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Strength and Durability Studies on Silica Fume in Slag Concrete

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Abstract:- Portland cement, as an ingredient in concrete, is one of the widely used construction materials, especially in developing countries. The CO2 emission during its production and the utilisation of natural resources are important issues for the construction industry to participate in sustainable development. These days the waste materials of industries is on its way to increase day by day due to strict environmental policies and this waste contains SCMs generally. They can be utilised not only to improve properties of concrete but also to prevent pollution due to reduction in carbon dioxide emission. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides hence steel slag aggregates are not used in concrete making. Proper weathering treatment and use of pozzolanic materials like silica fume with steel slag is reported to reduce the expansion of the concrete. The effect of oxide composition of the binder material used, on the strength and durability properties of concrete is also investigated.

Keywords – Fly Ash, Silica Fume, Strength, Durability, High-Volume Fly Ash Concrete, Oxide Composition.

1. INTRODUCTION

Concrete is one of the most versatile and widely produced construction materials in the world [1]. Fresh concrete is flowable like a liquid and hence can be poured into various formworks to form different desired shapes and sizes on a construction site. The maintenance cost for concrete structures is much lower than that for steel or wooden structures. Also, concrete can withstand high temperatures much better than wood and steel. All these characteristics make concrete, the most preferred structural material by civil engineers. The ever-increasing population, living standards, and economic development lead to an increasing demand for infrastructure development and hence concrete materials [2]. Steel slag was existed as by-product during melting of steel scrap from the impurities and fluxing agents, which form the liquid slag floating over the liquid crude iron or steel in arc or induction electrical furnaces, or other melting units. Knowing that steel slag from Basrah plant may reach sixty thousand MT per year with design capacity. This was removed from the furnace separately in a rate of about (10-15%) of the produced steel [3]. The properties and chemical composition of the slag were stated by Clarkson University, the specific gravity ranges from (2.85-3.0) and bulk density varies from (1.0-1.4 gm/cm3). The deterioration of concrete may occur due to physical, chemical, and mechanical causes. These factors may be acting alone or, in most cases, in a coupled manner. Physical causes may include surface wear caused by abrasion, erosion, and cavitation, the effects of temperature changes caused by alternating freezing–thawing cycle and exposure to fire, and cracking, which is common due to volume changes, normal temperature and humidity gradient. Chemical degradation is usually the result of an internal or external attack on the cement matrix.

Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stems from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions.

The Steel slag, a byproduct of steel making, is produced during the separation of molten steel from impurities in steel making furnaces. This can be used as aggregate in concrete. Steel slag aggregate generally exhibit a propensity to expand because of the presence of free lime and magnesium oxides that have not reacted with the silicate structure and that can hydrated and expand in humid environments. This potentially expansive nature (volume changes up to 10 percent or more attributable to the hydration of calcium and magnesium oxides) could cause difficulties with products containing steel slag, and is one reason why steel slag aggregate are not used in concrete construction. Steel slag is currently used as aggregate in hot mix asphalt surface applications, but there is a need for some additional work to determine the feasibility of utilizing this industrial by-product more wisely as a replacement for both fine and coarse aggregates in a conventional concrete mixture. Most of the volume of concrete is aggregates.

Replacing all or some portion of natural aggregates with steel slag would lead to considerable environmental benefits. Steel slag has high specific gravity, high abrasion value than naturally available aggregate apart from the drawbacks like more water absorption, high alkalis. Therefore with proper treatments it can be used as coarse aggregate in concrete.The production of a HSC[4] may be hampered if the aggregates are weak. Weak and marginal aggregates are widespread in many parts of the world and there is a concern as to the production of HSC in those regions. Incorporation of silica fume is one of the methods of enhancing the strength of concrete, particularly when the aggregates are of low quality. Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft^2/lb (20,000 m^2/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material particle.

Concrete having large amount of fly ash (usually above 50% of the total binder material) is termed as high-volume fly ash (HVFA) concrete. Canada Centre for Mineral and Energy Technology (CANMET) first developed high volume fly ash concrete for structural use by the late 1980's for mass concrete applications to reduce the heat of hydration. High Volume Fly ash Concrete mix contains lower quantities of cement and higher volumes of Fly Ash (above 50%). From the literature available, it is found that the proportions of Fly Ash in Concrete can vary from 30% - 80% for various grades of concrete [3]. High volume Fly Ash Concrete with larger replacement of Fly Ash in cement is a beneficial practice for sustainable, durable and economic concrete. HVFA concrete with 50% - 60% fly ash can be designed to meet the workability strength and durability requirements of concrete. [5]. The main features of silica fume are a high silica content, high specific surface area and amorphous structure. These characteristics account for the substantial pozzolanic activity of silica fume, in terms of both its capacity of binding lime and rate of reaction. The effects of silica fume on properties of the fresh concrete include improvement of the cohesiveness and reduction of bleeding. The main contribution of the silica fume to the strength development in hardened concrete at normal curing temperatures takes place from about 3 days onwards. At 28 days the strength of silica-fume concrete is always higher than the strength of the comparable Portland cement concrete. As the proportion of silica fume increases, the workability of concrete decreases nevertheless its short term mechanical properties such as 28-day compressive strength improves [6].

2.MATERIALS AND METHODOLOGY

2.1 MATERIALS

Silica Fume

Silica fume is a byproduct in the reduction of high-purity quartz with coke in electric arc furnaces in the production of silicon and ferrosilicon alloys. Silica fume consists of fine particles with a surface area on the order of 215,280 ft^2/lb (20,000 m^2/kg) when measured by nitrogen adsorption techniques, with particles approximately one hundredth the size of the average cement Because of its extreme fineness and high silica content, silica fume is a very effective pozzolanic material[7] particle. Silica fume is added to Portland cement concrete to improve its properties, in particular its compressive strength, bond strength, and abrasion resistance. These improvements stems from both the mechanical improvements resulting from addition of a very fine powder to the cement paste mix as well as from the pozzolanic reactions between the silica fume and free calcium hydroxide in the paste. Addition of silica fume also reduces the permeability of concrete to chloride ions, which protects the reinforcing steel of concrete from corrosion, especially in chloride-rich environments such as coastal regions .When silica fume is incorporated, the rate of cement hydration increases at the early hours due to the release of OH ÿ ions and alkalis into the pore fluid. The increased rate of hydration may be attributable to the ability of silica fume to provide nucleating sites to precipitating hydration products like lime, C±S±H, and ettringite. It has been reported that the pozzolanic reaction of silica fume is very significant and the non-evaporable water content decreases between 90 and 550 days at low water /binder ratios with the addition of silica fume.

Steel Slag

Steel slag is the residue of steel production process and composed of silicates and oxides of unwanted elements in steel chemical composition. Fifty million tons per year of LD slag were produced as a residue from Basic Oxygen Process (BOP) in the world. In order to use these slags in cement, its hydraulic properties should be known. Chemical composition is one of the important parameters determining the hydraulic properties[8] of the slags. In general, it is assumed that the higher the alkalinity, the higher the hydraulic properties. If alkalinity is> 1.8, it should be considered as cementitious material.

Investigations were carried out also on the usability of steel slag as construction material under laboratory and practical conditions. For this application, the required properties are high compression strength, wear strength and resistance to climatic conditions. The most important criterion is volume stability, in which free CaO and MgO contents of the slag play an important role. Both oxides can go into reaction with water. Hydration causes volume expansion and affects stability of volume. This is one reason why steel slag aggregate are not suitable for use in Portland cement concrete b. But at the moment, most steel slag being used as unbound aggregate for ashphalt concrete pavement in many countries.

Fly ash cement

Fly ash, which is largely made up of silicon dioxide and calcium oxide, can be used as a substitute for Portland cement, or as a supplement to it. The materials which make up fly ash are pozzolanic, meaning that they can be used to bind cement materials together. Pozzolanic materials, including fly ash cement[9], add durability and strength to concrete.

Fly ash cement is also known as green concrete. It binds the toxic chemicals that are present in the fly ash in a way that should prevent them from contaminating natural resources. Using fly ash cement in place of or in addition to Portland cement uses less energy, requires less invasive mining, and reduces both resource consumption and CO2 emissions.

2.2 METHODS

Compressive strength:

Compressive strength of concrete is the mostly valued property, which is used in both design and quality control. In the present study, compression tests were carried out on 100mm cube specimens immediately on removal from the curing water. The specimen was loaded at the rate of 14 N/mm2 per minute. The test was conducted to determine the 3, 7, 28, 56 and 90 day compressive strength of conventional mix[10], high volume fly ash mix and three mixes containing silica fume as the third binder material. For each test-age of these mixes, three specimens were tested and their average is reported.

Rapid chloride permeability test:

The rapid chloride permeability test (RCPT) was conducted according to ASTM C 1202 in order to determine the resistance of concrete to the penetration of chloride ions [11]. The resistance to the chloride-ion penetration was measured at the ages of 56 and 90 days. 100 mm x 50 mm disc specimens were cast for conventional, high volume fly ash and all silica fume replaced mixes. For the specimens to be tested at 90 days, steam curing was done for a period of 2 hours and then immersed in curing tank till the test age is reached. Another set of normal cured specimens were also tested at 90 days. For the specimens tested at 56 days, only normal curing was done.

Bulk diffusion test:

The depth of chloride ion penetration in concrete can be assessed by bulk diffusion test. This test method was based on Italian Standard[12] (UNI) in which a chemical manifests a colour change boundary in response to the quantity of chloride ions present. For conducting the test, 100mm x 200mm cylinder specimens were cast from all mixes. Six specimens were cast for each mix. The specimens were tested at ages of 56 days and 90 days.

Three curing regimes were adopted:

- curing in water for 3 days and immersing in 5% sodium chloride solution till test age is reached,
- steam curing for 2 hours and then curing in water for 3 days and dipping in 5% NaCl solution till test age is reached, and,
- curing in water for 7 days and then dipping in 5% NaCl solution till test age is reached.

The specimens were taken out and split when test age is reached. To the split face is sprayed with 0.1 M $AgNO_3$ solution. A white precipitate formed on the edges of split cylinder indicates the presence of chlorides.

3.EXPERIMENTAL PROGRAMME

The experimental design is designed to compare the mechanical properties i.e. compressive strength, flexural strength, porosity and capillary absorption. It will be carried in two stages

3.1. Stage 1

Experimental work is purposed with different percentages of silica fume in mortar having three proportions of slag cement, fly ash cement as 1:0, 0:1 and 1:1. In each type of combination of binder mix 0%, 10 % and 20 % percentage of silica fumes is to be added. Hence total 9 sets of mortar by mixing one part of binder mix with naturally available sand will be available.

3.2. Stage 2

In this stage concrete is purposed to be prepared with three different types of binder mix with silica fume as 1:1.5:3 proportion of Fly ash cement + Silica Fumes + Sand + Steel Slag as aggregate (for 0%, 10% and 20% silica fumes) 1:1.5:3 proportion of Slag Cement + Silica Fumes + Sand + Steel Slag as aggregate (for 0%, 10% and 20% silica fumes) 1:1.5:3 proportion of Slag Cement + Fly ash cement + Silica Fumes + Sand + Steel Slag as aggregate (for 0%, 10% and 20% silica fumes) Tests on compressive strength, flexural strength, porosity test and capillary absorption will be conducted on all concrete specimens after 7, 28 and 56 days and results are compared.

4.RESULTS AND DISCUSSIONS

4.1 Compressive strength test:

Compressive strength study was carried out on 100mm cube specimens at the ages of 3, 7, 28, 56 and 90 days. Test was carried out on specimens prepared from conventional mix, high volume fly ash mix and silica fume replaced mixes. Three specimens were tested at specified ages for all mixes. It is observed that the silica fume modified mixes show better strength than high volume fly ash mix after an age of 28 days. Maximum compressive strength is observed for high volume fly ash concrete with 10% replacement of cement with silica fume from the age of 28 days. It may also be observed that the rate of strength development is more for conventional, high volume fly ash and 5% silica fume added mixes when compared to the other mixes after 28 days. This could be due to the reduced workability of concrete containing higher percentage of silica fume.

4.2 Rapid Chloride Permeability Test (RCPT):

The RCPT was conducted on 100mm x 50 mm disc specimens at the age of 56 days and 90 days as explained in the previous session. The charge passed in 6 hours is calculated from the experimental data and is plotted against silica fume content in the mix. The charge passed decreases as the test age increases which indicate better resistance to the penetration of chloride ions[13]. Maximum resistance to chloride ion penetration was reported for steam cured specimens. It may also be observed that the charge passed decreases continuously with increase in silica fume content irrespective of testing/curing conditions. In both test ages of 56 and 90 days, addition of 5% silica fume resulted in a decrease in the charge passed.

5.LABORATORY TEST CONDUCTED

5.1 Capillary absorption Test

Two cube specimens were cast for both (Mortar and concrete cube) to determine capillary absorption coefficients after 7days, 28 days and 56 days curing. This test is conducted to check the capillary absorption of different binder mix mortar matrices which indirectly measure the durability of the different mortar matrices

5.2 Wet-dry Test:

Concrete cube were dipped inside a sea water for 4 hours and then exposed to dry for 20 hours. Sea water is prepared by dissolved 35 g of salt (Nacl) in one liter water. Here cubes were dipped inside the Sea water for 56 days and its compressive strength were determined by compressive testing machine.

5.3 Compressive test by pulse velocity.

The strength of concrete is generally governed by the strength of cement paste. If the strength of paste can be measured, then we can find reasonable indication for strength of concrete. This strength can be measured on site by rebound hammer method. The rebound hammer is an instrument which provides quick and simple non-destructive test for obtaining an immediate indication for concrete strength in every part of structure.

5.4 Flexural Test

It is the ability of a beam or slab to resist failure in bending. The flexural strength of concrete is 12 to 20 percent of compressive strength. Flexural strength is useful for field control and acceptance for pavement .but now a day's flexural strength[14] is not used to determine field control, only compressive strength is easy to judge the quality of concrete. To determine the flexural strength of concrete four numbers of prism were casting. Then it was cured properly.

Flexural strength = PL/BD2
Where P is load
L= Length of Prism.
B = Breadth of Prism.
D = Breadth of Prism

6.CONCLUSION

Silica fume added mixes shows higher strength values compared to their high volume fly ash counterparts at later ages (after 28 days).A linear logarithmic relation was developed for co-relating the compressive strength with age and silica fume content in various mixes. Using this correlation equation compressive strength values for various mixes are calculated and compared with the experimental results obtained.

The addition of supplementary cementitious materials improves the resistance of concrete to chloride penetration. Mathematical models for predicting the diffusion coefficient, total charge passed in 6 hours and carbonation depth by knowing the oxide composition of the binder material for various mixes were developed and compared with the experimental values.

The models gave satisfactory results. Equation for predicting the total charge passed in 6 hours knowing the initial current during the beginning of RCPT is formulated to overcome the disadvantage of longer test duration.

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