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Fundamental properties of epoxy resin-modified cement grouts

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HIGHLIGHTS

- Epoxy resin was used in thick superplasticised cement grouts.
- Epoxy resin improved final strength, toughness, bleeding and resistance to acid erosion.
- Epoxy resin increased viscosity, yield stress and setting time.

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ABSTRACT

The use of additives to improve the quality of cement grouts and their effects on strength, durability and resistance to chemical erosion of grouted soil or rock mass is crucial for geotechnical engineering, especially in foundation construction. The main objective of the current laboratory project was to comprehensively investigate the potential use of a two-component water soluble epoxy resin to improve the properties of thick superplasticised cement grouts. The experiments were conducted using different epoxy resin dosages with cement grouts proportioned with a water to cement ratio of 0.5, 0.4 and 0.33. The results indicated that the addition of epoxy resin increases the 28- and 90-day compressive strength, splitting tensile strength and elastic modulus by up to 21%, 84% and 190%, respectively, despite the extension of the setting time. Additionally, the toughness, stability and resistance to acid attack of epoxy resin-modified grouts appeared to improve significantly. On the other hand, grouts containing epoxy resin exhibited higher viscosity and yield stress values ranging from 0.09 to 0.67 Pa s and 10–45 Pa, respectively. This has to be considered when the viscosity of the grout is essential.

1. Introduction

The use of a wide range of additives and admixtures in cement-based grout formulations is crucial for grouting practices. They play an important role in the production of more durable grouts than could be obtained using pure cement suspensions and increase the effectiveness of grouting [1–4].

Various chemical admixtures such as superplasticisers, accelerators, antifreezers, air entraining agents, stabilizers and many others are utilized to modify the grout properties according to the in situ conditions and grouting purpose [5–13]. In recent years, powdered emulsions and water-soluble polymers such as ethylene vinyl acetate, styrene butadiene rubber and polyacrylic ester have been incorporated in cement mixtures because of their potential influence on rheological properties [14], strength [15], durability [16], impermeability [17] and resistance to chemical erosion [18]. Polymer-modified grouts or cement pastes show a noticeable increase in mechanical properties due to the strong binding between the cement hydrates and the formed polymer films and membranes [19–21].

Epoxy resin systems, especially water-soluble epoxy resins, are one of the principal resins used for the production of polymer-modified concretes and mortars. These can be used by themselves or in combination with cement for suitable solutions in construction or building restoration [22,23]. In particular, epoxy resins have the following advantages: (1) they increase workability and reduce segregation as well as bleeding; (2) they increase compressive, flexural and tensile strengths; (3) they increase ductility; (4) they reduce permeability and chloride-ion penetration; (5) they reduce shrinkage; (6) they increase the resistance to freezing and thawing; and (7) they increase resistance to acid erosion.

Although numerous studies [23–26] have been conducted concerning epoxy resin-modified concretes, there is no information

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available about the effect of epoxy resin on the properties of thick cement grouts. The experimental project reported herein studies epoxy resin-modified grouting material for ground improvements. A series of laboratory tests were performed to investigate the influence of epoxy resin on the physical and mechanical properties of thick superplasticised cement grouts of different water to cement (w/c) ratios.

2. Materials and laboratory methods

The experiments were carried out using a common type of Portland fly ash-pozzolan cement (CEM II/B-M 42.5 N) with sulfate resistance properties and a low heat of hydration. It has a specific gravity of 3.15 and a blaine fineness of approximately 4600 cm^2/g.

A polycarboxylate ether-type (PCE) high range water reducer was selected as the superplasticiser. Its properties are presented in Table 1.

The epoxy resin (ER) that was used is a commercial product that is widely distributed in Greece. It is water-soluble and composed of two components: epoxy resin based on diglycidyl ether of bisphenol-A (A) and an aliphatic amine-based hardener (B). The optimum mixture ratio by weight of components A (epoxy resin) and B (hardener) is A:B = 2.5:1. According to the manufacturer, without the addition of water, the epoxy resin attains its final strength after 7 days. The unconfined compressive strength reaches a maximum value of 70 MPa, and the flexural and adhesive strengths are in excess of 35 and 3 MPa, respectively.

Grouts were prepared with w/c ratios of 0.5, 0.4 and 0.33. The superplasticiser dosage (by cement mass) for the various grouts corresponded to the saturation dosage. The saturation dosage is considered to be the optimum superplasticiser dosage for a given cement paste, beyond which further addition of superplasticiser does not increase the fluidity significantly but can produce segregation. For all grouts with different w/c ratios, the optimum dosages were determined by using the Marsh cone test [27–29] and are presented in Table 2 along with the corresponding flow time. The water content of the superplasticiser was accounted for to maintain a constant w/c ratio. To study the effect of the epoxy resin-cement ratio on the various properties, grouts were proportioned by varying the epoxy resin to cement ratio from 0 to 30% by cement mass (Table 2).

All grouts were mixed using the high rotating mixer recommended in ASTM C938-10. Initially, appropriate amounts of cement, water and superplasticiser were thoroughly mixed for 5 min. Afterwards, the required amount of ER, whose two components were mixed in a separate container, was added to the grout, and the resulting mixture was blended for a few minutes to achieve a uniform mixture [30].

The grout setting time was investigated by conducting Vicat needle tests according to ASTM C953-10.

Bleeding was measured by conducting sedimentation tests according to ASTM C940-10.

Strength development was evaluated from compression and splitting tensile tests on specimens cured for 3, 7, 28 and 90 days.

Table 1
Properties of superplasticiser used in the study.

	PCE
Aspect	Slightly yellow
Specific gravity	1.05
pH	6.3 ± 0.5
Chloride ion content	Chloride free
Solid content	40%
Molecular mass	44,000 g/mol
Recommended dosage (% by cement weight)	0.6–1.4

Table 2
Composition of the tested grouts.

Designation	Proportion (w/c)	Superplasticiser (%)	Epoxy resin (%)	Marsh cone flow time (s)
G_1	0.5	1	0	7
		1	5	–
		1	10	–
		1	20	–
		1	30	–
G_2	0.4	1.5	0	8.5
		1.5	5	–
		1.5	10	–
		1.5	20	–
		1.5	30	–
G_3	0.33	2.5	0	10.5
		2.5	5	–
		2.5	10	–
		2.5	20	–
		2.5	30	–

Compression tests were performed on cubic specimens with an edge of 50.8 mm at an axial strain of 0.1%/min. The elastic modulus was calculated from the elastic part of the compressive stress-strain curve according to ASTM C469-10. Splitting tensile tests were conducted following the instructions of ASTM D3967-05 on cylindrical specimens with a thickness to diameter ratio of 100 mm/50 mm. The storage and curing of the specimens followed the suggestions provided by ASTM C109-12.

The resistance to acid attack was determined according to ASTM C 267-01. After 28 days of curing in water, the grout beams were submerged in a 10% H_2SO_4 solution for 7 days to determine the resistance to acid erosion. Afterwards, they were taken out of the solution to be washed with water and record their weight changes [31]. The weight change ratio was calculated as follows:

$$\text{Weight change ratio} = \frac{M_1 - M_2}{M_1} \times 100 \tag{1}$$

where M_1 is the weight of specimen before immersion and M_2 is after immersion. The reported weight loss is the average of three samples.

The rheological flow curves and viscosities of the epoxy resin-modified or un-modified grouts were obtained using a capillary tube viscometer to record the shear stress-shear strain rate relationship [32,33]. The capillary viscometer method was selected instead of the classical rotational viscometer method, which is commonly used because it is necessary to determine the flow properties of the grouts under conditions similar to those in situ and evaluate the test results in such a way that reliable data can be obtained. To conduct the rheological experiments, a special facility was constructed. This facility consisted of a mixing tank with a high speed rotating stirrer, air compressor, pressure and flow meters, and a test section of 1-m-long plastic tubing with an internal diameter of 5 mm (Fig. 1) with smooth interior walls to maintain perfectly laminar flow. The grout was allowed to flow through the pipe at the desired steady pressure for each test, and the resultanting flow rate was recorded. The shear stress τ and the shear strain rate $\dot{\gamma}$ were calculated by considering the Hagen-Poiseuille law as follows:

$$\tau = \frac{\Delta P}{L} \cdot \frac{R}{2} \tag{2}$$

$$\dot{\gamma} = \frac{4 \cdot Q}{\pi \cdot R^3} = \frac{4 \cdot V_{ave}}{R} \tag{3}$$

where ΔP is the pressure drop across the capillary tube. R and L are the inner radius and length of the capillary tube, respectively. Q is