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Direct shear tests on cemented paste backfill–rock wall and cemented paste backfill–backfill interfaces

Nabassé J.F. Koupouli [a], Tikou Belem [a,*], Patrice Rivard [b], Hervé Effenguet [c]

[a] Research Institute in Mining and Environment (RIME), Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, Québec, Canada
[b] Department of Civil Engineering, Université de Sherbrooke, Sherbrooke, Québec, Canada
[c] Department of Geology, Université Marien NGouabi, Brazzaville, People's Republic of Congo

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A B S T R A C T

This paper presents the results of the shear strength (frictional strength) of cemented paste backfill-cemented paste backfill (CPB-CPB) and cemented paste backfill–rock wall (CPB-rock) interfaces. The frictional behaviors of these interfaces were assessed for the short-term curing times (3 d and 7 d) using a direct shear apparatus RDS-200 from GCTS (Geotechnical Consulting & Testing Systems). The shear (friction) tests were performed at three different constant normal stress levels on flat and smooth interfaces. These tests aimed at understanding the mobilized shear strength at the CPB-rock and CPB-CPB interfaces during and/or after open stope filling (no exposed face). The applied normal stress levels were varied in a range corresponding to the usually measured in-situ horizontal pressures (longitudinal or transverse) developed within paste-filled stopes (uniaxial compressive strength, $\sigma_c \leq 150$ kPa). Results show that the mobilized shear strength is higher at the CPB-CPB interface than that at the CPB-rock interface. Also, the perfect elastoplastic behaviors observed for the CPB-rock interfaces were not observed for the CPB-CPB interfaces with low cement content which exhibits a strain-hardening behavior. These results are useful to estimate or validate numerical model for pressures determination in cemented backfill stope at short term. The tests were performed on real backfill and granite. The results may help understanding the mechanical behavior of the cemented paste backfill in general and, in particular, analyzing the shear strength at backfill–backfill and backfill-rock interfaces.

1. Introduction

Cemented paste backfill (CPB) technology is increasingly and widely used in many underground mines throughout the world and has become very popular over the last decade (Potvin et al., 2005; Belem and Benzaazoua, 2008). CPB is obtained from mixing tailings with water and a binding agent called hydraulic binder. This technology was initially implemented in Canadian mines in the early 1990s (e.g. Landriault and Tenbergen, 1995; Nantel, 1998; Landriault et al., 2007). This popularity is primarily observed due to the numerous environmental directives implemented in many developed and developing countries. This implies the reuse of at least 50% of the tailings as CPB for secondary ground support in underground mine stopes (Mitchell, 1989a; Belem et al., 2000). Thus, CPB provides stable working platform for miners and reduces the amount of open space that could potentially be filled with a collapse of the surrounding pillars (Barret et al., 1978). In order to retain the CPB during the open stope filling, the constructed barricades are designed to prevent any failure induced by high pressures generated by the saturated fill mass (excess pore water pressure). In most cases, the sequence of filling an open stope is to first pour a plug fill of a few meters high (up to 7 m), followed by pouring the residual fill (Fig. 1). The binder content in the plug fill is larger than 5 wt% (on average 7 wt% of Portland cement or a blended binder; wt% is the weight percentage), while the binder content in the residual fill is not more than 5 wt% (on average in the range 2–5 wt% of a blended binder). The plug fill is usually left between 2 d and 5 d of curing prior to the residual filling in order to avoid excess pressure on the barricade. However, the proper design of a barricade requires a good estimate of barricade loads which in turn depend on the pressure/stress distribution within the backfilled stope (Belem et al., 2013).

* Corresponding author. Tel.: +1 8197620971x2359.
E-mail address: Tikou.Belem@uqat.ca (T. Belem).
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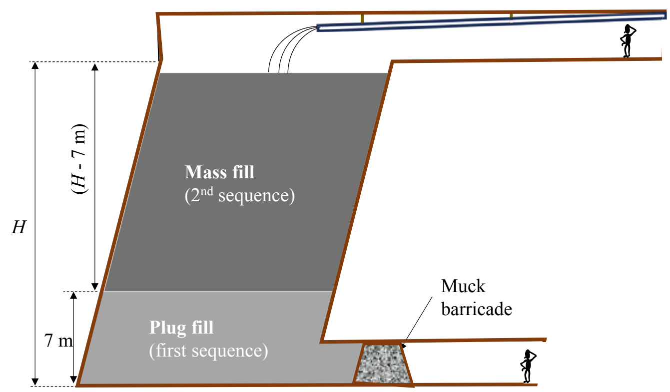

Fig. 1. Schematic of a typical underground stope filling sequences.

In many cases, the adjacent rock sidewalls actually help supporting the fill through boundary shearing and arching. Therefore, CPB and rock sidewalls may be mutually supported (Mitchell, 1989b). When arching occurs in a filled stope, the vertical pressure at the bottom of the fill is less than the overburden weight due to the horizontal transfer of pressure, somewhat like a trap door (Marston, 1930; Terzaghi, 1943). This pressure transfer is primarily associated with the frictional and/or cohesive interaction between CPB and rock sidewall (Belem and Benzaazoua, 2008). It should also be noticed that some "chemical" consolidation can occur within the fill mass due to the chemical shrinkage also designated as self-desiccation (Helinski et al., 2007). In fact, the binder hydration leads to the dissipation of pore water pressure which will increase the vertical effective stress causing consolidation. In-situ measurements conducted by Bridges (2003) show that pore water pressure on barricades is negligible after a few days. If the CPB permeability is very low and water does not drain out under gravity, no settlement of the CPB occurs. Without settlement, no shear stress is mobilized at the CPB-rock sidewall interface and no arching occurs. However, if the CPB is draining freely, the fill begins to settle virtually as soon as it is placed and the distortion associated with this settlement generates the mobilization of shear stresses at the fill-rock sidewall interface. The shear strength that can be mobilized at the interface will depend on the level of friction. This friction in turn is a function of the horizontal effective stress acting on the interface (Fourie et al., 2007). The determination of shear stress development allows understanding how arching effect can occur (and thus stress relief on barricades). Then this effect can be taken into account during preliminary backfill design process (de Souza et al., 2009). It is therefore necessary to quantify experimentally the shear strength parameters (interface cohesion or adhesion, interface friction angle) and the shear stiffness of CPB.

To the authors' knowledge, very few experimental studies have been conducted on CPB-rock sidewall interface behavior. A study on the shear behavior of artificial paste backfill-limestone smooth interface was carried out by Nasir and Fall (2008), followed by another one on artificial paste backfill-concrete and brick interfaces (Fall and Nasir, 2010). The normal stress ranging from 100 kPa to 200 kPa and four different curing times (i.e. 1 d, 3 d, 7 d, and 28 d) were tested with a single cement content of 4.5% (by dry mass of ground silica). The main observation was that, for the same stress conditions, the shear strength of the artificial CPB materials is greater than that of the artificial CPB-rock/concrete/brick interfaces. Their results also showed that the angle of friction of artificial CPB-rock/concrete/brick interfaces was greater than 2/3 of the angle of internal friction of artificial CPB. However, the results presented by these authors were obtained from tests conducted on purely artificial cemented backfill prepared with ground silica, namely SIL-CO-SIL 106, which is different from true tailings. A third study on the investigation of backfill–rock mass (simulated by concrete) interface failure mechanisms was conducted by Manaras (2009) who highlighted the importance of the binder content, the curing time and the rock (concrete) sidewall roughness quantified by the JRC (joint roughness coefficient) values ranging from 3 to 19. The normal stress ranging from 35 kPa to 1500 kPa and three different curing times (14 d, 28 d, and 56 d) were tested. The CPB samples were prepared at 80% of solid content with three different binder contents (2.5%, 5% and 8% by dry mass of tailings).

Although the results of these previous studies contribute to the understanding of interfaces phenomena, the fact remains that it would be more interesting to have results on the behaviors of interfaces between real CPBs and real rocks. But to the authors' knowledge, such a study has not been conducted to date on the interfaces between a real CPB and a real rock. Hence, the main objective of this paper is to conduct a laboratory investigation of the shear stress-shear displacement behavior and the determination of shear strength parameters of early age CPB-granite sidewall and early-age CPB-CPB interfaces using a direct shear machine. The curing times tested are 3 d and 7 d. The results of these tests will allow estimating the shear strength that develops in the short term (between 1 d and 7 d of curing times), during which the authors

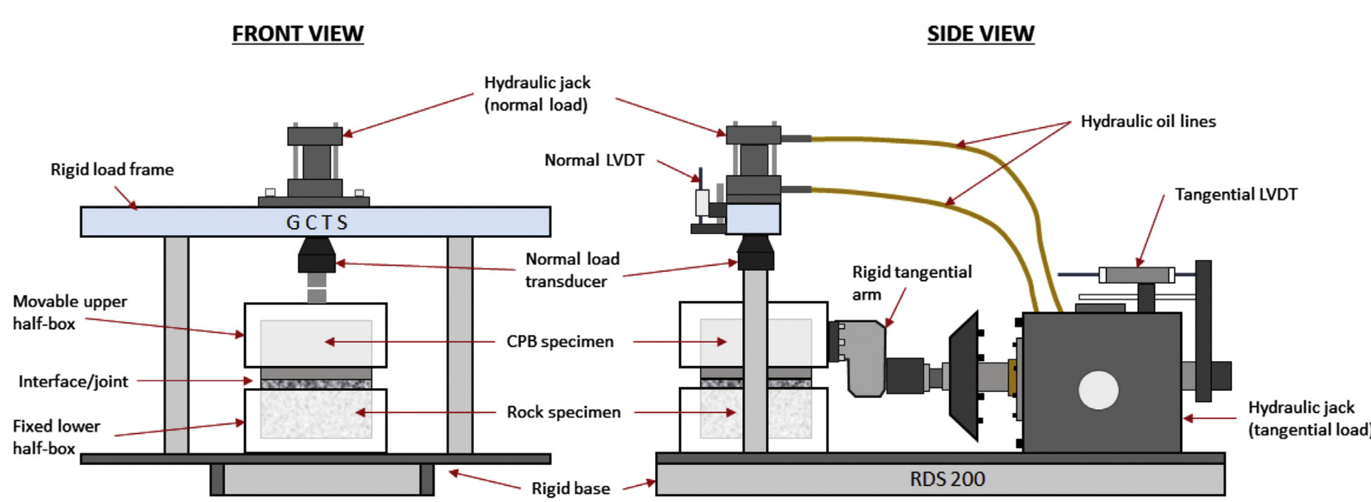

Fig. 2. Direct shear test machine RDS-200 from GCTS (Geotechnical Consulting & Testing Systems).