



Experimental investigation into the compressive strength development of cemented paste backfill containing Nano-silica



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ABSTRACT

This paper investigates the influence of Nano-silica (NS) addition on the consistency and compressive strength development of cemented paste backfill (CPB). Tetraethyl-Orthosilicate (TEOS) was used as the precursor of Nano-silica along with ether-based Polycarboxylate superplasticizer (PCS). Two binder types (Portland cement and Slag-cement) and different amounts of TEOS (0.7–14% by mass of binder) with and without PCS are examined for 3, 7, 14, and 28 days curing time. Uniaxial compression tests for unconfined compressive strength (UCS) determination, slump height measurement, changes in gravimetric water content, and differential thermogravimetric analysis (DTG) were used to assess the influence of NS and admixtures (TEOS-PCS) on CPB performance. The results of this experimental study indicate that the addition of approximately 5% TEOS along with 0.5% PCS (by mass of binder) provide the best compressive strengths that can also be anticipated through the higher amount of calcium silicate hydrate (C–S–H) on DTG curves. It is also noticeable that the positive influence of NS is more evident when the amount of binder was decreased. The addition of PCS to CPB containing NS improved both the consistency of the mixture and the compressive strength development of CPB.

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1. Introduction

Nowadays, use of nanoparticles in different applications interests many researchers due to the enhanced performance and sustainable features [1,2]. Even though different nanoparticles such as Nano-silica (NS), Nano-titanium, carbon nanotubes, and Nano-alumina exist, use of Nano-silica has reportedly been more extensive in cementitious materials [3–8].

Tetraethyl-Orthosilicate (TEOS) and Tetramethyl-Orthosilicate (TMOS) are the mostly used precursors for producing Nano-silica in cementitious materials [9]. Growth of nanoparticles by using such precursors basically occurs through the sol-gel process in which a precursor solution (sol) hydrolyzes and converts into an inorganic solid (silica gel) via inorganic polymerization (condensation) [10]. Chemical reaction that produce Nano-silica (silica gel) from TEOS precursor is illustrated in Fig. 1a [11].

As a highly pure pozzolanic material with high specific surface,

NS affects the cementitious materials by accelerating the hydration and pore volume filling [4,5] and reaches the maximum pozzolanic effect after three days of curing [12]. Because of pozzolanic effect and due to the molecular reactivity with hydroxides, NS reacts with calcium hydroxide or portlandite (CH) crystals to form calcium silicate hydrate (C–S–H) gel (Fig. 1b); hence, the amount of CH crystals decreases at early ages of hydration [13–16]. The effectiveness of NS to react with calcium hydroxide is due to its molecular reactivity with hydroxide groups (OH) on the surface of cement or other hydroxide minerals produced from cement hydration [17]. Hydrolysis of TEOS produces the OH groups at the surface of silica (silanols or SiOH in Fig. 1a) that can react with the CH to produce C–S–H gel (pozzolanic reaction); typical structure of this reaction is plotted in Fig. 1b [18]. By filling the Nano-pores of C–S–H and gaps between the aggregates and cement particles, NS improves the solidification and compactness [13,19] while it also decreases the water bleeding and segregation of cementitious materials by improving the cohesiveness at early ages [20,21]. However, nanoparticles are extremely susceptible to agglomeration, which is resulting in weaknesses of cementitious materials. Thus, use of any complementary materials (admixtures) such as

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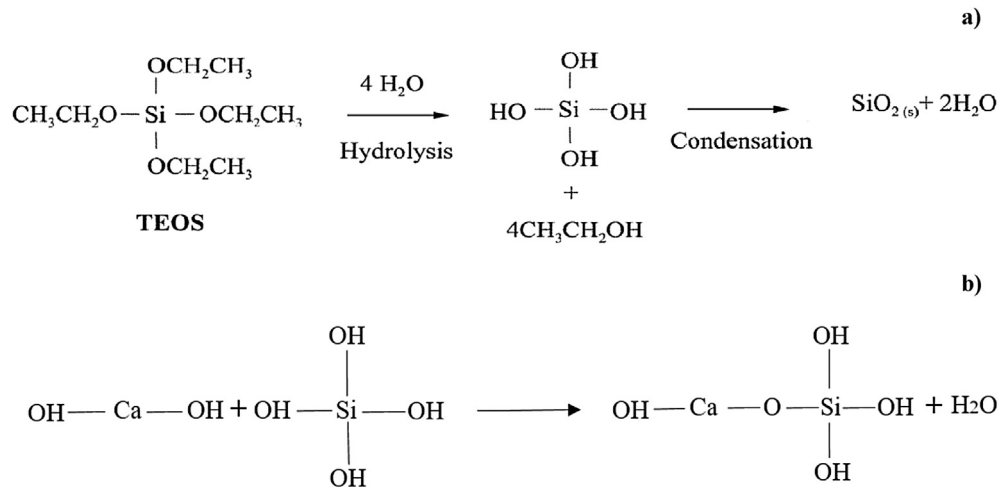


Fig. 1. a) Chemical reaction scheme of Tetraethyl-Orthosilicate, b) Typical pozzolanic reaction of TEOS and CH.

superplasticizer improves the dispersion of nanoparticles in cementitious materials [6,13,19–26]. Superplasticizer adsorbs to the cement particles and releases the trapped water by causing electrostatic-electrostatic/repulsive forces (such forces are generally ascribed to van der Waals forces). This phenomenon improves the workability of the mixture while facilitating the dispersion of nanoparticles through the mixture as well [7].

As an innovative mine tailings management technology, cemented paste backfill (CPB) can return up to 50% of the total produced tailings stream to underground mine stopes. Tailings are generated from mineral processing plant after the recovery of valuable parts of minerals such as metals. The aim of backfilling is to act as a secondary ground support while minimizing the environmental impact by reducing the amount of waste storage from the surface [27–29]. CPB consists of dewatered mill tailings (72–85 wt% solid content and corresponding water content of 38–18%), and a binding agent such as Portland cement or a combination of cement and pozzolanic materials (2–10 wt% by dry mass of tailings) [27–29]. Depending on the type of binding agent, mineralogy of the tailings and curing time, unconfined compressive strength (UCS) of CPB varies between 0.2 and 4 MPa [30–32]. It has been shown that any increase in the amount of binder in CPB, elevates the UCS values almost linearly [26]. In addition, the self-weight consolidation of CPB because of water drainage and/or bleeding (in backfilled stope) can increase or improve the UCS value. Since CPB is delivered from the surface of a mine to the underground stopes (by gravity or pumping), it should have a proper fluidity/consistency (estimated through slump height measurement using Abrams cone) [33]. Usually, a slump height of about 180 mm (≥ 7 inches) provides adequate fluidity to CPB which is delivered by pumping [34]. In order to reach the targeted fluidity for CPB's pipeline transport, additional water is often added to the mixture, hence the availability of water become very high (water/binder ≥ 3), which is not ideal for hardening.

To our knowledge, there is no published data regarding the influence of produced NS from TEOS on the properties of cemented paste backfill. Thus, this study attempts to highlight the benefits of NS as a pozzolanic material, especially when mixed with superplasticizer. The authors believe this combination can solve multiple problems in the case of paste backfill. Indeed, Nano-silica can improve the compressive strength of CPB, specifically at early ages of hydration while the addition of superplasticizer can also reduce the water consumption. While the targeted UCS value after 28 days of curing is around 500 kPa, CPB materials mostly will not

strengthen sufficiently at short period (especially for the first week) [27,35]. Hardening and strength development of CPB at early ages of curing can allow continuous backfilling and hence a possible reduction in binder consumption. Consequently, this can reduce the backfilling operating costs of a mine where the filling process is carried out in two different stages (a plug fill and a residual fill). A plug-fill of few meters' height (containing more than 5% binder by dry mass of tailings) is first poured into the open stope followed by the residual fill pouring (containing less than 5% binder by dry mass of tailings). Most of the time the plug-fill is left at rest between 1 and 3 days prior to the residual filling in order to avoid excess pressure on the barricade (backfill retaining structure); this fact emphasizes the importance CPB's early strength development. The backfilling procedure accounts for 10–20% of the total operating cost of a mine from which the binder cost represents up to 75–80% of that cost [36,37].

In this study, the influence of Nano-silica (NS) and Polycarboxylate superplasticizer (PCS) was assessed through the compressive strength development and slump height changes. Differential thermogravimetric analysis (DTG) is also performed to understand the effect of admixtures on the evolution of binder hydration products (such as calcium hydroxide CH and calcium silicate hydrate C–S–H) [13,15,38] because DTG analysis is a valid method for observing CH and C–S–H phase changes [14,17,39].

2. Materials and methods

2.1. Tailings characteristics

Tailings used in this study were sampled from the Casa Berardi Mine (CBM, Hecla Mining Company, a gold mine) located in North-West Quebec (Canada). Fig. 2 presents the cumulative grain-size distribution curve determined using a Malvern® Mastersizer S2000 laser particle size analyzer. From this figure, the fine ($d < 75 \mu\text{m}$) grains content ($P_{75\mu\text{m}}$) of the tailings is about 90% while the ultrafine ($d < 20 \mu\text{m}$) grains content ($P_{20\mu\text{m}}$) is about 60% and making these tailings a fine size class of tailings [30]. The mineralogy of the CBM tailings was determined by X-Ray diffraction (XRD) analysis using Bruker AXS Advance D8 diffractometer. The chemical composition of CBM tailings was analyzed by spectroscopy using Perkin-Elmer ICP-AES (Inductively Coupled Plasma-Atomic Emission Spectroscopy) Optima 3000 DV. Table 1 summarizes the results of analysis. The procedure of tailings preparation, XRD and ICP-AES analyses are explained elsewhere [28,40]. Specific

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