching of molten slag from the temperature of 1400°C facilitates formation of Granulated Slag a granular material with latent hydraulicity.

Ground granulated blast furnace slag or GGBFS is processed from granulated slag, a cementitious material that consists of lime (CaO), Silica (SiO_2), Alumina (Al_2O_3) and Magnesia (MgO).They are essentially the same constituents, which are also present in cement. The combination of the above constituents result s in the formation of Calcium Silico Aluuminates or “Glass”, the reactive component or GGBFS. In the presence of lime available from cement, glass breaks and produces cementing compounds similar to the one produced by ordinary Portland cement (OPC). [1],[3]

Physical properties

GGBFS cement is a near-white powder. It imparts a lighter, brighter colour to concrete, in contrast to the stony grey of concrete made with Portland cement. The colour of the finished concrete is lighter; the concrete has a smoother surface finish. Typical physical properties of GGBFS are given in Table 1.[3]

Fig. 1 Raw GGBFS

Table 1 Physical properties of GGBFS [3]

Property	Value
Physical form	Off white powder
Bulk density (kg/m^3)	1200
Specific gravity	2.9
Specific surface (m^2/kg)	425-470

Chemical composition
GGBFS comprises mainly of CaO, $Si0_2$, Al_2O_3, MgO. It has the same main chemical constituents as ordinary Portland cement, but in different proportions. Typical chemical composition of GGBFS as reported by is given in Table 2 [3]

Table 2 Chemical composition of GGBFS [3]

Composition	%
$Si0_2$	35.34
$A1_20_3$	11.59
Fe_20_3	0.35
CaO	41.99
MgO	8.04
MnO	0.45
S_2	1.18
SO_3	0.23

Engineering properties

Fineness
The specific surface, determined in accordance with shall be not less than 275m^2/kg.

Loss on ignition
The loss on ignition shall be not more than 3 %.
Moisture content
The moisture content shall be not more than 1.0 % of dry GGBFS.

Particle size distribution
Ground granulated blast furnace slag is ground finer to facilitate required reaction products; it is ground to an average particle size of 12-15 microns. It is engineered to align perfectly with cement particles, producing high quality blend.

Workability
Ground granulated blast furnace slag offers improved uniformity, workability, pumpability and compaction properties in concrete. It produces a larger volume of cement paste for equal weight of total cement content in concrete, making matrix easier to work, pump, place and compact. The smooth surface texture of ground granulated blast furnace slag particles also helps workability as it is also generally ground more finer than portland cement. [1],[3]

Hydration reaction mechanism
Ground granulated blast furnace slag is hydraulically latent material, in presence of lime contributed from cement, a secondary reaction involving glass (calcium alumina silicates) component sets in. As a consequence of this, cementitious compounds are formed. They are categorized as secondary C-S-H gel. The formation of CH increases the concrete's porosity and is susceptible to chemical attack. The Pozzolanic reaction converts the soluble CH to C-S-H, increasing the overall strength and durability of the concrete. This is the main attribute of ground granulated blast furnace slag which contributes to strength and durability. [1],[3]

Strength
Ground granulated blast furnace slag concrete develops strength more slowly than portland cement. Early strength is lower, 28-day strength is similar or a little higher and ultimate strength is significantly higher. Ground granulated blast furnace slag concrete has shown to continue to gain strength up to period of 1 year. [1],[3]

Durability properties

Chloride Penetration
If the Chloride ions penetrate the concrete, they cause severe damage through corrosion and expansion of embedded reinforcement. At 50% substitution rates and over, chloride ion diffusivity becomes practically insignificant. Ground granulated blast furnace slag offers resistance to chloride penetration. [1],[3]

Sulphate attack
Sulphate attack is mainly caused by reaction of sulphates with C_3A. This reaction leads to the formation of calcium sulpho aluminate, which is double salt, known as ettringite. The formation of this voluminous double salt absorbing much water in its formation causes the cracking and destruction of the concrete. Use of Ground granulated blast furnace slag preferably 50% and more, significantly reduces available C_3A content, this helps in preventing

the sulphate to form delayed ettringite in concrete, vis-a-vis safeguarding concrete against sulphate attack. [1],[3]

Permeability

Incorporation of granulated slag in cement paste helps in the transformation of large pores in the paste into smaller pores, resulting in decreased permeability of the matrix and of the concrete. Because of the reduction in permeability, concrete matrix becomes very dense, thus the penetration of moisture/water is significantly reduced leading to protection of the reinforcing steel. [1],[3]

Alkali silica reaction

With increasing percentage replacement of Ground granulated blast furnace slag, the micro structure of cement matrix gets refined thereby preventing damage to concrete by ASR. [1],[3]

Heat of hydration

The control of thermal stressing of concrete in large pours, members, mass concrete is very crucial to the quality and durability of the concrete. The hydration of ground granulated blast furnace slag concrete is less exothermic. At optimum substitution, use of it will sharply reduce thermal stressing of mass concrete, micro-cracking and subsequent deterioration. (1), (3)

Advantages of using ground granulated blast furnace slag

The addition of ground granulated blast furnace slag to OPC is not only cost effective but also benefits the structural elements in many ways and in general, extends the life of the structure by providing more durability. Utilization of GGBFS in cement and concrete results in:

- Improved workability, pumpability and compaction characteristics for concrete placement
- Increased strength and durability Increase cohesiveness.
- Improve stability against separation.
- Increase strength.
- Increase durability of concrete due to decrease in porosity.
  - Reduced permeability
  - High resistance to chloride penetration
  - High resistance to sulfate attack
  - High resistance to ASR
  - Very low heat of hydration
  - More chemically stable
  - Improved surface finish
  - Enhanced architectural appearance
  - Lighter and more even colour
  - Enhanced reflectivity for greater visibility and safety
  - Suppresses efflorescence
- Enhancement of the life cycle of concrete structures
- Reduction in maintenance and repair costs
- Slashes lifetime construction costs
- Production of GGBFS involves virtually zero $C0_2$ emissions, and no emissions of $S0_2$ and NO_2 [2],[3]

Conclusion

Thus it can be concluded looking to the above properties that ground granulated blast furnace slag can be used as a supplementary cementitous material.

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