# Effect on Compressive Strength of Epoxy-Modified Mortar with Further Dry-Curing

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**Keywords:** porosity; strength development; epoxy-modified mortar; epoxy resin.

**Abstract:** The percentage of concrete porosity will affects the strength and performance of the concrete. It is believed that, with an additional curing, the porosity of the concrete becomes lower and the strength will increase. This paper presents a relationship between the strength development and porosity of epoxy-modified mortar. Epoxy-modified mortar is a type of polymer-modified which uses an epoxy resin without hardener as an addition material. Mortar specimens were prepared with a mass ratio of 1:3 (cement: fine aggregates), water-cement ratio of 0.48 and epoxy content of 5, 10, 15 and 20% of cement. The specimens were subjected to dry and wet-dry curing and the tests conducted were workability, setting time, compressive strength, flexural strength, tensile splitting strength, porosity and strength development. Results show that workability and setting time of the mortar decreased as epoxy content increased. Compressive, flexural and tensile splitting strengths of epoxy-modified mortar with wet-dry curing were significantly higher and became constant at 10% of epoxy resin content. A significant improvement in strength development of mortar without hardener was achieved even after 365 days of curing. The porosity of the mortar decreased as strength development increased. This was due to the gradual hardening reaction of epoxy resin with cement hydrates that filled the void inside; hence produced a denser and stronger mortar.

## Introduction

Concrete has high compressive strength but is relatively weak in tension and adhesion, and its porosity can lead to physical and chemical deterioration. On the other hand, polymer is weaker in compression but can have higher tensile capacities, and provide a good resistance to physical and chemical attack [1]. The combination of these two materials can produce an excellent strength and durability properties for concrete. Recently, the rapid deterioration of concrete structures because of water leakage has become a serious problem. Water can be dangerous as it can deteriorate the existing concrete structure. At early stage, water is needed for curing process but later, excessive amount of water penetrate into the concrete can create a serious problem.

Polymers have long been used for modification of cementitious materials, for example in reducing the water absorption and adhesion improvement [2]. Desirable properties of epoxy resins such as high adhesion and chemical resistance have made them to be widely used as adhesives and corrosion-resistant paints in the construction industry. Epoxy resin is also used as an admixture of concrete to impart certain effects on mortar [3-5]. The preparation of conventional polymer-modified mortars using epoxy resin to this date considers the indispensable use of hardener for the hardening of the epoxy resin [6]. In this study, epoxy-modified mortars using a Bisphenol A-type epoxy resin without hardener were prepared with epoxy-cement contents of 0, 5, 10, 15, and 20 %, and tested for mechanical properties and strength development for one year curing period. Normal ordinary cement mortars were also prepared and tested in the same manner for comparisons.

## Materials

**Cement.** The cement used in the study was ordinary Portland cement (OPC) conforming to ASTM C150 / C150M-12 [7] standard.

**Fine Aggregates.** Local river sand in which specific gravity of 2.62 and fineness modulus of 2.85 in saturated surface dry conditions was used.

**Epoxy Resin.** Diglycidyl Ether of Bisphenol A-type epoxy resin was used in the mix proportion and stored in room temperature to avoid damage. The amount of epoxy resin added in the mix was in the range of 5 to 20 % of the cement content. The viscosity of epoxy resin used was 10000Pa.s. The viscosity of epoxy resin chosen was high as to create a bonding between epoxy resin and hydroxyl ion.

## Preparation of Epoxy-modified Mortar

With reference to JIS A 1171-2000 [8], the epoxy-modified mortars without hardener were mixed with a mass ratio of cement to fine aggregates of 1:3; epoxy content of 5, 10, 15, and 20 % of cement; and a water-cement ratio of 0.48. The flow spread diameter was in the range of 170 ± 5 mm. Mortar cube specimens of 70 x 70 x 70 mm were cast for compressive strength test. The mixing procedure was basically same as the ordinary cement mortar but with the addition of epoxy resin in the fresh mix. Table 1 shows the mix proportion of the epoxy-modified mortar. Normal mortar mix was prepared as control specimens.

**Table 1** Mix proportion of epoxy-modified mortar

| Sand ($kg/m^3$) | Cement ($kg/m^3$) | Water ($kg/m^3$) | Epoxy content (%) | Water /Cement ratio | Sand: Cement |
|---|---|---|---|---|---|
| 1517 | 506 | 228 | 0<br>5<br>10<br>15<br>20 | 0.48 | 3:1 |

## Curing Regime

For initial curing, wet-dry curing was applied to the specimens where the specimens were placed under wet burlap for two days followed by five days in water. After that, the specimens were taken out and placed at room temperature for 21 days. After the specimens matured, prolong dry-curing was applied until the day of testing. The normal mortar went through water curing.

## Tests

**Apparent Porosity**

Determination of apparent porosity of mortars was done in accordance to ASTM C1403-13 [9]. Three cubes of mortars were oven-dried at 85°C for 24 hours and then immersed in water for 48 hours. The cubes were further suspended in water and weighted. The data were recorded and calculated for average. The percentage of apparent porosity was determined at the age of 28, 56, 90, 120, 180, 270, and 360 days.

**Compressive Strength**

The compressive strength test for epoxy-modified mortar was conducted using a compression test machine with a maximum load capacity of 2000 kN and the loading rate was 0.3 N/mm2/s after 28 days of curing. The test was conducted in accordance to BS EN 12390-3 [10]. An increasing compressive load was applied to the specimen until failure occurred to obtain the maximum compressive load.

The cube size used was 70 x 70 x 70 mm and the calculated compressive strength was based on the average of three values. For strength development test, the compressive strength test was conducted at the age of 28, 56, 90, 120, 180, 270, 360, 425 and 485 days.

**Flexural and tensile splitting tests**

The prism specimen was tested for flexural strength after 28 days in accordance to ASTM C348-08 [11]. The size of mortar prism was 40 x 40 x 160 mm and tested for various percentages of epoxy content. This test was conducted to study the ability of the specimen to resist deflection under load.

For tensile splitting test, cylindrical specimen with the size of 150 mm in height and 70 mm in diameter was cast and tested at the age of 28 days. The test was carried out according to ASTM C496M-11 [12].

**RESULTS AND DISCUSSIONS**

**Flexural Test**

The flexural test was conducted to investigate the material's ability to resist deformation under load.

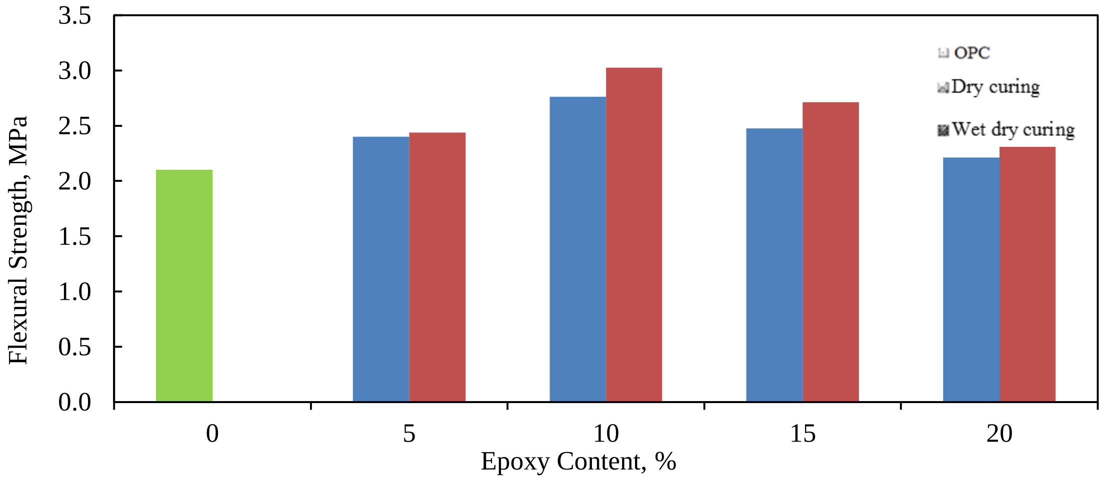


Figure 1: Relationship between flexural strength and percentage of epoxy content.

The result of the 28 days curing epoxy-modified mortar is shown in Figure 1. From the Figure, it can be seen that mortar with 10 % epoxy content gave the highest flexural strength for both curing regimes, followed by 5 %, 15 %, and 20 %. The 10 % epoxy-modified mortar had the highest flexural strength because the epoxy resin had reacted well with the hydroxyl ions from cement hydrate, which ultimately produced a denser and more durable mortar.

**Tensile Splitting Test**

Results of the tensile splitting strength test of all specimens are shown in Figure 2. From the graph, the tensile strength of normal mortar is lower than epoxy modified mortars. The 10 % epoxy resin show the highest tensile strength for specimens that were exposed to wet-dry curing condition, but any addition beyond 10 % had lowered the tensile strength. Again, this was attributed to the improvement in cement hydrate and polymer.

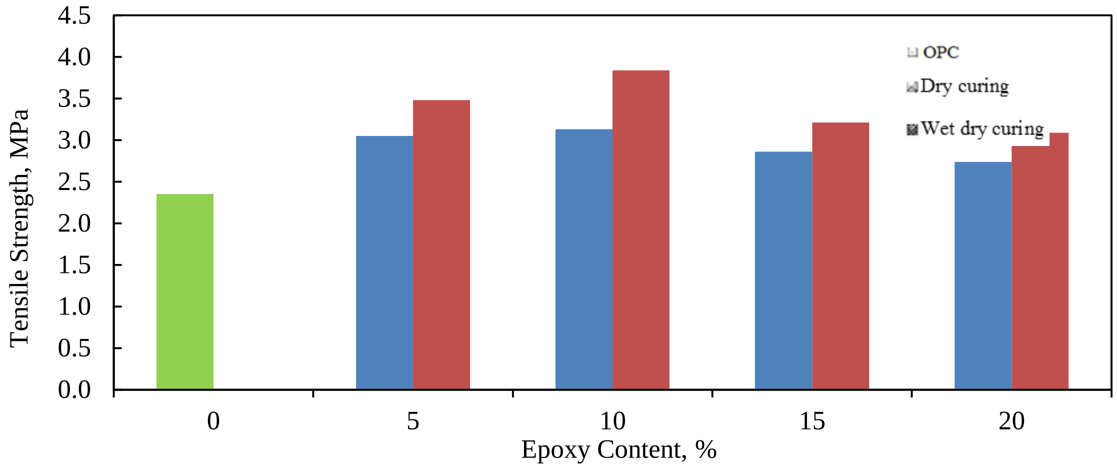


Figure 2: Relationship between tensile splitting strength and epoxy content.

**Compressive strength**

Figure 3 exhibits the different contents of epoxy resin in mortar under wet-dry curing, which has been added to the mortar to study its effect on compressive strength

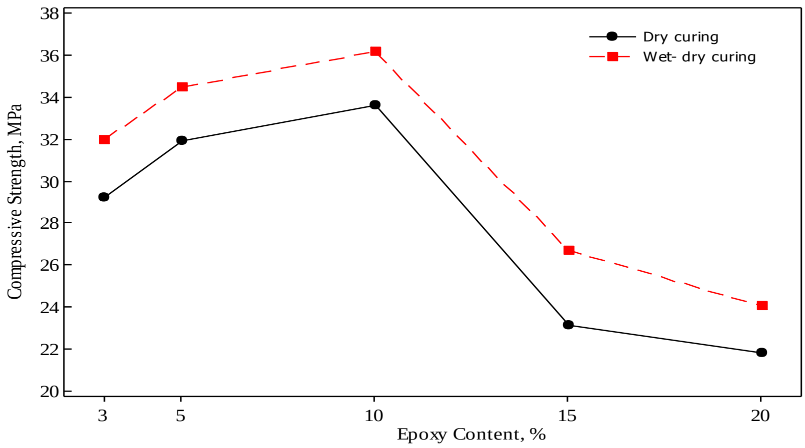


Figure 3: Relationship between compressive strength and epoxy content at 28 days in wet-dry curing condition.

. It is obvious from Figure 9 that wet-dry curing lead to a higher compressive strength compared to dry curing.  The phenomenon could probably be caused by the natural characteristic of cement where it needs water at early stage to initiate the hydration process. Wet-dry curing provided a suitable condition for hydration process to occur but in dry curing, the specimens only exposed to dry condition which is impossible for hydration process to be completed. Moreover, wet-dry curing provided the optimum condition for both hydration and polymerization processes to occur.  In this case, the amount of hydroxyl ions was enough and sufficient to react with epoxy resin and strengthen the mortar.

The compressive strength of normal mortar was 30 MPa at 28 days while the compressive strength of the 10 % epoxy resin was 36 MPa, which was the highest strength among all epoxy contents and higher than the strength of normal mortar. The increase in epoxy resin beyond 10 % has decreased the compressive strength probably due to the presence of epoxy resin that was not hardened and disturbs the bonding between hydroxyl ion and epoxy resin, which had been previously reported by Ohama et al. [13]. According to Ohama and Takahashi [14], the reductions in the flexural and compressive strengths of the polymer-modified mortars using epoxy resin without the hardener at polymer-cement ratios of 10 % or more may be explained by the presence of considerable amount of epoxy resin which cannot harden in the polymer-modified mortars. The unhardened epoxy resin become excessive and lowers the compressive strength of the mortar. Therefore, 10 % epoxy ratio was taken as the optimum content as to be used without hardener which gives higher compressive strength and was applied to others tests.

**Strength Development**

Figure 4 shows the strength development of epoxy-modified mortar in the period of one year of further dry-curing.

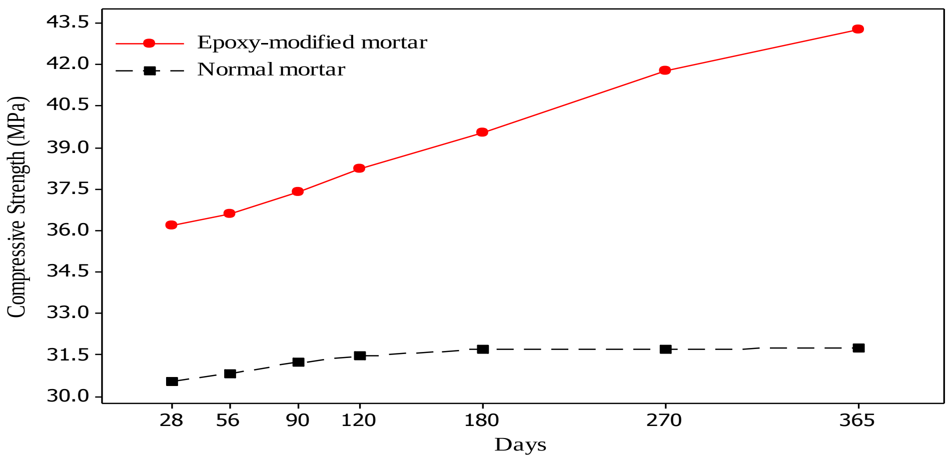


Figure 4: Strength development of epoxy-modified mortar with prolong dry-curing.

From the Figure, the strength development of epoxy-modified mortar keeps increasing after 365 days of curing. The initial compressive strength of epoxy-modified mortar was 36 MPa however, after 365 days; the compressive strength was 44 MPa. This trend shows that the increase of 25 % of compressive strength was recorded. On the other hand, for the normal mortar after 180 days curing, the compressive strength starts to be constant. No further increase in compressive strength was recorded. This phenomenon occurs to epoxy-modified mortars due to further reaction between epoxy resin and hydroxyl ion. The reaction between unhardened epoxy resin and hydroxyl ions has produced a denser and stronger mortar.

**Relationship between Strength Development and Porosity**

Porosity of the mortars highly influences the strength of mortar. The reduction of porosity in concrete will increase its strength as it make a concrete and mortar denser [15]. Figure 5 shows the result of strength development and apparent porosity of 10% epoxy content with wet-dry curing. This epoxy content and curing regime was selected as it gives a higher compressive strength and suitable condition for hydration and polymerization process.

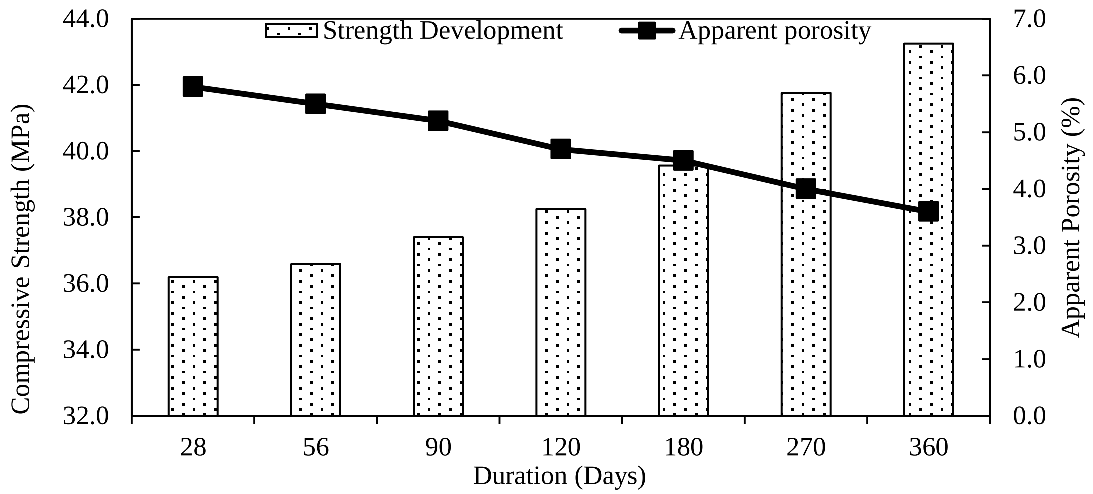


Figure 5: Relationship between compressive strength and porosity of 10% epoxy content with duration.

As shown in Figure 5, the 28 days apparent porosity was recorded at 6 % while the strength was 36 MPa. Prolonged curing period has shown to lower the porosity and increases the strength of mortar. After 365 days curing, the porosity was 3.7 % and the compressive strength was 44 MPa. The decreasing of porosity at 365 days was recorded almost 40 % of its initial porosity. In the meantime, the compressive strength increased 20 % from initial strength. The epoxy resin without hardener added into the mortar mixture was active even in dry condition that produces higher compressive strength and closes the pores within. The results of the test indicated that the epoxy resin without hardener can be used as an additive in mortar.

## CONCLUSIONS

The conclusions that can be drawn from the study are as follows:

1. The optimum amount of epoxy content that produced the highest compressive strength, flexural strength, and strength development was 10 %. The recorded compressive strength and flexural strength at 28 days were 36 MPa and 3 MPa, respectively.
2. The most suitable curing regime for epoxy-modified mortar is wet-dry curing; it provides a good condition for the hydration process of cement and polymerization process of epoxy to occur.
3. The trend of strength development of the 10 % epoxy-modified mortar kept increasing after 360 days of curing and the decreasing of porosity recorded almost 40 % of reduction.

## ACKNOWLEDGEMENT

The authors are grateful to the Ministry of Education (MOE), Universiti Teknologi Malaysia (UTM) and Research Management Centre (RMC), UTM for the financial support towards the research project; QJ1300000.2509.06H56 and QJ1300000.2517.07H32. The authors are also thankful to the technical staff of Structures and Materials laboratory for the facilities provided for experimental works. Special thanks to Sustainable Building Material Construction Lab, Hanyang University, South Korea for the facilities and testing provided.

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