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# Influence of superplasticizers on mechanical properties and workability of cemented paste backfill

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## ABSTRACT

This paper presents new insights into the mechanical properties and workability of cemented paste backfills (CPBs) containing various superplasticizers. Effects of these admixtures on cement hydration were also evaluated. Five admixtures belonging to the main superplasticizer groups (lignosulfonate, naphthalene, melamine, and polycarboxylate) were used at 5, 7, and 10% by dry mass of binder (a mixture of 20% ordinary Portland cement (OPC) and 80% slag). The effects on CPBs formulated with OPC and the most effective superplasticizers were also studied. Results showed that superplasticizers influence on CPB performances depends on the type and dosage of the admixture. Polycarboxylate presented the best performances and allowed the achievement of the target consistency at lower water content (between 6 and 10%) without altering the mechanical strength of the CPBs. The results also reveal that a reduction in binder content (from 5 to 3%) could be achieved while still conserving CPB strength when using polycarboxylate admixtures.

## 1. Introduction

Cemented paste backfills (CPBs) have become an essential component of underground mining in the last two decades (Benzaazoua et al., 2002, 1999; Dorricott and Grice, 2002). The increasing prominence of CPBs, with respect to other types of backfills, is primarily related to their mechanical properties, which corroborate their use as ground support. CPB may be used as floor, wall, or head covers to enhance ore recovery (Belem and Benzaazoua, 2007). Another attractive advantage of CPB is the reduction in the total volume of tailings requiring surface disposal and that may generate significant ecological disruptions if not properly monitored (Hassani and Bois, 1989; Kesimal et al., 2003; Landriault, 1995). CPB consists essentially of a hydraulic binder (between 3 and 7 wt%), thickened and/or filtered tailings, and water (added to achieve the desired consistency). The most common binder used for the manufacture of CPB is ordinary Portland cement (OPC). Various studies showed the possible use of pozzolanic materials (e.g., fly ash and blast-furnace slag or a combination of these; (Benzaazoua et al., 2002; Ercikdi et al., 2009), which may significantly influence the mechanical and rheological performance of CPBs. Although CPB technology has some environmental and economic benefits, the cost and transportation of paste fill practices are still of concern. De Souza et al. (2003) reported that paste fill practices consume significant amounts of binder ($10^5$ tons per year), which represents up to 80% of backfilling costs (Gauthier, 2004), and transportation system failures are mainly due to pipeline plugs. CPB properties (mechanical strength and flowability) depend on physical, chemical, and mineralogical characteristics of the tailings (Benzaazoua et al., 1999; Kesimal et al., 2005). In fact, the presence of iron sulphide minerals within mine tailings has a well-known deleterious effect on CPB performance due to sulphate attack (Benzaazoua et al., 1999). It is also important to underline that CPB is commonly transported from a paste plant to the underground openings, thus necessitating the use of sufficient water to achieve a desired consistency. This could result in a high water/cement (w/c) ratio, which may lower the strength and durability performance of CPB (Benzaazoua et al., 2002; Ercikdi et al., 2009; Kesimal et al., 2005). Therefore, the main challenge in CPB production is to use the appropriate water content, binder proportion and type in order to reach the desired consistency, strength, and long-term durability, while also minimizing costs.

Considering these challenges, many authors have worked on innovative techniques to reduce binder costs and enhance flow characteristics. One potential solution is to substitute traditional and expensive binders with alternative binders (e.g., wood bottom ashes, micronized glass wastes, paper sludge, cement kiln dusts, and anhydrite) which have low or no commercial value (Ercikdi et al., 2009;

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Mangane et al., 2016; Peyronnard and Benzaazoua, 2011, 2012; Tariq and Nehdi, 2007). Peyronnard and Benzaazoua (2012) reported that between 35% and 45% of industrial by-products can be used as substitutes for common binders (general use (GU) and slag). However, all tested alternative binders produced CPBs with insufficient mechanical strength compared with those of traditional binders. Mangane et al. (2016) showed that around 30% of substitution can be made with alternative binders, and that alkali-activation of CPBs formulated with industrial by-products allowed for attaining similar mechanical strengths as traditional binders. Moreover, Cihangir et al. (2012) demonstrated that alkali-activated neutral and acidic blast furnace slags enhanced the mechanical performances of CPB and can be used as alternative binders to OPC for CPB of high-sulphide mill tailings. On the other hand, considering reduction of mixing water to enhance mechanical properties, Erismann (2016) reported that incorporating superplasticizers (lignosulfonate, naphthalene and polycarboxylate-based products) in CPB formulations induced the reduction of binders consumption and the enhancement of CPB properties. Indeed, there are some chemical admixtures (e.g., superplasticizers) that allow achievement of target consistency with a reduced water content (Ercikdi et al., 2010). These additives are defined as organic polymer molecules with the ability to adsorb on cement and tailings particles and thus cause their dispersion through internal electrostatic and steric forces which affect rheological properties of cemented paste backfill as shown by Huynh et al. (2006). The predominant dispersant chemicals available in admixtures today are classified into four families: lignosulfonate, sulfonated naphthalene formaldehyde, sulfonated melamine formaldehyde, and polycarboxylate. These superplasticizers affect the microstructure of cement pastes by significantly reducing their porosity and permeability (Papayianni et al., 2005), which justify their intensive use in concrete preparations. When added at dosages less than 5%, they reduced water demand by up to 30% while increasing workability, mechanical and rheological performances, and durability of concretes (Mailvaganam and Rixom, 2002). However, for CPBs, only a few studies were conducted to evaluate their influence and performances due to additional costs involved and limited knowledge about admixture benefits (Farzam et al., 1998). The particularity of CPB is that during its upstream preparation, flocculent polymers are added to help the thickening and filtration processes. These additives may also adsorb onto particles and neutralize their charge. This might involve competition between antagonistic forces, and may increase superplasticizer demand (Yammamuro, 1997), which can cause a delay in CPB setting time (Khayat, 1998). In addition, unlike mortars and concrete, the superplasticizers interact with tailing particles more than cement. Therefore, higher superplasticizer demand are needed for fine tailing particles (Erdoğdu, 2000).

Ercikdi et al. (2010) studied the effects of lignosulfonate (EUCO-FILL 30), naphthalene sulfonate (IKSAMENT NS), and polycarboxylate-based admixtures (POLYCAR-100) on CPB performance. Paste fills were formulated using OPC and Portland composite cement. The required admixture dosages to reach the targeted slump (7 in.) were 7%, 6%, and 5.4% (by dry mass of binder) for lignosulfonate, naphthalene sulfonate, and polycarboxylate-based admixtures, respectively. The authors reported that the admixtures: lowered water content (~6.6%), enhanced the CPBs' mechanical properties (between 20 and 50%), and could be used in CPBs containing sulphide-rich tailings. Furthermore, the admixtures enhanced CPB durability. The mechanical strength loss of CPB formulated with OPC was between 1–8% (with admixtures) and 25% (without admixtures). Simon et al. (2011) investigated the effects of polycarboxylate-based admixtures on flow characteristics and mechanical properties of CPB formulated with Portland cement. Their results showed that the addition of 4% (by dry mass of binder) polycarboxylate-based admixture decreased fresh paste yield stress from 1000 Pa to 3 Pa, but workability loss seemed to occur over time. The mechanical strength also increased from 450 kPa to 1000 kPa. Huynh et al. (2006) reported that polyphosphate and naphthalene sulfonate formaldehyde condensate (NSF) based-admixtures influence rheological properties of CPB mixed with Portland cement by affecting the zeta potential of solid particles (tailings and cement particles). Moreover, incorporating polycarboxylate based-admixtures in CPB's recipes mixed with blended Portland cement-slag (20–80) significantly enhanced theirs flow characteristics as shown by Ouattara et al. (2017). However, additional data is required, especially for mixed binders (OPC 20% and slag 80%), which are commonly used in the mining industry, at different percentages.

The main objective of this work is to evaluate the influence of various superplasticizers at different dosages on the performances of CPBs mixed with the commonly used binder (OPC 20% and slag 80%). It is important to underline that most commercial superplasticizers are mixed with various chemical additives, which complicate the isolation of their influence on CPB. Therefore we used pure molecules of predominant chemical groups (lignosulfonate, naphthalene, melamine, and polycarboxylate) responsible of the dispersant effect.

## 2. Materials and methods

### *2.1. Binder and tailings sampling*

The binders used were supplied by Lafarge Canada Inc. A Type I OPC (GU) and a blend of GU (20%) and slag (80%) commonly used in the Abitibi region for CPB preparation. The properties of the binders used are presented in Table 1.

The tailings used in this study were collected from a polymetallic mine located in the Abitibi region of Québec, Canada. They were sampled directly after the filtration step (solid percentage around 80%) from the backfilling process at the mine site. After arriving at the laboratory, the tailings were homogenized, poured into hermetically sealed buckets, and CPB formulations were prepared immediately. The tailings samples were also subjected to physical, chemical, and mineralogical characterizations.

The grain size distribution (GSD) and mineralogical properties of tailings are presented in Figs. 1 and 2, respectively. Table 1 present physical and chemical properties of all materials used in this study. The grain size distribution was determined using a Malvern Mastersizer with a laser diffraction technique. Bulk density and specific gravity were analyzed according to EN 1097-3 using a Micrometrics helium pycnometer. Chemical analyses were performed using X-ray

**Table 1**
Physical and chemical properties of materials.

| | Tailings | GU | Slag |
|---|---|---|---|
| Blaine surface area ($m^2/g$) | – | 0.5 | 0.5 |
| Specific gravity ($g/cm^3$) | 3.28 | 3.12 | 2.84 |
| Specific surface area ($m^2/g$) | 1.69 | 1.1 | 2.75 |
| Bulk density ($kg/m^3$) | 1600 | – | – |
| $Cu = D_{60}/D_{10}$ | 9.31 | 7 | 6.1 |
| $Cc = D_{30}^2/(D_{60} * D_{10})$ | 1.08 | 0.8 | 0.9 |
| $D_{10}$ (μm) | 4.63 | 1.39 | 1.15 |
| $D_{50}$ (μm) | 31.31 | 6.75 | 5.18 |
| $D_{90}$ (μm) | 125.81 | 30.43 | 20.56 |
| $S_{total}$ (%) | 18.21 | – | – |
| $C_{total}$ (%) | 0.03 | – | – |
| *Oxide composition %* | | | |
| $SiO_2$ | 49.7 | 16.60 | 29.93 |
| $Al_2O_3$ | 9.35 | 5.14 | 9.86 |
| CaO | 0.68 | 67.80 | 40.56 |
| $Fe_2O_3$ | 23.1 | 3.40 | 0.04 |
| $K_2O$ | 0.9 | 1.06 | 0.52 |
| MgO | 0.22 | 2.19 | 9.92 |
| MnO | – | 0.04 | 0.48 |
| $Na_2O$ | 0.58 | 0.84 | 0.81 |
| $SO_3$ | – | 6.24 | 4.74 |
| $TiO_2$ | 0.4 | 1.30 | 1.68 |

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