Ternary Blends of High Aluminate Cement, Fly ash and Blast-furnace slag for Sewerage Lining Mortar

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Abstract. High aluminate cement (HAC), fly ash (FA) and blast-furnace slag (BFS) have been treated sustainable materials for the use of cement products for wastewater infrastructure due to their capabilities of corrosion resistance. The purpose of this study is to optimize a ternary blend of above mentioned materials for a special type of mortar for sewerage lining. By the using of Taguchi method, four control parameters including water/cementitious material ratio, mix water content, fly ash content and blast-furnace slag content were considered in nine trial mix designs in this study. By evaluating target properties including (1) maximization of compressive strength, (2) maximization of electricity resistance and (3) minimization of water absorption rate, the best possible levels for each control parameter were determined and the optimal mix proportions were verified. Through the implementation of the study, a practical and completed idea for designing corrosion resistive mortar comprising HAC, FA and BSF is provided.

1. Introduction
Infrastructure such as concrete sewer pipes, wastewater collection units and treatment plants are facing severe concrete cracks, fractures, deformations and collapse due to the sulfuric acid attack produced by sulfur oxidizing bacteria [1]. Therefore, it is critical to increase the durability of concrete which can reduce the biogenic acid attack [2] or to apply effective coating (lining) to concrete to protect the cement pipe surface from the acid attack [3]. With several distinct advantages over OPC concrete, HAC has been used in refractories, pipes, sewer constructions, industrial floors and dam spillways and more recently immobilization of metallic radioactive wastes and toxic metal solutions [4]. Research also indicated that HAC can be blended with different additions such as FA, BFS or natural pozzolans to obtain properties such as fast setting, rapid hardening, high early strength and shrinkage compensation [5]. This study, through the implementation of Taguchi’s experiment design method, reports a study of blends that composing HAC, FA and BFS to develop the optimal mortar mix design parameters for sewerage lining in respect to the maximization of compressive strength, electricity resistance and the minimization of water absorption rate.

2. Experimental significance
Various researches have been done on improving performance of concrete used in sewerage. In which, using alumina cement, incorporating supplementary cementitious materials (SCMs), designing low water-to-cement (w/c) ratio concrete, applying concrete with low water absorption rates and increasing the concrete electrical resistivity are primary methods to increase concrete durability and resistance to
against sulfate attack [4,5,6,7]. Concrete compressive strength is regarded as a valuable index in concrete structural design because it associates with most other properties and provides an overall quality parameter [8,9]. Electrical resistivity is an evaluation of the accessibility of aggressive agents before the beginning of the corrosive process [10], and is therefore used as a measurement of concrete durability [11]. Water absorption of concrete can be described as the ability to take in water or other aggressive agents by means of capillary action. The lower the water absorption in concrete, the finer the concrete is. It is treated an important factor for quantifying the concrete durability [12,13]. Based on the research results aforementioned, criteria shown below were designed to aim and comply in this study:

- W/cm % for each mix was assigned to be less than 0.4;
- Compressive strength tests performed according to ASTM C109/C109M [14], must be greater than 210 kgf/cm²;
- Electricity resistance tests performed according to AASHTO T277 [15], must be greater than 20 kΩ-cm;
- Water absorption tests performed according to the ASTM C 642 [16], must be less than 8.0 %.

3. Experimental details

3.1. Materials
HAC used met the requirements of GB201-2000 [17] with a specific gravity of 3.30 and a blaine fineness of 3700 cm²/g. FA and BFS used had properties that met the requirements specified in ASTM C618 [18]. The FA had a specific gravity of 2.69 and blaine fineness of 4080 cm²/g and the BFS had a specific gravity of 2.90 and blaine fineness of 4300 cm²/g. Standard sand with properties complied with ATM C778 [19] was used as fine aggregate. Tap water was used as mix water for each mix.

3.2. Taguchi method
Taguchi method was developed by Genichi Taguchi during the 1950s to be used to determine optimal parameters for performance and cost [20]. The method recommends the use of “loss function” to measure the deviation of obtained properties from the target properties. The value of loss function is further transformed into signal-to-noise (S/N) ratio. There are three performance characteristics to analyze the S/N:

\[
S/N = -10 \cdot \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} (Y_i - Y_0)^2 \right)
\]

- Larger is better: The S/N can be calculated using Eq. (2).

\[
S/N = -10 \cdot \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} \frac{1}{Y_i^2} \right)
\]

- Smaller is better: The S/N can be calculated using Eq. (3).

\[
S/N = -10 \cdot \log_{10} \left( \frac{1}{n} \sum_{i=1}^{n} Y_i^2 \right)
\]

where n is the number of experiments and Yi is the observed results for test.

In this study, “the larger the better” situation was applied for maximization of compressive strength and electricity resistance and “the smaller the better” situation was applied for minimization of water absorption rate.

3.3. Mix design using Taguchi method
Four control parameters including water/cementitious material ratio (W/cm), mix water content (W), fly ash content (FA/cm) and blast-furnace slag content (BFS/cm) at 3 levels were considered.
Table 1) in this study. According to the Taguchi method (standard L9 orthogonal array for four control parameters at 3 levels), the suggested experiments and the detailed mix proportion of the nine experiments were designed (see Tables 2).

**Table 1.** Control parameters and their levels.

| parameter 1 (W/cm (%)) | parameter 2 (W (kg/m³)) | parameter 3 (FA/cm (%)) | parameter 4 (BFS/cm (%)) |
|------------------------|--------------------------|-------------------------|--------------------------|
| 35                     | 140                      | 7.5                     | 7.5                      |
| 37                     | 160                      | 10                      | 10                       |
| 39                     | 180                      | 12.5                    | 12.5                     |

**Table 2.** Taguchi Standard L9 orthogonal array and detailed mix proportion.

| Trial No. | Performance parameter value | parameter 1 (W/cm (%) | parameter 2 (W (kg/m³)) | parameter 3 (FA/cm (%)) | parameter 4 (BFS/cm (%)) |
|-----------|-----------------------------|------------------------|--------------------------|-------------------------|--------------------------|
| M1        |                             | 1                      | 1                        | 1                       | 35                       | 140                      | 7.5                     | 7.5                     |
| M2        |                             | 1                      | 2                        | 2                       | 35                       | 160                      | 10                      | 10                       |
| M3        |                             | 1                      | 3                        | 3                       | 35                       | 180                      | 12.5                    | 12.5                     |
| M4        |                             | 2                      | 1                        | 2                       | 3                       | 37                       | 140                     | 10                      | 12.5                     |
| M5        |                             | 2                      | 2                        | 3                       | 37                       | 160                      | 12.5                    | 7.5                      |
| M6        |                             | 2                      | 3                        | 1                       | 2                       | 37                       | 180                     | 7.5                      | 10                       |
| M7        |                             | 3                      | 1                        | 3                       | 2                       | 39                       | 140                     | 12.5                    | 10                       |
| M8        |                             | 3                      | 2                        | 1                       | 3                       | 39                       | 160                     | 7.5                      | 12.5                     |
| M9        |                             | 3                      | 3                        | 2                       | 1                       | 39                       | 180                     | 10                      | 7.5                      |

3.4. Test procedures and results

A 0.1 m³ laboratory twin-shaft mixer manual electric mixer was used for mortar mixes. The total mix time was four minutes for each mix. Three 100mm x 100 mm cubic specimens for compressive strength, three 100mm x 100 mm cubic specimens for water absorption and for electricity resistance test were collected for each trial (electricity resistance tests were conducted on the same specimens prepared for water absorption rate tests). Specimens were kept in molds in ambient condition for 24 hours after their castings and were then demolded and stored in ambient condition until testing. Tests were performed on specimens at age of 28 days. Results of tests of each mix were reported as averages of three specimens (See Table 3). Compressive strengths were in the range of 204-326 kgf/cm² and the highest value was measured at M7. Trial No. 9 failed in the compressive strength test since the result was not complied with the criteria. The electricity resistance test results were all above the criteria and were in the range of 41-224 kΩ-cm. The highest electricity resistance was measured at M7. The results of water absorption rate test were in the range of 4.8-6.8 % and were all complied with criteria. The lowest water absorption rate was measured at M7, which was the best.

**Table 3.** Test results of trials.

| Trial No. | Compressive strength, (kgf/cm²) | Electricity resistance, (kΩ-cm) | Water absorption rate, (%) |
|-----------|---------------------------------|---------------------------------|---------------------------|
| M1        | 266                             | 103                             | 5.0                       |
| M2        | 289                             | 138                             | 6.6                       |
| M3        | 275                             | 56                              | 5.7                       |
| M4        | 230                             | 41                              | 6.8                       |
| M5        | 234                             | 52                              | 6.2                       |
| M6        | 269                             | 84                              | 6.4                       |
| M7        | 326                             | 224                             | 4.8                       |
| M8        | 272                             | 159                             | 6.8                       |
| M9        | 204                             | 96                              | 7.1                       |

4. Optimizing mix design proportions
The situations of “the larger the better” were used for maximization of compressive strength and electricity resistance and situations of “the smaller the better” were used for minimization of water absorption rate in this study. The S/N ratios of compressive strength and electricity resistance obtained by using Eq. (2) and water absorption rate obtained by using Eq. (3) (See Table 4). Based on the Taguchi method, the response S/N for each level of a parameter was obtained by averaging the S/Ns of that respective level (See Table 5). A higher response S/N value indicates a greater effect of the particular control parameter at that level. The proposed optimal mix proportions should be determined (See Table 6).

Table 4. S/N of results of trials.

| Trial No. | Parameter levels | W/cm (%) | W (kg/m³) | FA/cm (%) | BFS/cm (%) | Compressive strength | Electricity resistance | Water Absorption rate |
|-----------|------------------|----------|-----------|-----------|-------------|----------------------|------------------------|-----------------------|
| M1        | 35               | 140      | 7.5       | 7.5       | 47.6        | 40.3                 | -14                    |                       |
| M2        | 35               | 160      | 10        | 10        | 48.7        | 42.8                 | -16.4                  |                       |
| M3        | 35               | 180      | 12.5      | 12.5      | 48.5        | 35                   | -15                    |                       |
| M4        | 37               | 140      | 10        | 12.5      | 47          | 32.3                 | -16.6                  |                       |
| M5        | 37               | 160      | 12.5      | 7.5       | 16.3        | 34.3                 | -15.8                  |                       |
| M6        | 37               | 180      | 7.5       | 10        | 47.6        | 38.5                 | -16.2                  |                       |
| M7        | 39               | 140      | 12.5      | 10        | 49.4        | 47                   | -13.6                  |                       |
| M8        | 39               | 160      | 7.5       | 12.5      | 46.7        | 44                   | -16.6                  |                       |
| M9        | 39               | 180      | 10        | 7.5       | 46.6        | 39.6                 | -17                    |                       |

Table 5. Response S/N for each level of a parameter on properties.

| Properties                | W/cm (%) | W (%) | FA/cm (%) | BFS/cm (%) |
|---------------------------|----------|-------|-----------|-------------|
| Compressive strength      | 48.8     | 47.7  | 47.7      | 47.9        |
| Electricity resistance    | 39.3     | 35    | 43.6      | 39.5        |
| Water absorption rate     | -15.2    | -16.2 | -15.8     | -16.5       |

Table 6. Proposed optimal mix proportions.

| Optimal trial No. | Optimal mix proportions | W/cm (%) | W (kg/m³) | FA/cm (%) | BFS/cm (%) |
|-------------------|-------------------------|----------|-----------|-----------|-------------|
| 1                 | Compressive strength (kg/cm²) / Water absorption rate (%) | 35       | 180       | 12.5      | 10          |
| 2                 | Electricity resistance (kΩ·cm) | 39       | 160       | 7.5       | 10          |

5. Verifying the optimal mix proportions

Since the proposed optimal mix proportions (see Table 6) were not included in the mix proportions (see Table 2), verification trials were performed. The tests were performed on specimens at age of 28 days, experiment results showed that the proposed optimal mix proportions satisfied the expectancies (see Table 7).

Table 7. Optimal mix design verification test results (average of three specimens).

| Target properties | Optimal trial No. |
|-------------------|-------------------|
| Compressive strength (kg/cm²) | 286     |
| Electricity resistance (kΩ·cm) | 162      |
| Water absorption rate (%) | 5.4      |
6. Conclusions
As an effective and suitable experiment method for optimizing the proportion parameters of ternary blends of HAC, FA and BFS, Taguchi method was used to optimize the properties of sewerage lining mortar, following conclusions can be drawn from the results: Four control parameters including water/cementitious material ratio (W/cm), mix water content (W), fly ash content (FA/cm) and blast-furnace slag content (BFS/cm) were used in nine trial mix designs to maximize the compressive strength and electricity resistance and to minimize of water absorption. Two set of mix designs were verified optimal. Results of target properties of each optimal mix designs complied with the criteria.

7. References
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