The effect of cement mortar composition on the pH value

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Abstract. Cement-based materials (CBMs) initially start their life at a high pH of about 12.5-13.5 due to the presence of portlandite (CH or Ca(OH)2) contents. The portlandite is by-product of cement hydration process and the main reason of high pH of CBMs [1,2]. The pH of CBMs does not remain constant and varies with time due to several factors. These factors include carbon dioxide, acid gases, chlorides and moisture that can penetrate into the embedded reinforcement through the process of infiltration, diffusion and capillary action [3,4]. The main processes involved in pH reduction of concrete are, carbonation, corrosion, chloride ingress, biodegradation and acid attack [5].

The durability, strength and service life of concrete structures is directly affected by their pH values. Czarnecki and Woyciechowski [6] stated that CH contents and other alkaline hydroxides present in the concrete maintain the durability of concrete structures. According to Alotaibi [7], the high pH of concrete offers the best safety to embedded reinforcement against destructive agents. The high pH of concrete can protect passive layer of reinforcement for hundreds of years from damaging.

Both, low and high pH than normal pH value of concrete are dangerous for the durability and long service life of concrete structures. The pH of concrete does not remain constant and it may change due to the penetration of carbon dioxide, chlorides and moisture. The main processes involved in pH reduction of concrete are, carbonation [8], corrosion [9], chloride ingress, biodegradation and acid attack [5]. However, high pH of concrete may also cause deterioration in concrete such as alkali silica reaction, porosity and moisture related damages [10].

1. Introduction

Cement-based materials (CBMs), such as concrete, mortar and paste, start their life at a high pH of about 12.5 to 13.5 due to the presence of portlandite (CH or Ca(OH)2) contents. The portlandite is by-product of cement hydration process and the main reason of high pH of CBMs [1,2]. The pH of CBMs does not remain constant and varies with time due to several factors. These factors include carbon dioxide, acid gases, chlorides and moisture that can penetrate into the embedded reinforcement through the process of infiltration, diffusion and capillary action [3,4]. The main processes involved in pH reduction of concrete are, carbonation, corrosion, chloride ingress, biodegradation and acid attack [5].

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Both, low and high pH than normal pH value of concrete are dangerous for the durability and long service life of concrete structures. The pH of concrete does not remain constant and it may change due to the penetration of carbon dioxide, chlorides and moisture. The main processes involved in pH reduction of concrete are, carbonation [8], corrosion [9], chloride ingress, biodegradation and acid attack [5]. However, high pH of concrete may also cause deterioration in concrete such as alkali silica reaction, porosity and moisture related damages [10].
Currently, the use of supplementary cementitious materials (SCMs) such as fly ash (FA) and ground granulated blast-furnace slag (GGBFS) as partial replacement of ordinary Portland cement (OPC) has been increasing due to commercial, environmental and sustainable issues [11,12]. The SCMs contain high amounts of alumina and amorphous silica. Therefore, they are used to improve the durability of CBMs through filler effect and pozzolanic reaction [13,14].

According to some researchers [15-17], the SCMs decrease pH of CBMs by consuming CH contents in their pozzolanic reaction and small amount of pure cement in the mixes. However, the values of reduction in pH of CBMs due to addition of SCMs has not been reported in the present literature. Therefore, the aim of this study is to investigate the influence of using high volumes of FA and GGBFS on the pH of cement mortars with passage of time up to 150 days. In addition, the effect of CH contents on the pH of mortars have been studied in detail.

2. Experimental program

2.1. Materials

Ordinary Portland cement (OPC) with a specific gravity of 3.12 was used in all the mixes. The specific surface area (SSA) of the OPC based on the Blaine and B.E.T. tests were determined to be 351 m²/kg and 2667.24 m²/kg, respectively. The class F fly ash (FA) had specific gravity of approximately 2.29. The color of FA was whitish grey. According to the B.E.T. test, the SSA of FA was determined to be 2858.6 m²/kg.

The ground granulated ballast furnace slag (GGBFS) had specific gravity of approximately 2.83. The color of GGBFS was off-white. According to the B.E.T. test, the SSA of GGBFS was determined to be 3197.2 m²/kg. Local mining sand having maximum grain size of 4.75 mm and specific gravity of 2.68 was used in this study. The water from the pipeline of the lab was used in all mixes and for curing of the samples. The chemical composition of OPC, FA, GGBFS was determined by “X-ray fluorescence spectrometry (XRF)” and shown in table 1.

| Chemical composition | OPC       | GGBFS     | FA        |
|----------------------|-----------|-----------|-----------|
| CaO                  | 60.68     | 40.88     | 12.78     |
| SiO₂                 | 20.46     | 35.98     | 40.10     |
| Al₂O₃                | 3.86      | 13.47     | 17.05     |
| Fe₂O₃                | 3.38      | 0.43      | 15.05     |
| MgO                  | 3.10      | 5.42      | 6.68      |
| P₂O₅                 | 0.06      | 0.01      | 0.20      |
| TiO₂                 | 0.17      | 0.63      | 0.88      |
| K₂O                  | 0.26      | 0.36      | 1.05      |
| SO₃                  | 2.20      | 1.75      | 0.63      |
| SrO                  | 0.03      | 0.05      | 0.07      |
| MnO                  | 0.15      | 0.20      | 0.21      |
| LOI                  | 2.23      | 0.72      | 0.70      |

*LOI = Loss on ignition

2.2. Mix proportions and mixing procedures

A total of three different mortar mixes were produced. In a control mortar having cement to sand ratio of 1:3 and water to cement ratio of 0.48, the OPC was replaced with 50% of FA and GGBFS by weight. Table 2 shows the mix proportions of all mortars in one batch. All mortars had a flow of 210±10 mm. However, for GGBFS mortar SP was needed to achieve the same flow.

For mixing, at first, binder and sand were dry mixed for 2 minutes. Afterwards, the mixture of SP and about 70% of the mixing water were added to mixture and mixing was done for further 3 minutes. Subsequently, the remaining water was added to mixture and mixing was done for further 5 min to get homogeneous mixing. Then, the workability was performed using flow table test.
Table 2. Mix proportions of mortars in one batch.

| Mix       | Binder | Water (kg) | w/b | Sand (kg) | SP (% of binder) |
|-----------|--------|------------|-----|-----------|------------------|
| Control   | 12.50  | -          | -   | 6         | 0.48             |
| FA-50     | 6.25   | 6.25       | 6   | 37.5      | 0.48             |
| GGBFS-50  | 6.25   | -          | 6   | 37.5      | 1.5              |

Fresh mortar was then cast into 50 mm cube steel molds in two layers. Each layer was compacted using vibrating table. One day after casting, all the cube specimens were demolded and cured under water curing at room temperature (WC), until the samples were used for compressive strength test at the ages of 2, 28 and 150 days.

2.3. Test methods

Flow table test was used to control the workability of mixtures. All mixtures were maintained in a good workability with a flow of 210±10 mm. The calculated compressive strength for each mix was the average of four tested samples. The compressive strength measurements were carried out by using ELE testing machine press with a capacity of 3000 kN and loading rate 0.5 kN/s. Compressive strength tests have been done according to BS [18].

For pH measurement, initially, the inner portions of the cube were taken after crushing the specimen with compression machine. Then, these portions were grinded using grinding machine [19]. The 20g of prepared powder was used for the pH measurement. This powder was mixed with 40 g water (dilution ratio of 1:2) as recommended by Grubb et al. [20]. This solution was stirred using magnetic stirrer for 15 minutes. Then, the solution was filtered using no. 40 filter paper with a 110mm diameter. Finally, three pH readings were taken by digital pH meter. The prepared solution was not stirred during the measurement process. For each time of the pH reading, the pH value was recorded after pH meter showed a stable reading.

Due to availability of buffer solutions for this experimental work, the calibration of pH meter was done by buffer solutions of pH 7.01 and 4.01. It should be noted that based on the different experimental results of various CBMs done by the authors, the difference due to calibration with buffer solutions of pH 7.01, 10.01 and pH 7.01,4.01 was about 0.6.

The thermal gravimetric analysis (TGA) test was used to determine the CH contents for all mortars at the age of 2, 28 and 150 days. The TGA testing is used to measure the weight changes in relation to temperature changes. It highlights the point at which the weight loss is the most apparent, provides the decomposition rate and is helpful for evaluating the mass loss steps accurately. The obtained curves consist of mass loss (%) and derivative weight (%/min). During testing, sample of around 100 mg was heated at 10°C/min from about 30-1000°C in the nitrogen atmosphere at constant rate of 20 ml/min. According to several reports [21-23], the CH content is determined from the percentage weight loss between around 300-550°C.

3. Results and discussion

3.1. Compressive strength

The compressive strength results of control, FA-50 and GGBFS-50 are shown in table 3. The results showed reduction in compressive strength of mortars due to incorporation of FA and GGBFS as described by the previous studies [24, 25]. There was improvement in compressive strength of SCMs blended cement mortars with time due to pozzolanic reaction of FA and GGBFS. The strength of GGBFS-50 mortar was comparable with control mix at the ages of 28 and 150 days.
Table 3. Compressive strength test results.

| Mix Name  | Compressive strength (MPa) |
|-----------|---------------------------|
|           | 2-day | 28-day | 150-day |
| Control   | 24.3  | 46.9   | 62.7    |
| FA-50     | 9.2   | 25.1   | 37.8    |
| GGBFS-50  | 20.5  | 47.1   | 57.5    |

3.2. The pH measurements and CH quantity

The measured pH values of control, FA-50 and GGBFS-50 mortars at the ages of 2, 28 and 150 days are given in table 4. The CH quantities of all mortars obtained by TGA testing are given in table 5. The obtained results showed reduction in pH of blended cement mortars due to FA and GGBFS with age in accordance to the previous studies [15,26,27]. However, the TGA CH results showed increase in CH contents of FA-50 mix with time. It might be due to more dominant filler effect of FA than its pozzolanic effect [28]. The reduction in CH contents of GGBFS-50 mix showed pozzolanic reaction of GGBFS with passage of time [29]. It can be concluded from the obtained results that pH is not only dependent on the CH contents. Therefore, other factors affecting pH of SCMs-blended cement mortars should be investigated.

Table 4. The pH measurement results of mortars.

| Mix Name  | pH value at different ages |
|-----------|---------------------------|
|           | 2-day | 28-day | 150-day |
| Control   | 12.5  | 12.3   | 12.1    |
| FA-50     | 12.4  | 12.2   | 11.7    |
| GGBFS-50  | 12.4  | 12.2   | 11.9    |

Table 5. The CH quantities of mortars.

| Mix Name  | Quantity of CH |
|-----------|----------------|
|           | 2-day | 28-day | 150-day |
| Control   | 1.468 | 1.754  | 2.609   |
| FA-50     | 1.163 | 1.423  | 1.572   |
| GGBFS-50  | 1.360 | 1.252  | 1.223   |

4. Conclusions

This paper presents a detailed study on the pH of cement mortars containing 50% of fly ash (FA) and ground granulated ballast furnace slag (GGBFS) with passage of time. The following conclusions can be drawn from the study:

- There is reduction in pH of cement mortars due to incorporation of FA and GGBFS with passage of time. However, this reduction is not significant, and pH is in the safe range to avoid corrosion of rebars and any other durability related problems.
- The pH of blended cement mortars is not only dependent on the CH contents. Therefore, the other factors affecting pH of cement mortars should be investigated.

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