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Effect of different superplasticisers on the physical and mechanical properties of cement grouts

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HIGHLIGHTS

- Polycarboxylate ether (PCE) and polynaphthalene (SNF) based superplasticizers were used in grouts.
- PCE improved final strength and decreased yield stress.
- PCE increased viscosity, final setting time and bleeding.

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ABSTRACT

The use of superplasticisers in microfine or regular cement-based grouts has become of vital importance in advanced professional grouting practices. These superplasticisers play an important role in the production of more durable grouts with improved rheological characteristics. This report presents a laboratory study of the effects of a new-generation polycarboxylate superplasticiser (PCE) on the rheological properties, mechanical strength, final setting time and bleeding of cement grouts in comparison to that of a polynaphthalene superplasticiser (SNF). The experiments were conducted using different superplasticiser dosages with cement grouts proportioned with a water to cement ratio (w/c) of 0.33, 0.4 or 0.5. The results showed that grouts with PCE had higher viscosity, slightly increased bleeding and longer setting times compared with the SNF admixture. However, the PCE improved the final strength, especially for grouts with a w/c ratio of 0.4 and 0.5, and decreased the yield stress.

Introduction

Cement-based grouts are widely used in many construction domains [1], such as grouting of soil or rock, injecting cracks in massive concrete structures or masonries, coating pre-stressed cables, stabilising ground near tunnels [2], fixing reinforcing elements (e.g., cables) in pre-stressed concrete structures or rock pre-stressing anchors, and rehabilitating old defective masonries in historical buildings [3,4]. The strength of a grout is important whenever the purpose of the grouting is to strengthen the ground or an existing concrete structure. The ratio of water to cement (w/c) is the most significant factor that affects the strength of the grout. Consequently, the use of grouts with low w/c ratios necessitates the addition of a superplasticiser to obtain the appropriate rheological properties of the suspension so that grouts are able to flow sufficiently in boreholes, formation pores, and rock joints and ensure grouting effectiveness. Superplasticisers belong to the most common admixtures used in the production of concrete with high workability, excellent slump retention, high strength and durability. Particularly, superplasticisers have the following advantages: (1) They reduce water demand up to 30% when added during the preparation of concrete, and the resulting water/cement ratio significantly increases both initial and final strength; (2) They improve workability significantly without the need of additional water when added to the ready-mixed concrete; (3) They contribute to better hydration of cement; (4) They facilitate compaction of concrete, reduce segregation and bleeding and improve pumpability; (5) They reduce setting shrinkage (crack prevention) and creeping; (6) They improve water impermeability, resistance to carbonation and chloride ion attack, freezing and thawing durability, and adhesion between steel and concrete; and (7) They are compatible with all types of Portland cement. Currently, the most widely used superplasticisers are sulphonated naphthalene formaldehyde (SNF) condensates and a new-generation polycarboxylate-based dispersants (PCE) composed of comb-like copolymers with grafted chains of polyethylene oxide. The dispersion mechanism of the SNF superplasticiser occurs because the adsorption of the SNF anionic polymers can convey a net

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negative electrical charge to the surface of the cement particles, which induces repelling forces between neighbouring cement particles and causes increased dispersion [5,6]. However, the dispersion mechanism of a PCE superplasticiser is mainly attributed to steric forces, which are dominant for a copolymer and consist of one main linear chain with lateral carboxylate and ether groups [7–9]. Steric forces provide a higher dispersive action compared to electrostatic forces [10]. Although numerous studies have been conducted concerning the use of both dispersion mechanism admixtures for the production of concrete or mortar [11–14], there is minimal information available on the effect of the polycarboxylate ether type of superplasticiser on various physical and mechanical properties of cement grouts, which are directly related to the effectiveness of the grouting operation.

The overall goal of this study was to investigate the effect of a PCE dispersant on the rheological properties, setting time, strength development and bleeding of cement grouts in comparison to those of a SNF superplasticiser.

Materials and laboratory methods

The experiments were conducted using a common type of Portland cement (CEM I 32.5 N, according to EN 197-1), various w/c ratios of 0.33, 0.4 and 0.5, and two types of high-range water reducers (HRWR). The two types of HRWR were a polynaphthalene-based superplasticiser as well as a polycarboxylate ether-type superplasticiser (main chain consisted of a copolymer of methacrylic acid with lateral carboxylate and ether groups). Both superplasticisers are commercial products with the trade name Adium 110 (PCE) and Sikament 240 (SNF) and are distributed by Isomat SA and Sika AG, respectively. Their properties are presented in Table 1. The HRWR dosages (by cement mass) are summarised in Table 2. The water content of the superplasticisers was accounted for to maintain a constant w/c ratio. The w/c ratios and dosages of the superplasticisers were varied to maintain proper setting times and bleeding values, which are proposed by the European Standard EN 12715 and grouting practices, as discussed more thoroughly in the following sections.

All grouts were mixed using a three-blade paddle high rotating mixer suggested in ASTM C938-10. This high-shear mixing regime was used to ensure the complete dispersion of the cement particles. The addition of the superplasticiser in the grout was performed using the delayed addition method. Particularly, after 5 min of stirring cement and distilled water in the mixer and 2 min of static hydration, the appropriate dosage of superplasticiser was added into the grout. Then, an additional mixing sequence was performed for a total time of at least 2 min. The selection of this method for preparing superplasticised grout is because the delayed addition of superplasticiser in cement suspensions significantly enhances the efficacy of its dispersing power in comparison to the direct addition [15–20]. In the latter case, a higher quantity of superplasticiser becomes entrapped (adsorbed) in the early-forming hydrate products of tricalcium aluminate (C_3A) and, consequently, loses a part of its dispersing action. A detailed study by Uchikawa [21] depicted the comparison between the effects of direct addition and delayed addition of superplasticiser on the adsorption of the superplasticiser and the fluidity of the grout. By using electron spectroscopy, the study measured the thickness of the hydrates formed on a polished clinker surface, which was immersed into a solution of SNF superplasticiser. In the case of simultaneous superplasticiser addition, the adsorbed hydrate layer thickness of tricalcium silicate (C_3S) and C_3A was approximately 50 and 300 nm, respectively. When the addition of the superplasticiser was delayed, the thickness of the adsorbed hydrates was 20 nm for both C_3S and C_3A. This result corresponded to the thickness of the adsorbed polymer, which indicated that the molecules were not overgrown.

The grout setting time was investigated by conducting Vicat needle tests according to ASTM C 953-10.

Table 2
Dosages of superplasticizers on various grouts.

Proportion	SNF (%)	PCE (%)	Designation
w/c = 0.5	0.5	0.5	G_1
	0.75	0.75	G_2
	1	1	G_3
w/c = 0.4	0.75	0.75	G_4
	1	1	G_5
	1.5	1.5	G_6
w/c = 0.33	1.5	1.5	G_7
	2.5	2.5	G_8
	3.5	3.5	G_9

The strength development was measured from unconfined compression tests on cubic specimens with an edge of 50.8 mm that were performed 3, 7 and 28 days after grout preparation. The storage and curing of specimens were conducted using suggestions provided by ASTM C 942-10 and ASTM C 109-12, respectively. Particularly, immediately upon completion of moulding, test specimens were placed in a moist room with a temperature of 23 °C and relative humidity of 95%. After 24 h of curing, the specimens were demoulded and immersed in saturated limewater in a storage tank until required for testing. A BETA 5 loading machine (FORM + TEST PRÜFSYSTEME) with a maximum capacity of 300 KN was used for compression testing at an axial strain of 0.1%/min. The elastic modulus was determined from the linear section of the compressive stress–strain curve. Each of the reported compressive strength and elastic modulus values correspond to the average value of at least three specimens that have strength values that deviate no more than 10% from the average value of all tested specimens made from the same grout mixture.

Bleeding was investigated by conducting sedimentation tests according to ASTM C 940-10.

The rheological flow curves and viscosities of the superplasticised grouts were determined using a capillary tube viscometer recording the shear stress–shear rate relationship [22–24]. 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 are obtained [25–27]. Another advantage of the capillary viscometer, which was taken into account for this choice, is the functional dependence of shear stress on shear strain in a wide range of these variables in contrast to the limited shear rate range of rotational viscometers. The rheological measurements were completed between 10 and 12 min after the initial contact of cement with water.

To conduct the rheological experiments, a pipe-flow facility was constructed (Fig. 1). This facility consisted of a mixing tank (capacity of 100 l) with a high speed rotating stirrer, air operated double diaphragm pump, air compressor, pressure and

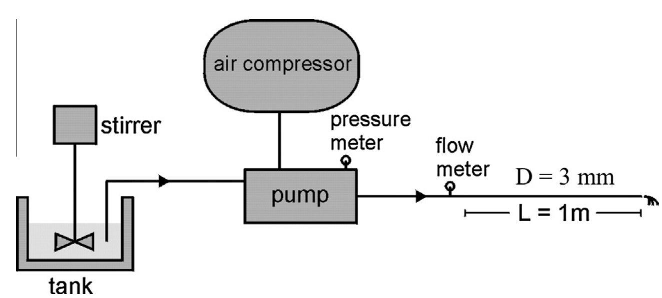

Fig. 1. Device for pumping grouts through capillary tube.

Table 1
Properties of superplasticizers used in the study.

	Polycarboxylate ether	Sulphonated naphthalene formaldehyde
Aspect	Slightly yellow	Dark brown
Specific gravity	1.05	1.2
pH	6.3 ± 0.5	6–8
Chloride ion content	Chloride free	Chloride free
Maximum alkali content:	⩽2% by weight	⩽8% by weight
Solid content	40%	40%
Molecular mass	44,000 g/mol	16,000 g/mol
Recommended dosage	0.6–1.4% by cement weight	0.5–2% by cement weight