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Strength properties and molecular composition of epoxy-modified mortars

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HIGHLIGHTS

- Addition of epoxy resin without hardener.
- Epoxy resin enhanced the mechanical properties of mortar.
- Epoxy-modified mortar increased strength with prolonged curing period.

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ABSTRACT

Even without hardener, epoxy resin is able to harden in the presence of hydroxyl ions produced during cement hydration process. In this study commercially available Bisphenol A-type epoxy resin without hardener was used as a polymeric admixture to prepare epoxy-modified mortars, whose properties and chemical composition were then investigated. The mortars were prepared with a mass ratio of 1:3 (cement:fine aggregate), water-to-cement ratio (W/C) of 0.48, and epoxy content of 5%, 10%, 15% and 20% of cement. The specimens were subjected to dry and wet–dry curing. Workability, setting time, compressive strength, flexural strength, and tensile splitting strength tests were conducted. A Fourier transformation infrared spectroscopy test was also administered to determine the molecular composition and structure of mortars. Results showed an inverse relationship between workability and setting time of mortars versus epoxy content. The compressive, flexural, and tensile splitting strengths of epoxy-modified mortars were noted to be the highest for mortars containing 10% epoxy in wet–dry curing. A significant improvement in strength development of mortars without hardener had been achieved through dry curing due to gradual hardening of epoxy resin with hydrated cement.

1. Introduction

High adhesion and chemical resistant properties of epoxy resins have led to their extensive usage as adhesives and corrosion-resistant paints in the construction industry. They are also used as an admixture in concrete to impart certain effects on mortars. However, the preparation of conventional polymer-modified mortars using epoxy resins cannot be realized without the use of hardener [1]. A previous study by Kakiuch [2] showed that epoxy resins can harden in the presence of alkalis whereby the authors succeeded in developing polymer-modified mortars using epoxy resin without any hardener. The aforementioned application was countered by Ohama [3] who posited that epoxy resin without hardener, in concrete and mortar at ambient temperature has lower rate of hardening and strength. In order to overcome that problem, an autoclave curing and steam curing process was used to bring about early strength development of epoxy-modified mortar and concrete. In contrast, the study reported in this paper found that applying ambient curing temperatures to the epoxy-modified mortar resulted in achieving the required strength of mortar. The recent study about the epoxy resin without hardener was reported by Jo [4]. The author stated that, the properties of epoxy cement mortars without hardener

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improved fairly when compared to epoxy mortar with hardener. This is due to the cross-linking of an epoxy resin in the environment of Portland cement that have accessibility to react with calcium hydroxide without the presence of hardener [5].

Beside mechanical properties, the molecular structure of epoxy-modified mortar is also important as it shows the reaction inside the concrete when epoxy resin was added. How epoxy resin would perform without added hardener can be analyzed through an experiment. For in-situ monitoring processes such as curing, phase separation or even ageing, the interpretation of the spectra and assignment of the bands are critical. Fourier transformation infrared spectroscopy (FTIR) has been widely used for the characterization of organic compounds for which reliable information and spectra can easily be located.

In the reported research, polymer-modified mortars using epoxy resin without hardener were prepared with various epoxy-cement contents; they were then tested for compressive strength and flexural strength. Normal ordinary cement mortars were also prepared and tested in the same manner as control specimens.

2. Experimental

2.1. Materials

2.1.1. Cement

The cement used in the study was ordinary Portland cement (OPC) obtained from Holcim Cement Manufacturing Company of Malaysia, conforming to ASTM C150 [6] standard. The chemical properties of the cement obtained from X-Ray Fluorescence (XRF) analysis test are given in Table 1. From the analysis, it shows that the highest constituent in Portland cement is calcium oxide which is 62% followed by silica oxide with 20%. Alumina and iron oxide give the percentage of composition of 6% and 3%, respectively. Fig. 1 shows the morphology of Field Emission Scanning Electron Microscopy (FESEM) picture of cement hydrate. Cement is generally comprised of various calcium silicates (alite, belite, etc.), tri-calciumaluminate and tetra-calcium aluminoferrite.

2.1.2. Fine aggregate

Local river sand with specific gravity of 2.62 and fineness modulus of 2.85 in saturated surface dry condition was used. The fine aggregate was oven-dried and then wetted until saturated surface-dry condition was reached.

2.1.3. Epoxy resin

Diglycidyl Ether of Bisphenol A-type epoxy resin was used in the proportion mixture as shown in Fig. 2. The epoxy resin was stored at room temperature to avoid damage. The amount of epoxy resin added in the mix was in the range of 5–20% of total cement content. The properties of pure epoxy resin are given in Table 2. The Diglycidyl Ether of Bisphenol A-type was chosen as the viscosity of epoxy resin must be high in order for it to react with cement phase. As mentioned earlier in the text, the epoxy resin used did not contain any hardener. The viscosity test of epoxy resin was conducted using Digital Brookfield Viscometer (20-2million cP) in accordance to ASTM D2983-09 [7]. The result showed the viscosity of epoxy was 10,000 Pa s.

2.2. Experimental procedure

2.2.1. Preparation of epoxy-modified mortar

The design mix of epoxy-modified mortar basically followed that of ordinary cement mortar and concrete. With reference to JIS A 1171 [8] the hardener-free epoxy-modified mortars were mixed with a mass ratio of 1:3 cement to fine aggregate; epoxy content of 5%, 10%, 15% and 20% of cement; and a water–cement ratio of 0.48. The flow diameters of the mortars were in the range of 170 ± 5 mm. Mortar cube specimens of 70 × 70 × 70 mm were cast for compressive strength test and prism specimens of 40 × 40 × 160 mm were cast for flexural test. For tensile splitting test cylindrical specimen sized 150 mm in height and 70 mm in diameter was used.

All specimens were subjected to dry and wet–dry curing for 28 days. Normal mortar was prepared as a control specimen. Table 3 shows the mix proportion of epoxy-modified mortar.

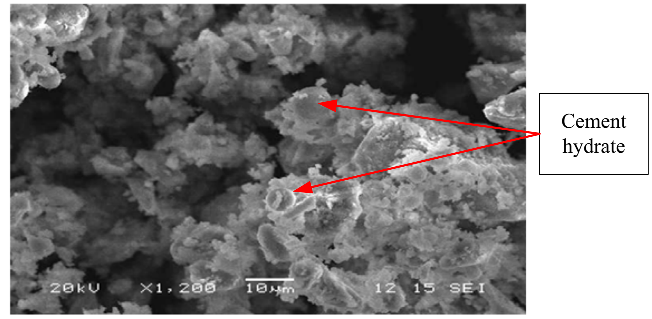

Fig. 1. FESEM morphology of cement hydrates without epoxy resin.

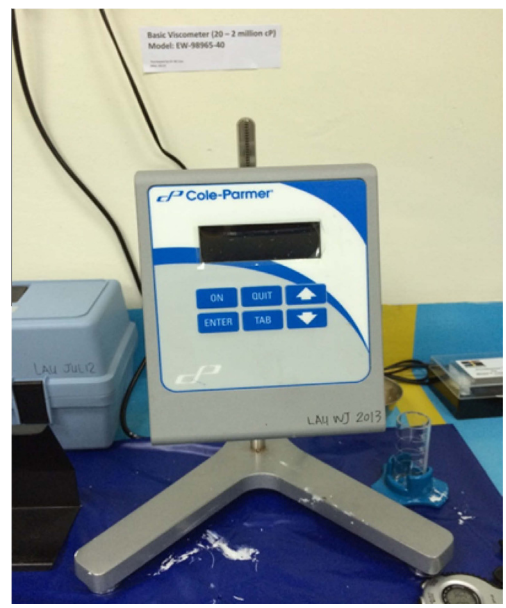

Fig. 2. Digital Brookfield Viscometer for epoxy resin viscosity test.

Table 1
Chemical composition of ordinary Portland cement.

Constituent	Percentage by weight (%)
Silica, SiO_2	19.8
Alumina, Al_2O_3	5.6
Iron oxide, Fe_2O_3	3.4
Calcium, CaO	62.7
Magnesia, MgO	1.2
Sodium, Na_2O	0.02
Phosphorus, P_2O_5	0.1
Loss of ignition, LOI	2.1
Lime saturated factor	1.0

Table 2
Properties of epoxy resin.

Epoxy equivalent	Molecular weight	Density (g/cm^3, 20 °C)	Viscosity (Pa s, 20 °C)	Flash point (°C)
184	380	1.16	10,000	264

Table 3
Mix proportion of epoxy-modified mortar.

Sand (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)	Epoxy content (%)	Water/ cement	Sand:cement
1517	506	228	0 5 10 15 20	0.48	3:1