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Assessment of rheological parameters of high density cemented paste backfill mixtures incorporating superplasticizers

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HIGHLIGHTS

- Use of high-range water reducer (HRWR) admixtures in cemented paste backfills (CPB).
- Reduction of the yield stress, flow index and dynamic viscosity of CBP by adding HRWR.
- Determination of the optimal HRWR dosage to produce pumpable CPB.
- Better performance of polycarboxylates than polymelamine and polynaphtalene sulfonates.
- HRWR performance affected by the binder type and content and by tailings characteristics.

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ABSTRACT

The addition of superplasticizers or high-range water reducers (HRWRs) to high density cemented paste backfills (CPBs) can improve their rheological behavior and facilitate pumping operations. This study aimed to assess the influence of various mixture parameters, including HRWR type and dosage, binder type and content, as well as tailings characteristics on the rheological properties of CPB mixtures. CPBs were formulated at a solid mass concentration of 80% with two types of tailings (T1 and T2) and three types of binders, including a general use Portland cement (GU), a blended binder (S-GU) comprising 80% ground granulated blast furnace slag and 20% GU, and another blended binder (GU-FA) comprising 50% class F fly ash and 50% GU. Five different types of HRWRs, including three polycarboxylate-based (PC), one polymelamine-based (PMS), and one polynaphtalene-based (PNS), were assessed. Results showed that HRWR addition to CPB reduced the rheological parameters, including yield stress, flow index, and infinite shear viscosity. Furthermore, the rheological behavior changed from shear thickening for control CPB to Binghamian with increasing HRWR dosage. The optimum PC dosage of 0.121% (by dry mass of total CPB solids) can ensure a CPB with yield stress lower than 200 Pa, which has been reported as the upper limit for effective centrifugal pumping of CPB. The PC-type HRWRs were more efficient than the PMS and PNS types. Superplasticized CPB mixtures made with S-GU and GU-FA binders exhibited better rheological properties than those using GU binder. Binder content ranging from 3.5 to 6% appeared to have a negligible effect on the performance of the PC-type HRWRs.

1. Introduction

Paste backfill is increasingly used in underground hard rock mining operations due to the production benefits it provides for cut-and-fill and long-hole sublevel mining methods [1,2] as well as the environmental benefits it provides by reducing the overall amount of tailings stored at the surface. Cemented paste backfill (CPB) is a homogeneous, non-segregating, complex composite produced by mixing filtered mine tailings, binder, and water [2–5]. CPB is transported by reticulated pipelines and deposited into underground mine stopes. Due to the hydration process of the binder and the self-weight consolidation effect, the CPB develops sufficient strength to provide adequate ground support, depending on the exposure conditions (e.g., free-standing pillar, working platform) [1,6,7]. Once hardened, CPB contributes to environmentally sound management of harmful tailings [8]. As the CPB hardens, some pollutants present in the tailings are encapsulated by solidification/stabilization [3,8–10].

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In conventional paste backfilling, tailings slurry (20–40% solid content, by mass) is densified using thickeners to produce thickened tailings (TTs) with about 50–70% solid content, by mass. Flocculent is added at a specific dosage to improve the performance of thickeners. The TTs are then filtered using, for example, disc filters to reach $\geq$ 80% solid content. The filtered tailings (FT) cake is then used to prepare CPB mixtures. The binder content in CPB mixtures generally ranges from 2 to 8% by dry mass of tailings. Currently, paste backfilling technology is moving towards high solids content CPB in order to improve the mechanical properties [11,12]. However, CPB with high solid content are highly viscous and can exhibit shear-thickening behavior in high solid granular suspensions, characterized by an increase in viscosity with shear rate [13–17]. Furthermore, increased solid content above a critical value resulted in exponential increase in yield stress and dynamic viscosity in CPBs [18,19], although CPB pumpability depends on its rheological properties. Even with the use of powerful and costly positive displacement pumps, pipeline plugs can occur during pumping of highly concentrated CPB for different reasons [20–22]. Pipeline blockages can be avoided by using CPB with a higher water content and low solid content or by incorporating HRWR admixtures to the highly concentrated CPB to obtain a targeted slump in the range of 6–10 in. ($\sim$152 to 254 mm). This slump range was shown to facilitate backfill transport in pipelines by pumping or by gravity [4,6,21,23] due to improved CPB rheological properties (lower yield stress and viscosity). For example, centrifugal pumps have been demonstrated efficient for pumping and transporting CPB with yield stress ranging from 100 to 200 Pa [24].

The rheology of cementitious materials (e.g., concrete, cement suspensions) is influenced by several parameters, including the particle-size distribution of the solids, the chemical composition of the pore water, the mixing procedures and energy, the solid content, and the presence of high-range water reducers (HRWR) [17,25–29]. Because CPB is used mainly as secondary ground support in underground mines, the incorporation of HRWR can improve both the rheological and mechanical performance [30–39] Gay et al. [31] evaluated the evolution of slump with time and mechanical strength of hydraulic backfill incorporating two different types of HRWR. Backfills incorporating HRWR showed good fluidity retention and slightly higher strength. Klein and Simon [33] reported improved flowability of fresh CPB incorporating four types of HRWR, as determined by slump tests. Ouattara et al. [39] assesses the effects of different types of high-range water reducer (HRWR): four polycarboxylates (PC), a polymelamine sulfonate (PMS), and a polynaphtalene sulfonate (PNS) on the consistency (slump) and unconfined compressive strength (UCS) of cemented paste backfills. The PC-type HRWR increased CPB consistency more effectively compared to PNS- and PMS-type HRWR. However, UCS values at 28 days were comparable for CPB incorporating all HRWR types.

In response to mostly positive laboratory results on the use of chemical admixtures in CPB, the mining industry is showing a great interest in using admixture and and successful results were obtained at the Tanami Gold Mine located in the remote Tanami Desert of Australia [40], at the Darlot Gold Mine located in Western Australia [41], and at mines located in Europe and Africa [42]. The introduction of admixtures in backfill plants on a regular basis remains however weak for different reasons related to cost and performance benefits [43].

Further studies are still needed to deepen the understanding of the effective dispersion of HRWR in CPB with high solid contents in terms of beneficial rheological effects. Ercikdi et al. [34] compared the water content (i.e. the water to cement ratio w/c) of CPB without admixture (control) and of superplasticized CPB mixtures, keeping the same flowability (7-inch slump). The water content of the superplasticized CPB mixtures containing 7%, 6%, and 5.4% (by mass of dry binder) of three different types of HRWR was approximately 6.6% lower than that for the control (CPB without HRWR).

The objective of this study was to investigate the performance of HRWR on the rheological properties of initially highly concentrated CPB mixtures and on the flow performance to ensure pumpability. For this purpose, the impacts were investigated of various factors affecting the performance of different types of HRWR and the consequent effects on the rheological parameters of CPB. These factors included HRWR dosage and type, binder content and type, and tailings characteristics.

2. Experimental program

2.1. Materials

The two filtered tailings samples (T1 and T2) used in this study were provided by two different mines located in the Abitibi-Témiscamingue region of Québec, Canada. Tailings T1 was derived from polymetallic ore and T2 from gold ore. Prior to testing, representative, homogenized tailings were analyzed to determine chemical, mineralogical, and physical characteristics. Chemical composition was determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES). Results are summarized in Table 1. The main chemical element in both tailings was silica, at contents of 51% and 93% for T1 and T2, respectively. Iron was the main metallic element, at 24% and 1.8% for T1 and T2, respectively. Relatively high sulfur content (19.8%) was found in T1, with lower content (0.84%) in T2. The aluminum contents were 3.98% and 1.7% in tailings T1 and T2, respectively. The other elements were calcium (0.63% in T1; 0.75% in T2) and magnesium (0.19% in T1; 0.54% in T2). Cadmium, chromium, manganese, arsenic, and other metal contents were detected at less than 0.1%.

The mineralogical composition of the tailings was determined using X-ray diffraction (XRD). Results of the qualitative and quantitative analyses of micronized tailings samples are presented in Table 2. The main mineral found in both tailings was quartz, at 42.7% and 86.6% content for T1 and T2, respectively. Albite, muscovite, and pyrite were found in T1 and T2, while paragonite and

Table 2
Mineralogical characteristics of tailings T1 and T2 obtained by XRD analysis.

Mineral	T1 (wt%)	T2 (wt%)
Quartz	42.7	86.6
Albite	13.6	5.4
Chlorite	5.5	–
Ankerite		2.4
Paragonite	4.9	–
Gypsum	0.5	–
Muscovite	2.5	4.5
Pyrite	30.5	1.04

Table 1
Chemical composition of tailings T1 and T2.

Chemical elements	Al	Ba	Na	K	Ca	Fe	Si	Mg	Mn	Stot	Ti	Zn	Pb	As
T1 (%)	3.98	0.02	–	–	0.63	24.10	50.95	0.194	0.026	19.80	0.08	0.14	0.05	0.01
T2 (%)	1.7	–	0.34	0.56	0.75	1.8	93.24	0.54	0.02	0.84	–	–	–	0.21