Effects of Mineral Admixtures on Pore Structure and Compressive Strength of Mortar Contaminated Chloride

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Abstract. This study evaluates the mechanical properties of performance fly ash, silica fume, metakaolin and blast furnace slag mortars due to contaminated chloride. The compressive strength and pore structures at water-to-binder ratios of 0.4, 0.5 and 0.6 are investigated. The result, in general, showed mineral admixtures mortar contaminated chloride improved compressive strength and porosity but different rates depending on their binder type.

1. Introduction

The pore structure of concrete includes air voids, capillary pores, and gel pores. As one of the important characteristics of concrete materials, pore structure possesses an important role determining its mechanical, durability and transmissive characteristics [1, 2]. Pore structure parameters such as porosity, pore size distribution and so on are progressively employed to evaluate permeability, frost resistance, carbonation resistance and physical strength of concrete [3-5].

In order to improve the performance of concrete capable of withstanding serious environmental conditions, mineral admixture including industrial by-products such as blast-furnace slag, fly ash and silica fume are commonly used in combination with OPC in concrete for many applications because they improve durability and reduce porosity of concrete [6]. They also could lower cement requirement resulting in leading to a reduction for CO2 generated by the production of cement [7]. Due to this advantage, there are many studies on the use of the mineral admixture for structural concrete [8-11]. Even though the partial replacement of the mineral admixtures by weight increase the later strength of concrete [12], use of the mineral-admixed concrete in construction fields has been reluctant because of lower early strength.

Therefore, in the present study, strength characteristics in early the age of mortar contaminated chloride content incorporating mineral admixtures such fly ash, silica fume, metakaolin and blast furnace slag with water-to-binder (W/B) ratio of 40%, 50% and 60% on pore structure and compressive strength of mortar ware evaluated.

2. Test Programs

2.1. Materials

The specimens were made with plain cement by Ordinary Portland Cement (OPC) and supplementary cementitious materials by Fly Ash (FA), Silica Fume (SF), Metakaolin (MKP) and Blast Furnace Slag Type B (BB/BFS). Table 1 shows the chemical properties of binders and the physical properties such density, fineness, and water absorption are shown in Table 2.
Table 1. Chemical properties of binder

| Constituent | OPC | FA | SF | MKP | BFS |
|-------------|-----|----|----|-----|-----|
| MgO, %      | 1.31| -  | 0.56| 1.04| 3.26|
| SiO2, %     | -   | 60.60| 95.5| 52.37| 34.10|
| SO3, %      | 2.14| -  | 0.18| 7.56| 2.04|
| LoI, %      | 1.97| 2.40| 1.22| -   | 1.46|
| Total Alkali| 0.43| -  | -   | -   | -   |
| Chloride, % | 0.016| - | -   | -   | 0.00 0.010|

Table 2. Physical properties of material

| Material     | Density, g/cm³ | Fineness, cm²/g | Water absorption, % |
|--------------|----------------|-----------------|---------------------|
| OPC          | 3.16           | 3400            | -                   |
| FA           | 2.26           | 3970            | -                   |
| SF           | 2.35           | 1800            | -                   |
| BBMKP        | 2.75           | 9030            | -                   |
| BFS          | 3.02           | 3860            | -                   |
| Washed Sea Sand | 2.49         | -              | 1.42                |

2.2. Series of Mixture

Fifteen series of mortar mixtures with three types water-to-binder (W/B) ratio of 40%, 50% and 60% were set for mixing mortar contaminated chloride were prepared. Two influencing parameters of chloride content in mortar were used. One is interpreted in %-cement (mass ratio of cement), another is interpreted in kg/m³ (total chloride weight in mortar). Table 3 presents all cases of chloride content in each mix and the mortar mixture proportions of specimen are shown in Table 4. In this reference, chloride content in mortar is 0.57 %-cement in accordance to 3.31 kg/m³, 2.91 kg/m³, 2.59 kg/m³ at W/B=40%, 50%, and 60%, respectively. Series N is OPC-100% as control specimen. Series D is OPC-100% as mortar contaminated chloride content. And, Series S is mortar contaminated chloride content and incorporated with FA-20%, SF-5%, and BFS-45%. However, BBMKP is blast furnace slag incorporated with metakaolin (BB-80% and MKP-20%).

2.3. Test Methods

2.3.1. Compressive Strength and Elastic Modulus. Mortar cylinder specimens in size of φ 100x200mm were demolded at 24-hours after casting then cured by wrapping with wet towel and plastic sheet in a room maintained at 20ºC, R.H. 60% controlled room. After 28 days and 91 days curing, compressive strength was measured in accordance with JIS A 1108. The average compressive strength of three specimens were determined for each mortar mixture in three curing conditions.

2.3.2. Pore Structure. The total pore volume and pore size distribution of concrete specimen were tested by Mercury Intrusion Porosimetry (MIP). After curing for 28 days and 91 days, mortar prism specimens were cut into 5mm-thick slice samples. Subsequently, the fragments were immersed in acetone for 15 minutes to stop further hydration of cement, and then dried in the vacuum desiccator for 2 days. In this MIP test, complete drying of the samples was required to obtain results without error [13]. In this study, the maximum applied pressure of MIP test was 33,000 psi (227MPa), and the surface tension and contact angle of mercury was 485 dynes/cm and 130o, respectively. Both surface tension and contact angle were used in the Washburn equation to convert applied pressure to pore diameter. The pore width corresponding to the highest rate of mercury intrusion per change in pressure is known as the “threshold” pore width [14]. After achieving this highest rate of intrusion, mercury has been shown to penetrate the interior of the specimen.
Table 3. Mixture series of specimen

| Series | W/B (%) | Replacement (%) | Chloride content |
|--------|---------|-----------------|-----------------|
|        |         | OPC  FA  SF BBMKP BFS | kg/m³ | %-cement |
| N      | 40      | 0    -    -    - | 0 | 3.31 |
|        | 50      | 0    -    -    - | 0 | 2.91  0.57 |
|        | 60      | 0    -    -    - | 0 | 2.59  |
| S      | 40      | -    0    0    0 | 3.31 |
|        | 50      | -    0    0    0 | 2.91  0.57 |
|        | 60      | -    0    0    0 | 2.59  |
| D      | 40      | 0    -    -    - | 3.31 |
|        | 50      | 0    -    -    - | 2.91  0.57 |
|        | 60      | 0    -    -    - | 2.59  |

Table 4. Mix proportion of mortar

| W/B (%) | Unit content (kg/m³) | Remarks |
|---------|----------------------|---------|
|         | W  | OPC  | FA  | SF  | MKP | BB  | Sea Sand |
| 40      | 232| 581 | -    | -   | -   | -   | 1490 Normal |
|         | 232| 465 | 11   | -   | -   | -   | 1452 FA |
|         | 232| 552 | -    | 29  | -   | -   | 1481 SF |
|         | 232| -   | -    | 116 | 465 | -   | 1458 BBMKP |
|         | 232| 320 | -    | -   | -   | 261 | 1480 BFS |
| 50      | 255| 510 | -    | -   | -   | -   | 1490 Normal |
|         | 255| 408 | 10   | -   | -   | -   | 1452 FA |
|         | 255| 484 | -    | 26  | -   | -   | 1481 SF |
|         | 255| -   | -    | 102 | 408 | -   | 1458 BBMKP |
|         | 255| 281 | -    | -   | -   | 230 | 1480 BFS |
| 60      | 272| 454 | -    | -   | -   | -   | 1490 Normal |
|         | 272| 363 | 91   | -   | -   | -   | 1452 FA |
|         | 272| 431 | -    | 23  | -   | -   | 1481 SF |
|         | 272| -   | -    | 323 | 91  | -   | 1458 BBMKP |
|         | 272| 250 | -    | -   | -   | 204 | 1480 BFS |

3. Result and Discussion

3.1. Compressive Strength

The compressive strength results of different mortar mixes at 28 days and 91 days is shown in Figure 1. days and 91 days, the compressive strength on OPC and SCMs decreasing with increase W/B ratio. The SF mortar showed higher strength values to that of another’s mortar at all tested ages. Only the result of the FA was different, as it gave the lowest compressive strength at 28-days and 91-days. The compressive strength lowest is related to the properties of FA that declines the heat of hydration process. As a result, FA slows the rate of hardening and reduces the compressive strength [14]. In addition, perhaps this condition may be due to chloride contaminated.
Table 5 gives the compressive strength expressed as fraction of that of normal OPC. It is found that strength performance in early age up to 91 days of normal OPC is larger than OPC mortar contaminated chloride. This implies OPC mortar contaminated chloride less effective on compressive strength up to 91 days compared with normal OPC. Compressive strength of OPC contaminated chloride and FA decreased about 20% when compared to normal OPC.

| Series   | W/B = 40% | 28-d | 91-d | W/B = 50% | 28-d | 91-d | W/B = 60% | 28-d | 91-d |
|----------|-----------|------|------|-----------|------|------|-----------|------|------|
| Normal OPC | 1.00      | 1.00 | 1.00 | 1.00      | 1.00 | 1.00 | 1.00      | 1.00 | 1.00 |
| SCMs     |           |      |      |           |      |      |           |      |      |
| FA       | 0.74      | 0.83 | 0.81 | 0.98      | 0.72 | 0.92 |           |      |      |
| SF       | 1.01      | 1.05 | 1.05 | 1.15      | 1.09 | 1.14 |           |      |      |
| BBMKP    | 1.07      | 0.96 | 1.08 | 0.97      | 1.02 | 1.04 | 1.07      | 0.96 | 0.97 |
| BFS      | 1.03      | 0.95 | 0.95 | 0.96      | 0.90 | 0.98 | 1.03      | 0.95 | 0.96 |
| Normal OPC-Cl | 0.89 | 0.86 | 0.95 | 0.87 | 1.00 | 0.99 |           |      |      |

### 3.2. Porosity

Porosity is a measure of the proportion of the total volume of concrete occupied by pores. The total volume of pores obtained by Mercury Intrusion Porosity (MIP) tests of mortar specimen at 91 days are shown in Figure 2. It is shown that OPC contaminated chloride increased pore volume of mortar compared with normal OPC. The relatively high of porosity values implies the effect of additional chloride effects the increment of porosity. Further, some results also showed by SCMs that more increase in porosity is achieved by the use of SCMs with contaminated chloride content. The SF and BFS mortar exhibited slightly same porosity values when compared to the OPC mortar contaminated chloride. Unlike most other mineral admixtures, FA and BBMKP mortar the highest porosity values at the age 28 days and 91 days.

Table 6 gives the total pore volume expressed as fraction of that of normal OPC. It is found that total pore volume of FA and BBMKP in early age of SCMs is the larger than OPC mortar. The total pore volume of FA increased about 37%, 41%, 21% for W/B 40%, 50% and 60%, respectively, when compared to normal OPC at 91-days. And, the total pore volume of BBMKP increased about 21%, 45%, 26% for W/B 40%, 50% and 60%, respectively, when compared to normal OPC at 91-days.
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5

Figure 2. Porosity of concrete at 28-days

Table 6. Total pore volume of as fraction of Normal OPC

| Series        | W/B = 40% | W/B = 50% | W/B = 60% |
|---------------|-----------|-----------|-----------|
| Normal OPC    | 1.00      | 1.00      | 1.00      |
| SCMs          |           |           |           |
| FA            | 1.49      | 1.37      | 1.15      |
| SF            | 1.27      | 1.21      | 1.26      |
| BBMKP         | 1.21      | 1.22      | 1.36      |
| BFS           | 1.31      | 1.03      | 1.18      |
| Normal OPC-Cl | 1.24      | 1.17      | 1.14      |

The relationship between compressive strength and porosity is shown in Figure 3. The results show the porosity decreased with increasing compressive strength at the age of 28 days and 91 days. In addition, a good correlation is acquired in which R² values are around 0.90 at 28 days and 91 days, only FA mortar have low correlation after 91 days. This suggests that the compressive strength of with SCMs are influenced by porosity. The same tendencies as reported in previous studies that strength and elasticity of concrete were affected by the total pore volume or porosity [15].

Figure 3. Compressive strength and total pore volume at 28-days and 91-days

4. Conclusions

From this research, several conclusions can be drawn as follows:
- At the age of 28-days and 91-days, mostly W/B more affect than SCMs on the compressive strength. However, mortar with and without SCMs were increased in compressive strength.
- At the age of 28-days and 91-days, SCMs less affects in reducing total pore volume.
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