Performance of Modified Mortar Containing Epoxy

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Abstract. Performance of FRP are highly depending on the adhesive used. FRP known to have high specific strength and specific stiffness, high durability against corrosion, light in weight, easy and quick installation therefore reduced manufacture time, great versatility and reduced maintenance. Despite all the the advantages possessed by FRP, there are actually several drawbacks which mainly causes by the epoxy resin. The organic binder are harmful towards humans, expensive and not applicable on wet surface. This study modified and elevated the binder materials by combining different percentage of mortar and epoxy. Compressive strength, density and water absorption of the specimen were tested and the optimum percentage were determined. Epoxy without hardener that were tested in this study is ranging from 0-5 % and composite cement consist of 50% of Ground Granulated Blast Slag (GGBS) and 50% of Ordinary Portland Cement (OPC). From the experimental results, 3% of epoxy gives promising results as partial replacement of mortar.

1. Introduction
Deterioration of a concrete structure are mainly due to exposure to a harsh environment over a long period of time. Therefore the needs in finding alternative in strengthening or rehabilitate the structure is highly crucial. Strengthening of an element comes in many forms either as a composite materials or as an accessories. Fibre reinforced polymer (FRP) has been widely used in strengthening and rehabilitation of existing concrete structure. Jacketing concrete columns with steel or fibre-reinforced polymer (FRP) has been identified as an effective way of restoring and enhancing the strength and ductility of columns damaged by catastrophic events such as earthquakes, blasts and vehicle impact according [1].

FRP comprises of continuous fibres which can be either carbon, glass or aramid immerge in resin which varies from epoxy, vinylester or polyester. The resin will holds together the fibers and the concrete and exchanges the load between them. The performance of an element reinforced by FRP is depending on the adhesive or the binder materials used. Epoxy resin is a common adhesive in FRP application. Epoxy resins has been used widely mainly due to many advantages it possesses. FRP has high specific strength and specific stiffness, high durability against corrosion, light in weight, easy and quick installation therefore reduced manufacture time, great versatility and reduced maintenance. Different structures can be installed by using FRP. However, the long term durability have not been proven [2].

Polymers also known as epoxy have played an important role in repairing works mainly in constructions. Epoxy can either be used by itself as a single binder or can be incorporated in a cement mix or also known as modified epoxy [3]. According to El-Hawary and Abdul-Jaleel [4], addition of epoxy enhances the durability of concrete as it reduces the permeability of the concrete. The increase of the epoxy content able to increase the corrosion resistance of the modified concrete. In this study,
modified epoxy containing different percentage of epoxy and composite cement mortar was further studied to determine the best percentage which are needed to achieve high compressive strength and density and high tensile strength.

Despite the advantages possessed by FRP, there are actually several drawbacks that can be observed. The flaws form FRP are mainly from the use of epoxy resins as adhesive. Triantafillou and Papanicolaou [5] stated that the drawbacks includes poor behaviour at temperatures above the glass transition temperature, relatively expensive cost of epoxy resins, potential hazard for manual workers, not suitable on wet surfaces or at low temperature, lack of vapour permeability, incompatibility of resins and substrate materials, absorption of water due to polar groups reduces stiffness and vulnerable towards fire since resins are organic materials.

Therefore, further studies has been conducted and an alternative has been identified. It is found out that replacing organic binder (epoxy resins) with inorganic binder (cement-based mortar) can eliminates most of the flaws form epoxy resins. However, there are some issues with the inorganic binders. The cement-based mortar has poor bond condition due to the granularity of the mortar. Hence, penetration and impregnation of fibre sheet is very difficult to achieve. The geometry structure of a concrete structure will be change affected by the mortar [5]. Modifying epoxy with composite cement mortar can elevates the performance of the modified epoxy in terms of strength and durability [6]. The effectiveness will varies depending on the percentage content of both cement based-mortar and epoxy [7].

2. Experiment

2.1. Materials

Epoxy that were used for this research is Sikadur 31 without hardener. Sikadur 31 possessed a texture similar to sand which made it easier to mix. GGBS is used as replacement at percentage of 50% of OPC which were fixed on every specimen. GGBS were mix together along with cement, sand, epoxy and water. GGBS were known to have small particles similar to cement. Ordinary Portland Cement (OPC) were used in this study. Fine aggregates that were used have an appropriate particle size of 5.00 mm.

2.2. Preparation of specimens

This study produced modified mortar containing contains cement, sand, ground granulated blast furnace slag, water together with epoxy which is Sikadur 31 without hardener. The main element of this study was the content of epoxy and the composite cement mortars which were varies in different percentages. Table 1 shows the percentage of each materials. A total of 36 specimens were casted in the shape of cube with measurement of 50×50×50 mm and cured for 7 and 28 days. The specimen were covered with damped cloth as method curing The density of the specimen were obtain by weighing using an electronic weighing machine while the compression strength were obtain from the compression test. The study were also able to determine the water absorption of the specimen. After the experiment is completed and all the data is obtained the result were evaluated and compared to determine the best percentage and concluded which perform best in terms of compressive strength, density and water absorption.

| Composite cement | Cement (%) | GGBS (%) | Epoxy (%) |
|------------------|------------|----------|-----------|
| 50               | 50         | 0        |
| 49.5             | 49.5       | 1        |
| 49               | 49         | 2        |
| 48.5             | 48.5       | 3        |
| 48               | 48         | 4        |
| 47.5             | 47.5       | 5        |
2.3. Compressive strength test
All specimens at the age of 7 and 28 days were tested. The specimen were position on a crushing machine also known as universal testing machine. Loading were applied until the specimen breaks. The final load applied will be taken as results. The average result will be considered as the compressive strength of the specimen. The procedure of handling compressive strength test according to BS EN 12350-3:2010.

2.4. Density and Water Absorption
The test is simple and the procedure is direct. Before proceeding to the test, all specimens were weigh using a digital weighing machine and the weight is recorded. Water absorption were conducted by weighing the specimen before and after curing for both 7 and 28 days. The increment of weight were expressed as its absorption (in percentage)

3. Results

3.1. Compressive Strength
Compression test were conducted on 36 specimens after undergoing the process of curing for 7 and 28 days. All the results obtained from the testing were recorded and tabulated as shown in Table 2. Based on Table 2, the highest compressive strength value recorded was for sample containing 3% of epoxy at 7 days which was 23.4 MPa and 34.4 MPa at 28 days. Compressive strength for modified epoxy were slightly higher and almost similar to the control samples which was 22.4 MPa and 34.1 MPa at 7 and 28 days respectively. The lowest compressive strength were recorded at 5% of epoxy which were 18.2 MPa and 19.3 MPa at 7 and 28 days respectively.

Figure 1 illustrated the trend for overall results for compression test. Based on Figure 4.1 the compressive strength increases as the epoxy content increases up to 3% of epoxy and started to decline after 3% until 5% of epoxy content for 7 and 28 days. This shows that the optimum epoxy content is at 3%. However in comparisons with past research from Ariffin et al. [7], the optimum epoxy content should be 5%. This occurrence would probably cause by the replacement of 50% GGBS which were the difference between this research and past research.

The declination of compressive strength were most probably due to the unhardened epoxy [7]. As the epoxy content increases, the process of hardening of cement will slows downs due to the unhardened epoxy thus weaken the strength of mortar. This occurrence should be due to the absent of hardener and alkalis in the epoxy which in results retards the polymerization of epoxy. The increment of compressive strength as epoxy content increased are due to the improvement of bonding between hydrated cement to epoxy itself. Epoxy also enhance workability as a result improve the compressive strength.

Table 2: Results for Compressive Strength

| Epoxy (%) | Compressive Strength (MPa) |
|-----------|----------------------------|
|           | 7 days | 28 days       |
| 0         | 22.4   | 34.1          |
| 1         | 18.9   | 27.3          |
| 2         | 19.3   | 29.9          |
| 3         | 23.4   | 34.1          |
| 4         | 19.4   | 27.2          |
| 5         | 18.4   | 19.3          |
3.2. Density

Before compression test were conducted, all specimen were weighed to obtain their masses before and after curing. Table 3 shows the results for density test. Based on Table 3, the highest density were at 3% of epoxy for both 7 and 28 days with 2325 and 2336 kg/m$^3$ of density. The density were higher than control which were 2189 kg/m$^3$. However after reaches the highest peak, the density decreases abruptly at 5% of epoxy for both 7 and 28 days with 2168 and 2245 kg/m$^3$.

**Table 3:** Results for density

| Epoxy (%) | Density (kg/m$^3$) |
|-----------|-------------------|
|           | 7 days            | 28 days         |
| 0         | 2189              | 2243            |
| 1         | 2184              | 2200            |
| 2         | 2267              | 2280            |
| 3         | 2325              | 2336            |
| 4         | 2293              | 2299            |
| 5         | 2168              | 2245            |

The overall pattern of density for 7 and 28 days were presented in Figure 2. The optimum density for both 7 and 28 days were at 3% of epoxy which were higher than control. The increase in density were due to the ability of the epoxy to absorb water and the polymerization of epoxy [8]. The polymerization of epoxy fills the pores between cement particles thus producing denser mortar. The declination of the density are most probably due the unhardened epoxy as the epoxy content increases that were unable to fills the voids in the mortar. Other than that, the mixture of sand and epoxy were probably not uniform thus affecting the density of mortar.
3.3. Water Absorption

Water absorption results were very simple to obtain which were by using simple calculation. Table 4 shows all the data of water absorption for 7 and 28 days. Based on the data recorded, the water absorption for 2%, 3% and 4% were almost the same and recorded as the highest for water absorption with 3.686%, 3.512% and 3.614% at 7 days while 3.68%, 3.515% and 3.482% at 28 days respectively. However the values of water absorption with epoxy were lower than normal mortar which was 3.924% and 3.827% at 7 and 28 days.

The overall pattern for water absorption is shown in Figure 3. The trend was inconsistent. As the epoxy content increases, the water absorption were also increases up to 4% of epoxy then decreases at 5%. The same trend were also can be shown in a study conducted by Borhan and Sutan [9]. The addition of polymer in mortar increase the water absorption but did not affect the compressive strength [9]. Based on observation during mixing process, the absorption of water can clearly be seen during 2%, 3% and 4%. The absorption of water causes the workability to improve. However, as the epoxy content gets higher, the absorption of water slows down thus makes it harder to mix and distribute during mixing. This is because epoxy possesses its own polymer membranes which prevent water from intruding [6].

| Epoxy (%) | Water Absorption (%) |
|-----------|----------------------|
|           | 7 days               | 28 days               |
| 0         | 3.924                | 3.827                 |
| 1         | 2.244                | 2.814                 |
| 2         | 3.686                | 3.68                  |
| 3         | 3.512                | 3.515                 |
| 4         | 3.614                | 3.482                 |
| 5         | 2.31                 | 2.494                 |

Figure 2: Graph of Density versus Epoxy Content
3.4. Relationship between Compressive Strength and Density

The relationship between compressive strength and density at 7 and 28 days were presented in Figure 4 and Figure 5. The trend of the graph showed that as the density increases the compressive strength also increases up to 3% of epoxy then decreases as the compressive strength decreases. It is found out that the optimum compressive strength and density of modified epoxy is when epoxy content is at 3% for both 7 and 28 days. The optimum density and compressive strength of modified epoxy were higher than control. This is probably due to the water absorption process were on pause at 3% of epoxy thus makes it more durable.
3.5. Relationship between Compressive Strength and Water Absorption

Figure 6 and Figure 7 concluded the relationship between compressive strength and water absorption at 7 and 28 days. The trend of the graph were inconsistent. It is found out that the compressive strength increases as the water absorption increases up to 2% of epoxy only. The water absorption were inconsistent but remains almost the same when epoxy at 2%, 3% and 4%. Water absorption slows down then declined at 5% of epoxy. In comparisons with the control specimen, modified mortar has slightly lower water absorption compared to the control specimen. However, the addition of epoxy did not help in reducing water absorption.

![Graph of Compressive Strength and Water Absorption at 7 days](image1)

**Figure 6:** Graph of Compressive Strength and Water Absorption at 7 days

![Graph of Compressive Strength and Water Absorption at 28 days](image2)

**Figure 7:** Graph of Compressive Strength and Water Absorption at 28 days

4. Conclusion

Epoxy plays an important role in strengthening however the production of it is costly and causes health deficit to whoever exposed to it. This study combines epoxy with mortar to reduce the usage of epoxy and elevates the performance of mortar and the results were analyzed and can be concluded as follows:

1) In terms of compressive strength, the addition of epoxy enhances the compressive strength of mortar. The compressive strength was the highest at 3% of epoxy but declined at 4% and 5%.
2) In terms of density, the addition of epoxy increases the density of mortar. The optimum density is at 3% of epoxy with 2325 kg/m³ and 2336 kg/m³ for 7 and 28 days. However, at 5% of epoxy the density declined abruptly.

3) In terms of water absorption, as the epoxy increases the water absorption also increases up to 2%. However, water absorption remains almost constant at 2%, 3%, and 4% and started to drop at 5% of epoxy. However, when compared to the control specimen, the water absorption of modified mortar were lower than normal mortar.

4) The optimum percentage of epoxy for this research was 3%, 48.5% for ground granulated blast slag (GGBS) and 48.5% of OPC as it recorded the highest compressive strength of 23.4 MPa and 34.1 MPa for both 7 and 28 days respectively. The compressive strength of modified mortar were slightly higher and almost the same as normal mortar which were 22.4 MPa and 34.1 MPa for 7 and 28 days respectively.

5) Overall, it can be concluded that the addition of epoxy can elevate the performance of modified mortar by enhancing the compressive strength and density but not water absorption even though compressive strength should increase as the water absorption decreases.

5. References

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