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Evaluation of the effect of sodium silicate addition to mine backfill, Gelfill – Part 2: Effects of mixing time and curing temperature

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ABSTRACT

The effects of mixing time and curing temperature on the uniaxial compressive strength (UCS) and microstructure of cemented hydraulic fill (CHF) and sodium silicate-fortified backfill (Gelfill) were investigated in the laboratory. A series of CHF and Gelfill samples was mixed for time periods ranging from 5 min to 60 min and cured at temperatures ranging from 5 °C to 50 °C for 7 d, 14 d or 28 d. Increasing the mixing time negatively influenced the UCS of Gelfill samples, but did not have a detectable effect on CHF samples. The curing temperature had a strong positive impact on the UCSs of both Gelfill and CHF. An elevated temperature caused rapid UCS development over the first 14 d of curing. Mercury intrusion porosimetry (MIP) indicated that the pore size distribution and total porosity of Gelfill were altered by curing temperature.

1. Introduction

Mine backfill consists of tailings, binder and water. Gelfill is a new mine backfill material, in which the binder component includes an alkali activator, i.e. sodium silicate. Although sodium silicate has been used in concrete manufacturing, its use in mine backfill is relatively new. Until very recently, there have been only a few publications regarding Gelfill (Kermani and Hassani, 2012; Kermani et al., 2014). This paper presents the second part of a comprehensive study of Gelfill. The first paper (Kermani et al., 2015), published in this journal, investigated the effects of sodium silicate concentration and binder dosage on the mechanical and microstructural properties of Gelfill and cemented hydraulic fill (CHF). It showed that Gelfill samples had higher mechanical strength than CHF samples. However, elevated sodium silicate concentrations (0.5 wt%, wt% is the percentage by total dry weight) detrimentally affected the mechanical strength of Gelfill. Pore structures and pore size distributions differed between Gelfill and CHF samples, which could have contributed to the enhanced mechanical properties of Gelfill. Finally, the addition of sodium silicate to CHF reduced the volume of water released from fill materials during curing. This paper expands upon the previous findings by investigating the effects of mixing time and curing temperature on the uniaxial compressive strength (UCS) and microstructure of Gelfill and CHF.

Mixing time and curing temperature are critical to mine backfill placing. Backfill materials must be mixed to produce a homogeneous cemented fill. Insufficient mixing leads to inconsistent distribution of cement and water, and reduces backfill strength. However, mixing consumes large amounts of energy and extended mixing is costly. Furthermore, overmixing inhibits gel formation during the hydration of cementitious materials. Therefore, it is essential to determine an optimal mixing time to reduce energy requirements and ensure backfill homogeneity. Curing temperature plays a key role in determining the mechanical characteristics of cemented materials. However, investigations on the influence of curing temperature on cemented backfill are very limited. Fall et al. (2010) conducted the uniaxial compression tests on paste backfill specimens cured at 0 °C, 20 °C, 35 °C and 50 °C. The strength development rate decreases with curing temperature due to the increasing hydration rate of the binders. Therefore, samples cured at lower temperatures had lower UCS. Moreover, the mode of strength development differed among binder types (Fall et al., 2010).

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The objective of this research was to investigate the effects of various mixing times and curing temperatures on the mechanical strength of CHF and Gelfill.

2. Materials

2.1. Tailings

Tailings are waste products from ore processing plants, and primarily consist of fine ground host rock. When used as a component of mine backfill, the physicochemical properties of tailings significantly affect the mechanical performance of the backfill (Benzaazoua et al., 2004; Kesimal et al., 2004). In this research, the classified tailings from one of Vale's mines in Sudbury, Ontario, Canada, generally consist of quartz, albite and small quantities of calcite, muscovite, pyrrhotite, chalcopyrite, anorthite, and chlorite. The particle size distribution determined using laser diffraction (ASTM, 1996) indicates that the Vale mine tailings are coarser than the average particle size of 11 mine tailings samples from the provinces of Quebec and Ontario (Ouellet et al., 2008) (Fig. 1, Table 1).

2.2. Binder

Binders are mainly used to increase the mechanical stability of fill materials. They are the most expensive component of mine backfill, representing up to 75% of backfill costs (Hassani and Archibald, 1998). Normal Portland cement (NPC), fly ash and blast furnace slag (BFS) are commonly used for mine backfill. In this research, a combination of 10% type 10 NPC and 90% BFS, both provided by Lafarge Canada was used since its binder formulation is generally used in Vale mines in Ontario. The densities of the NPC and BFS were 3.07 g/cm^3 and 2.89 g/cm^3, respectively. The Blaine specific surface areas of the NPC and BFS were 3710 cm^2/g and 5998 cm^2/g, respectively. The chemical compositions of the NPC and BFS are shown in Table 2.

For this application, BFS has generally been associated with three main limitations: (i) low hydration rate, (ii) low early strength, and (iii) relatively slow strength development. In order to overcome these limitations, BFS must be activated. Many studies have shown that BFS can be successfully activated by alkali activators such as sodium silicate (Anderson and Gram, 1998; Bakhareva et al., 1999).

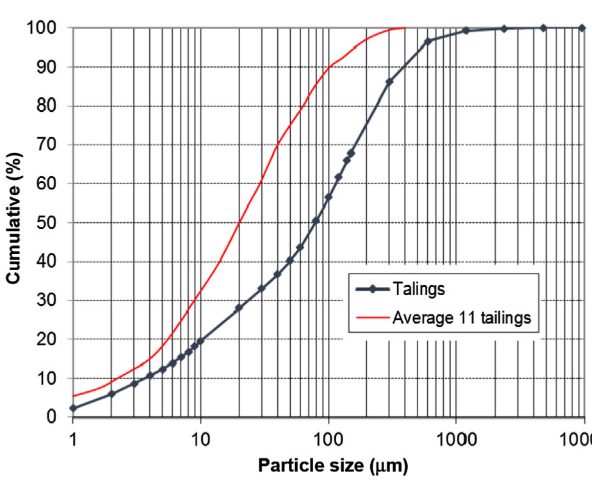

Fig. 1. Particle size distributions of the Vale mine tailings and 11 mine tailings samples from Ontario and Quebec.

Table 1
Physical properties of the tailings.

Material	D_{10} (μm)	D_{50} (μm)	D_{60} (μm)	D_{90} (μm)	C_U	C_C	Specific gravity, G_s
Tailings used in this study	4.1	82.1	52.4	116.5	28.4	2.39	2.85
11 mine tailings reported by Ouellet et al. (2008)	2.2	20	29	102	13.2	1.24	Not available

Note: D_{10}, D_{30}, D_{60}, D_{90} are the particle diameter sizes that 10%, 30%, 60%, 90% of the sample particles are finer than corresponding size of the sample particles, respectively; $C_U = D_{60}/D_{10}$; $C_C = D_{30}^2/(D_{60}D_{10})$.

Table 2
Chemical compositions of the NPC and BFS provided by Lafarge Canada.

Chemical composition	NPC (wt%)	BFS (wt%)
CaO	61.1	37
SiO_2	19.4	36.1
Al_2O_3	4.6	10.1
MgO	3.3	12
SO_3	2.3	3
Fe_2O_3	2	0.7
Na_2O	2	0.4
K_2O	0.7	0.5
Other minor elements	4.6	0.2

2.3. Sodium silicate

In addition to acting as an alkali activator of BFS and fly ash, sodium silicate has been used in glues, cements, paints, and detergents, and as a hardening agent for natural and artificial stones (Shi et al., 2006). It is manufactured from Na_2CO_3 and SiO_2 by smelting silica with sodium carbonate at approximately 1100–1200 °C. The general formula for sodium silicate is $Na_2O \cdot nSiO_2$, with n ranging from 1.6 to 3.85 for most commercially available sodium silicate materials. Sodium silicate is the most effective alkali activator for most pozzolans, including BFS and fly ash (Anderson and Gram, 1998; Bakhareva et al., 1999; Brough and Atkinson, 2002; Hilbig and Buchwald, 2006; Chen and Brouwers, 2007). Type N® sodium silicate, provided by the PQ National Silicate Company, was chosen because it is the most efficient activator for ground BFS (Table 3).

2.4. Sample preparation and curing

To investigate the effect of mixing time and curing temperature on CHF and Gelfill, 198 CHF and Gelfill samples were prepared (Table 4). In both types of fill, the pulp density was kept constant at 70%, as is practiced in Vale mines in Sudbury. Also, the binder consisted of 5 wt% tailings. The binder for the Gelfill samples was a combination of NPC, BFS, and 0.3 wt% sodium silicate. CHF and Gelfill were mixed according to ASTM C305-14 (ASTM, 2014) in small batches in a 5-L stainless steel bowl for six mixing times (5 min, 10 min, 15 min, 20 min, 30 min and 60 min) using a mixer

Table 3
The properties of sodium silicate (PQ National Silicate Company).

Value type	Na_2O content (%)	SiO_2 content (%)	Weight ratio (SiO_2/Na_2O)	Specific gravity at 20 °C	Viscosity at 20 °C (centipoise)	Solids (%)
Standard	8.9	28.66	3.22	1.394	177	37.56
Maximum	9.1	29	3.27	1.401	213	38.1
Minimum	8.7	28.2	3.15	1.388	141	36.9