Performance of modified epoxy mortar using composite cement containing Ground Granulated Blast Furnace Slag (GGBS)

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Abstract. The applications of modified epoxy mortar have been widely used in civil engineering construction field to reduce the usage of epoxy in strengthening applications. In the construction field, the usage of epoxy resin mortar was known as repair materials. For this research, an experimental work has been conducted on modified mortar containing epoxy with and without hardener. This research was conducted to analyze the compressive strength, density and water absorption of the specimen. The cement used for this study was a composite cement with the combination of 50% ordinary Portland cement and 50% Ground Granulated Blast Slag (GGBS). The mortars were prepared with water-cement ratio of 0.60, sand-cement ratio of 2:1 and the epoxy content of 1%, 2%, 3%, 4%, 5%, 6%, 7%, 8%, 9% and 100%. In this research, the type of epoxy used is Sikadur-31 CF Normal with and without hardener. The test was carried out by using cube mortar of size 50 mm x 50 mm x 50 mm. From the experimental results, the optimal percentage of epoxy content for compressive strength and water absorption was 3%. Besides, the highest compressive strength was 31.7 MPa of modified epoxy mortar without hardener and 34.8 MPa of modified epoxy mortar with hardener. It was concluded that 3% of epoxy was the optimal percentage for the modified mortar because of the compressive strength reached the nearest with the control mortar specimen.

1. Introduction

Nowadays, there were many applications of modified epoxy used to reduce the usage of epoxy. The epoxy introduced into the industry in 1946. It can be used for a variety of applications and manipulated according to its intended use [1]. Mortar had a various function or used in the construction industry. According to Gambhir and Jamwal [2], the mortar has improved the effects of structural cracking in the building. Many previous research conducted experimental testing of mortar using the pozzolanic materials especially Ground Granulated Blast Furnace Slag (GGBS) [3]. Rather than using Ordinary Portland Cement (OPC), composite cement also had been widely used. Moreover, the composite cement would reduce cement usage in the mortar.

In addition, OPC has disadvantages such as poor bonding strength, curing time becomes longer, weak of flexural strength, the problem of durability, and high shrinkage [4]. According to Gerrard [5], a poor mortar was another cause of cracking in the structure. Moreover, the cause of most failures in the mortar was water penetration [6]. It can happen in many ways such as water penetrates the layers of sediment structures, brick or concrete block, and others. These problems has led to using polymer materials as repair material. Indirectly, it led to the introduction of epoxy mortar [7].
The different percentage of epoxy and composite cement in the mortar is to lessen the epoxy usage. The modified epoxy also can work the same as well as epoxy to repair the cracks in structural and can restore the structural strength. According to Jupiter et al. [8], the acceptance of modified epoxy mortar is getting a good response from the construction industry. Moreover, the modified epoxy mortar has a high level of thermal stability, the favourable water resistance, rapid hardening process, high modulus of elasticity and the bending strength compared to other liquid polymers. This study focus on the investigation of modified mortar using epoxy and composite cement containing GGBS. The use of GGBS was the new approach, which had increasing concrete performance as well as concrete durability. In placing more emphasis, Suresh and Nagaraju [9] claimed that a combination of ordinary Portland cement with GGBS or other pozzolanic materials was to increase the durability of concrete structures. Usually, GGBS regularly used in Europe, and start getting attention from the United States and Asia, especially in Japan and Singapore. About 50% of GGBS portion was commonly use but it can reach up to about 70% in replacing the ordinary Portland cement of concrete. The higher usage of the portion of GGBS, a better resistance of the concrete.

2. Methodology

Before the specimen was casted, a trial mix of the designed mix ratio was conducted. The purpose of trial mixes was to check the strength, workability, density and other properties of the designed mortar. Trial mixes also often undertaken when new materials or admixtures were used. When setting up batch data, trial mixes also can help to maximize all materials in mixes. The type of epoxy used for the trial mix was Sikadur 330. The water-cement ratio used was 0.50 and sand-cement ratio was 2:1. The trial mix was included 1% epoxy without hardener and 1% epoxy with hardener. Several trial mix were tested to determine the effect of water-cement ratio and the suitable technique to mix the modified epoxy mortar uniformly. The 50 mm × 50 mm × 50 mm of mortar dimensions were produced.

2.1. Identification of the suitable water-cement ratio

This trial mix conducted by using the water-cement (w/c) ratio and the sand-cement ratio as stated before. The flow of the trial mix for the normal mortar should flowing smoothly. However, the mix has low workability and low setting time, which make it get hardened in a short period, either for the trial mix for the modified epoxy mortar without hardener or with hardener. Consequently, another trial mix was conducted using a different w/c ratio of 0.60. This ratio was used in the study by Nahata et al. [10], Singh et al. [11] and Bu et al. [12]. It was found that, the flow of this mix was better in terms of the workability. Another concerned was the compressive strength of the mortar. Table 1 shows the average compressive strength of the trial mix for both water-cement ratio. It can be observed that all average compressive strength of 0.60 ratio was higher than 0.50.

|                      | Age (Days) | Compressive strength (MPa) | Age (Days) | Compressive strength (MPa) |
|----------------------|------------|-----------------------------|------------|-----------------------------|
|                       | w/c ratio = 0.50 |                       | w/c ratio = 0.60 |                       |
| Control 100% OPC      | 3          | 19.0                        | 3          | 27.5                        |
|                       | 7          | 27.8                        | 7          | 27.1                        |
| 1% Epoxy without hardener | 3          | 18.3                        | 3          | 21.5                        |
|                       | 7          | 22.9                        | 7          | 29.3                        |
| 1% Epoxy with hardener | 3          | 17.3                        | 3          | 19.6                        |
|                       | 7          | 22.2                        | 7          | 29.8                        |
2.2. Identification of the suitable technique for the modified epoxy mortar

After the decision of the suitable w/c ratio, the suitable technique for mixing the modified epoxy mortar was determined. The next trial mix focused on modified epoxy mortar rather than the normal mortar. This trial mixes were conducted using 0.60 of the water-cement ratio (w/c) and 2:1 of sand: cement ratio. The first technique was to add the epoxy after mortar was formed. The second method was to add the epoxy into the sand first, then add water to mix it together [13]. The result for the first technique (method) was not consistent. However, the second technique show more consistent result for both samples. Even so, the result for the first technique was higher than the second technique but the result was not consistent as shown in Table 2. Besides, the second technique was better to be used than the first technique because the mortar can be mix with the epoxy to form a smooth paste. Therefore, this research used the second technique for mixing the specimen.

| Method | Age (Days) | Average Compressive Strength (MPa) |
|--------|------------|-----------------------------------|
| 1% Epoxy without hardener | 3 | 21.5 |
| | 7 | 29.3 |
| 1% Epoxy with hardener | 3 | 19.6 |
| | 7 | 29.8 |

2.3. Modified epoxy mortar

The modified epoxy mortar in this research use composite cement and epoxy resin with and without hardener. Apart from that, the composite cement was a mix of cement and ground granulated blast furnace slag (GGBS). 50% of cement and 50% of GGBS was used as composite cement. The percentages proportions of the materials to be used for modified epoxy mortar is as shown in Table 3. The water-cement ratio used in this research was 0.60 while the sand-cement ratio used was 2:1. The size of the specimens was 50 mm x 50 mm x 50 mm.

| Modified epoxy mortar with and without hardener | Composite cement | Epoxy (%) |
|-----------------------------------------------|------------------|-----------|
| C100 | 100 | 0 | 0 |
| C50 | 50 | 50 | 0 |
| ME1 | 49.5 | 49.5 | 1 |
| ME2 | 49.0 | 49.0 | 2 |
| ME3 | 48.5 | 48.5 | 3 |
| ME4 | 48.0 | 48.0 | 4 |
| ME5 | 47.5 | 47.5 | 5 |
| ME6 | 47.0 | 47.0 | 6 |
| ME7 | 46.5 | 46.5 | 7 |
| ME8 | 46.0 | 46.0 | 8 |
| ME9 | 45.5 | 45.5 | 9 |
| ME10 | 45.0 | 45.0 | 10 |

3. Results and discussions

3.1. Density

The density of 7 days for C100 was higher than C50. However, at 28 days of curing, the density of C100 was less than C50. Based on Figure 1, the density graph pattern of 7 days and 28 days was almost similar and does not show any significant different. Please be noted that Figure 1 is the result for modified
epoxy mortar without hardener. The density of 7 days for modified epoxy mortar was the highest at ME2 (WOH – Without Hardener) which is 2332 kg/m$^3$. However, the density of modified epoxy mortar for 28 days was the highest at ME1 (WOH), which is 2360 kg/m$^3$. The density of all specimen shows almost similar value with the density of the control specimen. There is no significant difference observed. The slight difference tells that the higher percentage of epoxy added into the modified epoxy mortar, the denser the specimen. However, the density of ME100 (WOH) was not obtained because the cube does not hardened and could not be tested.

![Figure 1. Density of modified epoxy mortar without hardener.](image)

Figure 2 shows the density graph pattern of 7 days and 28 days for modified epoxy mortar with hardener. The density of 7 days for modified epoxy mortar was the highest at ME1 (WH – With Hardener) which is 2280 kg/m$^3$. However, the specimens of ME5 (WH) and ME8 (WH) was highest at 2280 kg/m$^3$ for the density of 28 days. These show that the density of ME1 (WH) was denser than other modified epoxy mortar of 7 days curing. Apart from that, the specimens of ME100 (WH) was light and less dense because 100% of epoxy was used. As the specimen for modified epoxy mortar without hardener, specimen for modified epoxy mortar with hardener also shows no significant difference between the control specimen and modified epoxy mortar specimen. There is just slightly decreased in overall pattern of the density as the percentage of epoxy increased. It was also observed that the density of modified epoxy with hardener recorded slightly lower value compared with the density of modified epoxy mortar without hardener.
3.2. Compressive strength

Figure 3 and 4 show the results of compressive strength for 7 and 28 days of modified mortar containing epoxy with and without hardener. For modified mortar using epoxy without hardener, it can be observed that the compressive strength of modified mortar decreased when epoxy was added to the mortar mix compared with control specimen of C100 and C50. The compressive strength obtained were also inconsistent. The compressive strength of modified mortar increased up to 3% of epoxy replacement. The replacement of 4% to 9% of epoxy shows lower compressive strength compared with 3% of replacement. 100% epoxy results for epoxy without hardener cannot be obtained because the mix was not hardened.
Figure 4 shows the compressive strength of modified mortar using epoxy with hardener. The trend of the compressive strength results was almost similar with modified mortar using epoxy without hardener. However, it can be clearly seen that 100% epoxy shows the highest strength compared with the other specimen. For the other epoxy replacement, it can be observed that specimen with 3% of epoxy replacement shows the highest compressive strength among specimen ME1 to ME9 which shows the same pattern as epoxy without hardener.

![Compressive Strength of Modified Epoxy Mortar with Hardener](image)

**Figure 4.** Compressive strength of modified epoxy mortar with hardener.

### 3.3. Water absorption

Based on Figure 5, the water absorption graph pattern of 7 days and 28 days was almost similar. The lowest value of water absorption of 7 days was recorded at ME1 (WOH) with the value of 1.7% while for 28 days was ME9 (WOH) with the value of 2.198%. The overall pattern shows inconsistent trend of increased decreased of the water absorption. However, despite the unclear trend of the water absorption, it was observed that for most of the specimen, as the percentage of epoxy increased, the water absorption decreased. This shows that epoxy has a little contribution in retaining water absorption into the specimen.

![Water Absorption of Modified Epoxy Mortar without Hardener](image)

**Figure 5.** Water absorption of modified epoxy mortar without hardener.
From Figure 6, the water absorption graph pattern of 7 days and 28 days was almost similar. However, the highest water absorption was ME4 (WH) showed that water absorption of 7 days curing was 4.175%. Meanwhile, the highest water absorption for 28 days was 4.206 % at ME5 (WH) and ME8 (WH). Furthermore, the lowest water absorption of 7 days and 28 days was ME1 (WH). It shows that ME1(WH) hardly and slow to absorbed the water into the mortar.

![Water absorption graph pattern](image)

**Figure 6.** Water absorption of modified epoxy mortar with hardener.

4. Conclusion
This research attempted to study the performance of modified epoxy mortar using composite cement containing GGBS. Furthermore, the optimal percentage of modified epoxy mortar containing the different percentage of epoxy and composite cement was determined. Based on the results of this study, some conclusion can be summarized as below:

- the density of modified epoxy mortar for both with and without hardener shows no significant difference between control and modified specimens.
- The compressive strength shows a slightly decreased value as the percentage of epoxy increased.
- the optimal percentage of modified mortar in compressive strength and water absorption was the mix with 3 % of epoxy. Therefore, the highest compressive strength was 31.7 MPa of modified epoxy mortar without hardener and 34.8 MPa of modified epoxy mortar with hardener. Moreover, the highest density was 2360 kg/m$^3$ of modified epoxy mortar without hardener and 2280 kg/m$^3$ of modified epoxy mortar with hardener. Besides, water absorption was 3.371% of modified epoxy mortar without hardener and 3.663 of modified epoxy mortar with hardener.

Therefore, 3 % of epoxy was suggested as the optimal percentage for the modified mortar because of the compressive strength nearest the control mortar (C100 and C50).

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