Assessment of the Effect of Different Cementing Materials on the Strength of Cemented Paste Backfill

Daniela IONESCU\textsuperscript{1}, Joe PETROLITO\textsuperscript{1}, Adam DARE\textsuperscript{2}, Zac PENTREATH\textsuperscript{3} and Laura SONNBERGER\textsuperscript{4}

\textsuperscript{1}Department of Engineering, La Trobe University, Australia
\textsuperscript{2}Murray Irrigation Ltd, Deniliquin, Australia
\textsuperscript{3}Kirkland Lake Gold Ltd, Fosterville, Australia
\textsuperscript{4}West Wimmera Shire Council, Edenhope, Australia

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Abstract. The extraction and use of mineral resources are critical to modern societies. New technologies and practices have ensured the development of the mining industry. Currently, the industry is striving to become more efficient and more environmentally-friendly. This paper reports on continuing research at La Trobe University on the behaviour of cemented paste obtained from fine, sulphide-rich gold tailings from the local Fosterville Mine. The effects of cementitious binders and the age of the hardened cemented paste on the mechanical properties are presented. The findings to date show that there is potential to replace the current backfill material with cemented paste backfill to increase mine productivity and ore profitability.

Introduction

Mining gold is a multi-billion-dollar activity in many countries around the world. In Australia, gold extraction has a long history in Bendigo and its surroundings. In this area, the rich gold-bearing quartz reefs are hosted by tightly folded Ordovician (480 Mya) marine sediments [1]. Recent drilling and bulk sampling by Kirkland Lake Gold Ltd at their operation at Fosterville Gold Mine (FGM) have shown that the gold resources exceed 1.03 million ounces in this region, and more than half of the estimated gold reserve has an average grade of 58.8g/t [2].

FGM is located about 155 km north of Melbourne, in Central Victoria. It uses open stoping mining with delayed backfill in its operation. This method employs blasting to create a void called a stope. The ore from the stope is removed and transported to the extraction plant to separate the gold. Subsequently, the created void is backfilled with waste rock (rockfill, RF) and cemented rockfill (CRF), which is left to cure. The CRF backfill is used to increase the recovery of ore by minimising the requirement of leaving ore pillars, providing ground support for the mine structures and a safe working environment. In addition, the CFR backfill minimises the risk of surface subsidence due to underground stopes, provides a disposal site for the waste rocks, and controls ore dilution from hanging walls and footwalls. This extraction technique is one of the better choices for mining steeply dipping tabular ore bodies [3], as is the case at FGM, and it also provides a good production and ore recovery rate. Annually, around 80,000 m$^3$ of voids are backfilled at FGM using a proportion of 75% CRF and 25% RF. Whilst the current CRF backfilling method is working effectively, the operators at FGM have observed that when a new stope is created by blasting, hardened fill material from the adjacent stope can collapse, resulting in delays, reduced productivity and higher processing costs. It has been reported that vibrations from blasting are the main cause of collapse for CRF stopes [4].

Over time, new backfilling methods have been introduced in open stoping mining with delayed backfill operations. One of these methods uses cemented paste backfill (CPB), which has gained worldwide acceptance due to its economic and environmental benefits [5]. CPB is a heterogeneous material made of tailings, water and a hydraulic binder. Hence, the FGM operators have
commissioned this study to identify if CPB is a better option than the current CRF backfill system. This paper discusses the results of a continuing study at La Trobe University into the use of fine tailings supplied from FGM for CPB. FGM has an annual production of about 550,000 tonnes per year, which is expected to increase with time. Since a significant volume of tailing results from gold processing plant, the FGM operators are interested in finding environmentally-friendly ways to use this waste material, while increasing their productivity and minimizing production costs.

**Material Requirements**

CPB is made from tailings that are mixed with a binding agent and water, and it has the consistency of a fine slurry [5]. Typically, CPB contains about 75% - 85% by weight tailings, around 3% - 6% by weight cement and water to form a dense, pumpable mix. It has also been suggested that tailings should have a minimum of 15% of the solid particles finer that 20µm, to increase the pumpability of the mix [6]. In terms of the compressive strength of CPB, the water to cement ratio influences the unconfined compressive strength (UCS), as is the case for concrete. A higher ratio lowers the strength, due to the increase in porosity, which is typically around 30% [7]. Furthermore, sulphate or sulphide minerals present in gold mine tailings reduce the strength of CPB and increase the setting time of the mix [7].

**Experimental Program**

The physical characteristics of the materials used in the study were determined in accordance with relevant Australian Standards [8]. The governing factors were the compliance with current specifications and the feasibility of obtaining an acceptable material.

**Tailings**

The supplied tailings used in this study were ‘moist’ tailings that were reclaimed from one of the two tailing storage facilities (TSF) currently in use at FMG. The chemical composition of the tailings is presented in Table 1. Tailings were sampled from both the entrance and the exit to/from the ponding area to provide a better picture of the tailings grading. Fig. 1 shows that the particle size distributions of the tailings are close for both sampling areas. The coarser tailings were sampled from the entrance into the sedimentation pond and the finer tailings were collected from the exit. Since the content finer than 20 µm was about 35% - 41%, the tailings are ideal for CPB. The moisture content of the desiccated tailings varied from 22.6% for the coarser tailings to 31.3% for the finer tailings, while the specific gravity of the tailings varied from 1.39 to 1.46 for the finer and coarser tailings, respectively.

**Binder**

General-purpose Portland cement (type GP) was used for the control mix. To check the effect of binder type on the mechanical properties of CPB, three supplementary cementitious materials were also used in various proportions. These cementitious materials were class F fly ash (FA), ground granulated blast-furnace slag (GGBS) and silica fumes (SF). Past research [9] showed that CPB achieves acceptable strength even when the binder proportion is as low as 3% - 7% by weight. Hence, the binder content was limited to 5% in this study, and the following blends of cementitious materials

<table>
<thead>
<tr>
<th>(K)(Al)xSiO$_2$ (wt.%)</th>
<th>CaSO$_4$.2H$_2$O (wt.%)</th>
<th>FeOOH.0.4H$_2$O (wt.%)</th>
<th>FeS (wt.%)</th>
<th>Fe(AsO$_4$).2H$_2$O (wt.%)</th>
<th>H$_2$SO$_4$ (wt.%)</th>
<th>As$^5-$ (wt.%)</th>
<th>Fe$^{3+}$ (wt.%)</th>
<th>FeAsS (wt.%)</th>
<th>Sb$_2$O$_3$ (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>35-45</td>
<td>30</td>
<td>~1-5</td>
<td>0.5-1</td>
<td>0.1-0.5</td>
<td>0.5</td>
<td>0.2-0.3</td>
<td>0.1-0.2</td>
<td>0.1-0.2</td>
<td>0.1-0.2</td>
</tr>
</tbody>
</table>
were used:
- 5% General-purpose Portland cement (5GPC, the control mix)
- 3% Fly Ash + 2% GP Portland cement blend (3FA-2GPB)
- 1% Silica Fume + 4% GP Portland cement blend (1SF-4GPB)
- 4% Ground Granulated Blast-furnace Slag + 1% GP Portland cement blend (4GGBS-1GPB).

Mix Proportioning and Specimen Preparation

The required quantities of tailings, binder and water that were used for each batch type are summarized in Table 2. The moisture content of the supplied tailings was taken into account to achieve the required workability for a 200-mm slump. The four batches were mixed in a flat pan mixer following the standard procedure for concrete preparation in the laboratory [10]. Compressive and indirect tensile strength specimens were prepared using the standard concrete moulds corresponding to each test. Moulds were removed after 24 hours, and the specimens were placed in plastic containers and closed tightly. The specimens were dry-cured at room temperature until the test time (i.e., 7, 14 and 28 days), to simulate the underground environment where CPB would be placed. After the required curing times, the CPB specimens were subjected to various tests.

Table 2. Main chemical properties of the tailings supplied from FGM.

<table>
<thead>
<tr>
<th>Mix type</th>
<th>Tailings (kg)</th>
<th>Binder (kg)</th>
<th>Water (L)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GPC</td>
<td>FA</td>
<td>SF</td>
</tr>
<tr>
<td>5GPC</td>
<td>93.5</td>
<td>10.8</td>
<td>-</td>
</tr>
<tr>
<td>3FA-2GPB</td>
<td>93.5</td>
<td>4.1</td>
<td>6.5</td>
</tr>
<tr>
<td>1SF-4GPB</td>
<td>93.5</td>
<td>8.0</td>
<td>-</td>
</tr>
<tr>
<td>4GGBS-1GPB</td>
<td>93.5</td>
<td>2.2</td>
<td>-</td>
</tr>
</tbody>
</table>

Strength of Cemented Paste Backfill

**Compressive Strength.** One of the functions of CPB is to provide ground support to create a safe working environment, as well as to minimise surface subsidence. Hence, it is expected that the CPB would have a reasonable compressive strength for both short- and long-term operations. The variation of the compressive strength with curing time is presented in Fig. 2(a). It should be observed that the partial replacement of general purpose cement with fly ash and silica fume caused a reduction in the compressive strength of about 36% - 45% and 12% - 35%, respectively, when compared with the control batch prepared with GP cement. This reduction was independent of the age of the CPB. This shows that the hydration of the binder containing fly ash and silica fume was adversely affected by the
sulphate content present in the tailings. In contrast, partial replacement of GP cement with blast-furnace slag resulted in a strength that is 2 to 3 times higher than the strength of the control batch (5GPC). Typically, GGBS is used as a partial replacement for GP to produce sulphate-resistant concrete, and hence the test results were expected. It is interesting to note that the 4GGBS-1GPB batch displayed a 16% reduction in compressive strength at 14 days. However, the loss in strength is recovered after longer curing times.

![Compressive strength vs Curing time](image1)

![Indirect tensile strength vs Curing time](image2)

**Figure 2.** Effect of binder type and proportion on the strength of the proposed cemented paste backfills: (a) compressive strength; (b) indirect tensile strength.

**Indirect Tensile Strength.** Another function of CPB is to provide stability for a freshly exposed stope. Hence, it is expected that the CPB would have reasonable tensile strength, especially for short-term operations. The variation of indirect tensile strength with curing time is presented in Fig. 2(b). Similar trends were observed as for the compressive strength, and the trends were independent of the age of the CPB. The partial replacement of general purpose cement with fly ash caused a strength reduction of about 15%–28%. Interestingly, the effect of partial replacement of the general-purpose cement with silica fume caused an insignificant change in the strength, when compared with the control batch (5GPC). As expected, the highest indirect tensile strength was obtained by the batch containing GGBS, which had a strength of 2 to 2.5 times higher than the control batch (5GPC). Furthermore, the rate of strength increase was highest for the 4GGBS-1GPB batch.

**Conclusions and Recommendations**

The effects of various binders on the strength of cemented paste backfill produced with tailings from a gold processing plant were discussed in this paper, and the following conclusions can be drawn.

Partial replacement of GP cement with FA resulted in lower compressive and indirect tensile strengths, when compared with the CPB produced only with GP cement, and this result was independent of the curing time. Similar outcomes were obtained when GP cement was partially replaced with SF, although the change in the indirect tensile strength was minimal.

As expected, partial replacement of GP cement with GGBS resulted in a CPB with significantly higher compressive and indirect tensile strengths. In addition, the rate of increase of the indirect tensile strength was highest for this batch (4GGBS-1GPB). Hence, the use of the GGBS binder as a partial replacement for GP cement proved to be the optimal cemented material to produce CPB using the sulphide-rich gold tailings from FGM. However, further research is needed on the elastic properties of the proposed mixes to enable numerical modelling of the performance of CPB in a...
practical mine to be undertaken. Furthermore, as the effect of sulphide has a detrimental long-term effect on the strength of CPB, this aspect also needs further investigation.

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References