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Effect of Micro Silica and GGBS on Compressive Strength and Permeability of Impervious Concrete as a Cement Replacement

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Abstract:

This paper describes the aim of research which was to evaluate the performance of ordinary Portland concretes containing cement replacement materials in both binary and ternary system. Concretes were prepared to have constant water-binder ratio of 0.30. The test variables included the type and the amount of the supplementary cementious materials (SCMs) such as class Silica Fume (SF) and ground granulated blast furnace slag (GGBS). Portland cement was replaced with Silica Fume (SF) up to 7.5% and GGBS up to a level of 50%. The physical properties were assessed from the compressive strength and Permeability.

Key words: Micro Silica, GGBS, Impervious Concrete, Cement Replacement

1. INTRODUCTION

Concrete deterioration is related to its permeability. Most researchers believe that a well designed and manufactured concrete is originally water-tight, containing discontinuous pores and microcracks. When subjected to extreme loading or weathering, concrete deteriorates through a variety of physical and chemical processes, which result in cracking. Cracks in concrete generally interconnect flow paths and increase concrete permeability. The increase in concrete permeability due to crack progression allows more water or aggressive chemical ions to penetrate into the concrete, facilitating further deterioration. The addition of silica fume to concrete is effective for increasing the compressive strength, decreasing the drying shrinkage, increasing the abrasion resistance, and decreasing the permeability. As a result, silica fume concrete is increasingly used in civil structures.

2. LITERATURE REVIEW

➢ GGBS

The hydraulic potential of blast furnace slag was first discovered in Germany in 1862.In 1865, lime-activated blast furnace slag started to be produced commercially in Germany and in 1880 GGBS was first used in combination with Portland cement (Concrete Society, 1991). In Europe, GGBS has been used for over 100 years. In North America, the history of the use of GGBS in quality concrete dates back about 50 years (Yazdani, 2002). In South East Asian countries including Mainland China and Hong Kong, GGBS was used in concrete in around 1990. Between 1955 and 1995, about 1.1 billion tons of cement was produced in Germany, about 150 million tones of which consisted of blast furnace slag (Geiseler et al, 1995). In China, the estimated total GGBS production was about 100 million tons in 2007 (Chen, 2006).There is abundant examples of the use of GGBS concrete in construction projects. In New York, the concrete used in the construction of the World Trade Centre has about 40% GGBS replacement (Slag Cement Association, 2005). The Atlantas Georgia Aquarium which used 20% to 70% GGBS replacement. In China, GGBS has been widely used in major construction projects such as the Three Gorges Dam, Beijing-Shanghai Express Rail, and Cross-bay Bridge of Hangzhou Bay. The GGBS replacement level is generally around 40% (China Cements, 2009; ChinaBiz, 2009).

- **Silica Fume**

In some cases, SF was added to compensate for the decrease in early strength (Erdem and Kirca, 2008; Shehata and Thomas, 2002; Thomas et al., 1999; Popovics, 1993) whilst trying to maintain/enhance the durability characteristics associated with high level replacements of Portland cement with these materials. Silica fume, also known as micro silica or condensed silica fume, is a relatively new material compared to fly ash and GGBS, having come into increased use in the concrete industry only in the 1980s (Malhotra and Mehta, 1996). It is produced by electric arc furnaces as a byproduct of the metallic silicon or ferrosilicon alloys (Mehta, 1983). It is supplied in different forms such as undensified powder (bulk density approx. 200 kg/m3), densified powder (bulk density approx. 500-600 kg/m3), micropelletised (bulk density approximately 700 kg/m3), or pre-mixed with water into a slurry (Bartos, 1992).Silica fume consists of spherical particles of an almost pure silicon dioxide which are approximately 0.00015 mm in diameter. These are approximately 100 times smaller than the particles of cement (Bartos, 1992). Due to its extremely fine particle size and amorphous nature, it is a highly reactive pozzolan and its addition to concrete accelerates the temperature rise during the first 72 hours. However, the overall temperature rise in later ages of the silica fume concrete was still lower than that of the reference concrete (Malhotra and Mehta, 1996). The main advantage of using silica fume is that, when used with super plasticizers, it is possible to obtain good strengths at lower temperatures (Jahren, 1983). Khayat, et al (1997) reports that the use of blended silica fume cement resulted in approximately

20% strength gain compared to similar mixtures containing Type 10 and 20 cements (similar toASTM C 150 Type I and Type II cements). Silica fume, aside from increasing the rate of hydration of C3S, combines with the lime formed as a reaction product of cement hydration. Its effect on the kinetics of hydration is difficult to follow not only because it influences the rate of hydration but also because it is consumed by the reaction products (Malhotra, 1987).The reactivity of condensed silica fume can be related to its fineness and its composition: 100% glass with 90% active silica (Aitcin, 1983). The high reactivity of silica fume leads to an increase in early heat liberation in concrete, but according to Bye (1999), as the replacement level exceeds 10%, silica fume progressively reduces the total heat liberation. Jahren (1983) reports from his literature review that the activity of silica fume compared to cement called activity index, substitution index, or efficiency index, ranged from 2 to 5. This activity index, denoted as “k”, expresses the efficiency of silica fume compared to cement in the relationship between concrete strength and w/c ratio and varies considerably with dosage, curing conditions, age, plasticizer dosage, and type of cement. A review of existing literature shows that there are conflicting results with regard to the effect of silica fume on the temperature rise of concrete but most agree that its use results in an earlier time to arrive at the maximum temperature. According to Malhotra and Mehta (1996), the addition of silica fume accelerates the temperature rise during the first 72 hours but the overall temperature rise at later ages was lower compared to a similar Portland cement concrete. Alshamsi (1997) reported that micro silica reduced the temperature rise in the mortar mix and slightly accelerated the time to arrive at the maximum temperature. Domone and Soutsos (1995) also reported acceleration in the time to reach the maximum temperature but their mix with 10% micro silica showed an increase in temperature. Meland (1983) observed that a moderate addition of condensed silica fume to normal Portland cement seems to accelerate hydration. A 10% substitution accelerates the rate of heat evolution while a 20% substitution retards the heat liberation. On the other hand, Pinto and Hover (1999) concluded that more heat was generated at medium levels of additions of silica fume than at zero or high additions. At low levels of addition, the heat generated from the pozzolanic reaction was greater than the decrease in heat liberation resulting from a reduction in cement hydration. At high levels, the inverse was observed. For mixtures without silica fume, the maximum temperature rise was 4.6°C/kg-mortar, while for mixtures with silica fume the maximum temperature rise was 5.2°C/kg-mortar. Silica fume increased the maximum rate of hydration of cement and shortened the dormant period. Khayat, et al (1997) monitored the temperatures of two 100 x 200 mm cylinders for 24 hours. The maximum temperature rise at early ages was not significantly affected by the replacement of cement mass by 7.5% of silica fume. However, despite the lower cement content and lower maximum temperature rise of silica fume concrete, they exhibited greater rates of temperature rise than corresponding mixes made with Type 10 or 20 cement (similar to ASTM C 150 Type I and Type II cements)

3. EXPERIMENTAL PROGRAMME

Concrete specimens used in the research of compressive strength are 150 mm (6 in) diameter and 300 mm (12in) where as in permeability 2 cylinders and 2 cubes are used. Permeability cylinders had diameter of 150 mm (6 in) and 100 mm (4 in) are used with 150 mm (6 in) of each cylinder height whereas permeability cubes have 150mm x150mm x150mm (6in x6in x 6 in)and 100mm x 100mm x 150mm (4in x 4in x 6in) dimensions. By means of a compressive strength test the cylinders were loaded to have a rate of 50kN/min. After loading, the cracks appeared and ultimate crush of cylinders giving compressive of concrete cylinders which were noted. In four cells automatic concrete water permeability apparatus permeability test were performed. Each cell had an internal pressure 0 to 30 bar applies on specimens up to 10 min (600 sec). The water permeated through the specimen is directly collected and measured in a graduated cylinder to find out the permeability coefficient in cm/s.

3.1. Mix Proportions for Binder

The mix proportions for binder used in the study are given in Table 1

Table 1:

Mix ID	**w/ b**	**% of binder materials**		
		OPC	**SF**	**GGBS**
MIX A	0.3	100	0	0
MIX B	0.3	92.5	7.5	0
MIX C	0.3	65	0	35
MIX D	0.3	50	0	50
MIX E	0.3	70	5	25
MIX F	0.3	67.5	7.5	25
MIX F	0.3	60	5	35
MIX G	0.3	57.5	7.5	35

The water/binder ratio used in research was 0.3 (by weight). The slump of fresh concrete was 75 to 100 mm. The compressive strength specimens were cured under water are for 3,7,21,28 and 56 days where as permeability specimens were cured for 14,21,28 and 56 days at a room in a temperature of about 20^0C before being performing the tests.

3.2. Compressive Strength

The compressive strength test was conducted on three standard cylinders using a compression testing machine (Fig. A)with a rate of loading of 50kN/min(0.140 to 0.350 MPa per second). One day prior to the test, the cylinders were removed from the curing tank. Immediately removing of cylinders before testing is not welcomed. This was to ensure that the cylinders were tested at a dry condition.

Fig. A: Compressive Strength Apparatus

3.3. Permeability

Automatic concrete water permeability apparatus consists of four cells. This fully automatic apparatus is designed to carry out water permeability tests on cubic concrete specimen max. 150 mm side and cylinder specimen max 160mm diameter. The specimens are subjected to hydrostatic stress for pre-stress period. The water permeated through specimen is directly collected and measure in a graduated cylinder. It is therefore possible to determine permeability coefficient in cm/sec by using formula

$$K = \frac{cc \times h}{A \times t \times P}$$

Here: cc= permeated water in cm^3

h= specimen height (cm)

A= specimen area surface (square cm)

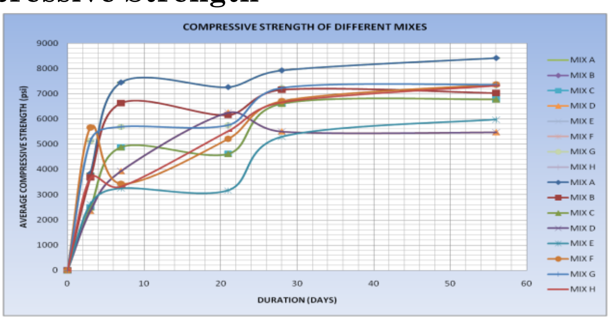
t= time to permeate (sec)
P= hydrostatic pressure in cm of water column

And two days prior to the test, the cylinders and cubes were removed from the curing tank and place in oven at temperature of 105°C for complete dry, after that these specimens are painted from all sides except top and bottom surface.

Fig. B: Automatic Concrete Water Permeability Apparatus

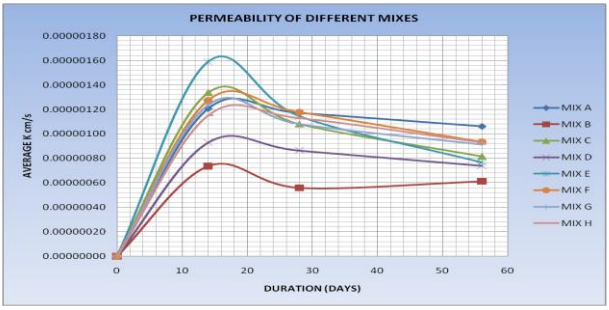
4. RESULTS

4.1 Compressive Strength



The compressive strength of all the mixes was performed at 3, 7, 21, 28, and on 56 days duration. From the above graph it was clear that the compressive strength of mix A was greater than the other mixes. Use of silica fume and GGBS (alone and by combination of both) as a replacement cause the decreases the compressive strength of concrete at early ages and increases it later. With SCMs, adequate early age and high later age strengths can be achieved if proper selection of cement type and amount is done. The strength increases with time.

4.2 Permeability



From the above graph it is clear that when we use combination of silica fume and GGBS as cement replacement, permeability of hardened concrete increases at early age but decreases later on permeability of concrete specimen decreased with time.

5. CONCLUSIONS

On the basis of the results obtained from this research work, the following conclusions have been drawn:

5.1. High Compressive Strength of Concrete

The use of supplementary cementious materials (SCMs) in the concrete mixes produced a lower strength value at the early age. However, at later ages, the strength was either more or comparable to the specimen named OPC 100% this indicates these mixes can produce comparable specimen of concrete with comparable or high strength concrete. These concerts can be successfully used where early strength has no problem. We conclude from research data that, the gain in strength after 56 days is well pronounced for Mix A having 1000% OPC is greater than that of the SF and GGBS concrete at all stages, from cost point view, it can be suggested that combination of 60% OPC, 5% SF and 35% of GGBS can be beneficially used to improve the compressive strength of concrete which will produce concrete of higher strength.

5.2. Lower Early Strength but Higher Long Term Strength:

With the w/b ratio kept constant at 0.3, the compressive strength was detrimentally affected by the replacement of OPC with both SF and GGBS at all stages up to 56 days. It was possible to enhance the long-term compressive strength of both SF and GGBS mixes, but there was a decrease in compressive strength at early ages.

5.3 Permeability

Use of silica fume and GGBS as a replacement cause the decreases in the permeability of concrete at early ages and also decreases on later age. With SCMs, adequate decrease in permeability can be achieved if proper selection of cement type and amount is done. The permeability decreases with time.

5.4 Combinations of Different Mixes & Best Mix Design:

The results of the tests carried out on ordinary concrete containing SF and GGBS in large volumes clearly illustrated that some mix combinations are superior to others for the property of compressive strength presented in this research work. Clearly this would mean that combination of different CRMs and the exact choice of these combinations should be based on the physical properties relevant the strength and performance expected from the concrete.

These conclusions would highlight that ordinary concrete containing CRMs require different types of blends in order to obtain the best performance regarding strength. As a consequence, mixes need to be designed for different strengths.

5.5 Better Value for Money

When these materials are used then they Enhanced durability and strength and decrease the permeability and provide longer life. Due to their small size they enhanced architectural appearance and reduced need for other expensive finishes or painting. They Enhanced environmental performance—reduce the risk of attracting carbon taxes. The structure that will be built from theses will have these extra properties Lower maintenance costs, Enhanced life cycle, No additional premium on material costs, overall better value for money.

6. RECOMMENDATIONS

In this work we have seen many of their beneficial effects are observed based on these observations following recommendations can be made.

- When SCMs are used it is observed that the early strength of concrete is lower. it means early strength using these materials will be lower than conventional concrete so it is Specified that concrete strengths should be taken @ 56 days for any concrete designed with more than 30% SCMs. Specifying all concrete @ 56 days can further reduce the overall cementious in a mix design.
- The replacement of cement by SCMs has substantial advantages, not only increased durability and service life of concrete, but also additional ecological benefits. Therefore, every time specify a concrete mix for a particular design.

- Do not specify SCMs percentages for specific elements. Allow the contractor to have some flexibility that meets their Schedule.
- If high volume SCMs replacement is a key component of a project, then the schedule has to be planned around the concrete.
- Do not insist on ready-mix producers to submit mix designs showing the amount of SCMs used for each mix (prescriptive). The ready-mix producer can provide the overall percentage of SF and GGBS used at the end of the project.
- In addition, we have design such combinations/mixes using SCMs instead of just using the ordinary Portland concrete, to achieve the design service life to 100 years or 150 years. This would mean less use of energy and resources in the long run for the price of a relatively marginal capital cost increase.

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