Effects of settlement and drainage on strength development within mine paste backfill

T. Belem, M. Benzaazoua, B. Bussière & A.M. Dagenais
Département des Sciences Appliquées, Unité de recherche et de service en technologie minérale
Université du Québec en Abitibi-Témiscamingue, Rouyn-Noranda, Québec, Canada

ABSTRACT: Paste backfill mixture with binder was poured and cast into rigid PVC moulds especially designed to permit load application to the paste in both drained and undrained conditions. After 28 days of curing, uniaxial compression tests and microstructure analysis through the measurements of specific surface area were accomplished to investigate the mechanical strength development within paste backfill samples. The results of the study showed that external loading leads to an increase in compressive strength (UCS) when paste backfill sample is drained, but a reduction of UCS when paste backfill sample is undrained.

1. INTRODUCTION

In the past, the Canadian mine wastes were stockpiled in tailings ponds designed for this specific purpose. However, when such tailings contains sulfide minerals, these react with rainwater oxygen to form acid mine drainage (AMD). This acidified water may also lead to the leaching of heavy metals which can contaminate the environment. However, because of recent environmental legislation, mining companies have the obligation and duty to manage properly the tailings in order to replace the environmental impact.

In order to achieve this legislation, a new type of backfill was then developed, namely the paste backfill, to replace the traditional hydraulic backfill. This new technology reuse the full size fraction of the tailings in a mixture with a binding agent (e.g. ordinary Portland cement, hydraulic minerals, silica fume, etc) and water (e.g. mine process water, rainwater, lake water, etc.) to fill underground mine excavations. The use of paste backfill became an increasingly common practice in the hard rock mines worldwide (Barsoti 1978; Stone 1993; Bodi et al., 1996) and in Canada since the 1990 (Viles and Davis 1989; Landriault 1992 & 1995; Landriault and Lidkea 1993; Landriault and Tenbergen 1995; Landriault et al., 1997; Naylor et al., 1997). Among the numerous advantages attributed to the use of paste backfill one can cite (i) a significant tonnage reduction of tailings to store on surface infrastructures (Hassani and Archibald 1998), (ii) the stability of underground excavations and consequently, an increase in extracted ore body (Mitchell 1989a &b; Lamos and Clark 1989; Lawrence 1992; Petrolito et al., 1998; Ouellet et al., 1998a & b; Benzaazoua et al., 1999a & b; Bernier et al., 1999; Benzaazoua and Belem 2000; Belem et al., 2000), (iii) a reduction in mine operating costs (Hassani and Bois 1992; Hassani and Archibald 1998) and (iv) an increased in safety for miners.

One of the difficulties in using paste backfill is that it is a complex material, in continuous evolution since its preparation in the backfill plant, and through the different stages like its underground delivery by pipelines to the disposal point, its setting in the stope until its short-term, mid-term and long-term hardening in the excavations. Due to this complexity, paste backfill is the object of numerous studies by various research centers and teams. Despite this, many questions remain unanswered concerning physical, chemical and mechanical properties of paste backfill. The object of this study is to understand the effects of settlement and drainage on strength development within in situ paste backfill. The basis for this study was observations made by ground control engineers that the mechanical strength of core samples taken from certain in situ paste backfill was greater (sometimes by a factor of 2) than the one coming from samples of the same paste backfill poured into plastic cylinder moulds and intended to the quality control follow-up. It clearly follows that the differences in mechanical strength between the paste backfill moulded into the plastic cylinders and the in situ core samples coming from the same paste backfill mixtures are likely due to a difference in the mechanical strength development within the paste backfill during curing time (e.g. hydration mode of the binding reagents). Among the numerous probable hypotheses explaining these differences one can cite: (i) in situ exudation or vertical drainage of part of the water used for the paste backfill preparation which favors a rapid and massive formation of binder hydrates (e.g. saturation of hydration reactions), (ii) combination of drainage and settlement of the in situ paste backfill mass and, (iii) confining pressures exerted by the excavation walls on the in situ paste backfill.
Because all the laboratory studies and quality control follow-up are carried on cylindrical plastic moulds of paste backfill, the direct application of such results to mine designs requires that one work with high factor of safety, implying an increase in backfill operating costs.

The purpose of this paper is to identify the probable causes of the differences in mechanical strength between the *in situ* and experimental paste backfills. It is a preliminary and prospective study of the combined effects of paste backfill drainage and settlement on its mechanical strength development. To this end, tailings from a Canadian hard rock mine were sampled for the paste backfill mixtures preparation using 5 wt.% of a binder agent made up of 50:50 of ordinary Portland cement (Type I) and sulfate-resistant Portland cement (Type V). The resulting paste backfill was then poured and cast into rigid PVC moulds especially designed to permit different load application to the paste. Two types of moulds were used: moulds with a perforated bottom to favor drainage and non-perforated moulds to prevent it. Uniaxial compression tests and microstructure analysis and specific surface area measurements were done to investigate the changes in physical properties of paste backfill samples.

2. EXPERIMENTAL PROCEDURES

### 2.1 Tailings characterization

Tailings from a Canadian underground rock mine (mine M1) was sampled after having been filtered for the backfill preparation. Cyanides present in the tailings were removed by the SO$_2$-Air method prior to the filtration process. The resultant tailings contain about 60 wt.% sulfides, essentially pyrite, and thus giving it a specific gravity, $G_s$, of 3.78. Particle size distribution was determined using a Malvern® Mastersizer laser granulometer under humid conditions.

### 2.2 Load application device

To reach the objectives of this study, a device was designed and manufactured that allows load application on the paste backfill mass during the curing process. Figure 1 presents a schematic representation of this device. Two types of experiment set-up with this device were used: (i) the perforated bottom set-up was used to assess the effects of drainage (D-test) and, (ii) the non-perforated bottom set-up for simulating undrained conditions (U-test). Control moulds (perforated and non-perforated bottom) were also used in order to understand the effect of the applied loads on the mechanical strength development within the backfill.

The moulds have an average diameter of 10.125 cm and 24 cm in height. As shown in Table 1, three different loads were applied in the drained and undrained tests: 10 lbs, 20 lbs and 50 lbs. It should be noted that a first load of 5 lbs was applied after 3 days of curing, followed by the addition of 5 lbs per day until the target load is reached. This procedure simulates a sequential backfilling of 0.12 m of paste backfill each day. Thus, the total duration of loading was 2 days for D-test 1 and U-test 1, 4 days for D-test 2 and U-test 2, and 10 days for D-test 3 and U-test 3. Table 1 also presents the values of the loads applied to paste backfill in terms of mass (lbs) and weight (N) and the corresponding simulated backfill column height.

<table>
<thead>
<tr>
<th>Applied mass (lbs)</th>
<th>Applied load (N)</th>
<th>Applied pressure (kPa)</th>
<th>Column height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>10</td>
<td>44.5</td>
<td>5.5</td>
<td>0.23</td>
</tr>
<tr>
<td>20</td>
<td>89.0</td>
<td>11.1</td>
<td>0.47</td>
</tr>
<tr>
<td>50</td>
<td>222.5</td>
<td>27.6</td>
<td>1.18</td>
</tr>
</tbody>
</table>

Tailings, binder agent and water were mixed and kneaded in a 3-speed cement mixer for about 15 minutes in order to obtain a homogenous paste. The mixture was calculated so that the final solid mass percentage, $C_w$, was 78% and the moisture content, $w$, of 28%. This
corresponds to a solid volume percentage, \( C_v \), of 66%, a water-to-cement ratio (w/c) of 6 and a water-to-solids ratio (w/s) of 0.28.

The resulting paste backfill was then poured into the different devices for both D-tests and U-tests (see Fig. 2) according to B.N.Q. 2622-913 standard method and modified by the URSTM Laboratory (procedure PE4 EG-04). This consists of pouring three layers of approximately equal volume, each layer being consolidated by pounding it 25 times with a rounded end stainless steel rod of 9.5 mm in diameter. These blows were evenly distributed over the entire section of each mould. Finally, all samples were stored and conditioned in a humidity chamber at about 70% humidity with an average temperature of 24° for a total curing period of 28 days (see Photo 1). These conditions are similar to those observed in the concerned mine M1.

In the present study, drainage was measured by using the second method, at a time interval of 30 minutes. The first measure was taken 1 hour after molding of the paste. Figure 2b presents the set-up for drainage measurements used in this study, in comparison to the classical percolation test set-up (Fig. 2a). The fundamental difference between these two tests set-up being that in the case of the percolation test an external supply of water is necessary to maintain a constant water level (Fig. 2b).

In the drainage test the starting height of the water column (H) is equal to the height of the backfill column (L). The percolation rate or the drainage rate, \( v \) (cm/s) of the paste backfill is given by the following equation:

\[
\frac{q}{t} = \frac{v}{A}
\]

where \( q = \frac{V}{t} \) is the volume of drained water \( (V) \) at the time interval \( t \); \( A = \) mould section area.

### 2.5 Uniaxial compression tests

After 28 days of curing, all the devices were dismantled (see Photo 2). Uniaxial compression test were done on the recovered samples to determine their mechanical strength. This test consists of placing a sample between two plates of a mechanical press and applying an axial force until the sample breaks. The stress corresponding to this maximum force is the uniaxial compressive strength (UCS). The compression tests were carried out using a rigid mechanical press MTS 10/GL with a loading capacity of 50 kN and a minimum deformation rate of 0.0001 mm/min. The applied force to the sample was measured by a pressure cell while the displacement was measured by a magnetic induction displacement sensor. The accuracy of the force measurement is about 1%. The shape factor (height-to-diameter ratio) of the backfill samples for these tests was of 2.
2.6 **Specific surface area measurements**

The specific surface area, \( S_s \), is a good indicator of the fineness of backfill particles. This fineness depends on both the fineness of the initial tailings and that of the hydrates formed. That is only \( S_s \) can be used to characterize the microstructure of the paste backfill. To be more precise, the specific surface area of a material includes the external and internal surfaces. This measure includes also all of the surface irregularities at the molecular scale level as well as the surface represented by pores in the solid matrix.

As such, the value of the specific surface area allows us to determine the influence of the load application on the strength development within the paste backfill. By definition, \( S_s \) is the ratio of the sum of the surface areas to the mass of the sample (m²/g or m²/kg). The specific surface area measurements were performed by B.E.T method (Brunauer, Emmett and Teller) which consists of an argon adsorption using *Micromeritics® Gemini* surface analyzer.

3. RESULTS

3.1 **Paste backfill drainage and percolation**

3.1.1 **Paste backfill drainage**

As mentioned before, paste backfill drainage was measured by collecting the drained water at a 30 minutes time interval. Drainage period lasted 21 hrs and the total cumulative volume of water collected was about 147 cm³. Figure 3 presents the evolution of collected water as a function of time for the paste backfill sample M1 compared to the data obtained from the paste backfill sample M2 (from another mine not presented in this study). This diagram shows that the quantity of collected water increases gradually with time but seems to plateau after a characteristic time \( t_c = 21 \) hrs.

One can conclude that if this type of paste backfill is placed in mine excavation the resulting drainage will be minimal and almost inexistent after 24 hrs of curing. The validity of this observation is supported by the fact that recuperation of water was continued for 5 days after obtaining a plateau. Also to be noted is the fact that the drainage capacity of backfill sample M1 (present study) is 4 times greater than the one for backfill sample M2. This can be explained in part by the difference in the particle size distribution of these two types of tailings. But in addition to the tailings particle size distribution, the type of binder agent used plays probably a certain role in drainage that has not been identified in this study.

Figure 4 presents the particle size distribution curves of the tailings samples M1 and M2 used for the preparation of paste backfill samples M1 and M2. It should be noted that despite the strong similarity between the particle size distribution of these two types of tailings, the particles of tailings sample M1 are slightly coarser than the one of tailings sample M2. This difference is evident from Figure 5 for parameters \( D_{60} \) and \( D_{90} \).

![Figure 3. Variation in collected water with time elapsed from the beginning of drainage.](image)

![Figure 4. Grain size distribution of tailings samples M1 & M2.](image)
The two curves on Figure 3 are well fitted by the following general regression equation:

\[ V(t) = \frac{V_m \cdot t}{a + t} \]  

where \( t \) (min) = time elapsed from the beginning of drainage; \( V_m \) (cm\(^3\)) = maximum volume of collected water at the end of drainage; \( a \) (min) = constant corresponding to the drainage characteristic time.

Results from regression gave \( V_m = 172.523 \) cm\(^3\) and \( a = 212.899 \) min for the backfill sample M1; and \( V_m = 38.6 \) cm\(^3\) and \( a = 153.303 \) min for the backfill sample M2 with a correlation coefficient \( R = 0.99 \). Although, the maximum total volume of collected water at the end of the test was 147.48 cm\(^3\) for the backfill sample M1 and 37.75 cm\(^3\) for the backfill sample M2. Authors suggest that this equation could be used for different types of paste backfill by calibrating \( V_m \) and the constant \( a \) with regard to the particle size distribution of different types of tailings. \( V_m \) should depend on the particle size distribution of the initial tailings, particularly the parameters \( D_{90} \) and \( D_{60} \) (large fraction) as well as the coefficient of uniformity, \( C_u \), and the void ratio (\( e \)).

3.1.2 Paste backfill percolation rate

Data of the paste backfill drainage (see §3.1.1) were converted into percolation rates (or drainage velocity), \( v \) (cm/s) using Equation 1, and plotted on Figure 6 as a function of time elapsed from the beginning of drainage. As it could be anticipated from the cumulative volume of drained water (Fig. 3), the drainage velocity (or the percolation rate) decreases gradually with time. Under certain conditions, the drainage velocity may be directly related to the coefficient of permeability or hydraulic conductivity \( k \) (cm/s).

Figure 5. Grain size vs cumulative % of passant of tailings samples M1 & M2.

In fact, these two parameters are equivalent if the hydraulic gradient \((H/L)\) used when measuring the percolation rate is 1, when the tortuosity of the porous medium formed by the paste backfill is neglected (Thomas 1966; Hassani and Archibald 1998). These observations are of greater concern for hydraulic backfill.

The percolation data of backfill samples M1 (present study) and M2 (Fig. 6) was best fitted by the regression curves given by the following equation:

\[ v = 10^5 \times (v_0 + a \times t)^{\frac{1}{b}} \]  

where \( t \) (min) = time elapsed from the beginning of drainage; \( v_0 \) (cm/s) = percolation rate at the drainage start; \( a \) and \( b \) = material constants. From the regression curves, \( v_0 = 0.014737064 \) cm/s, \( a = 0.00022823277 \) and \( b = 1.3143908 \) with \( R = 0.999 \) for the backfill sample M1 and \( v_0 = 0.065354171 \) cm/s, \( a = 0.00187135 \) and \( b = 1.1711637 \) with \( R = 0.999 \) for the backfill sample M2.

3.2 Chemistry and geochemistry of collected water

Water drained from the mould was collected for pH, oxydo-reduction potential (Eh) and electric conductivity measurements using a selective electrode. Water was then acidified for chemical analysis by ICP ES (Inductively coupled plasma emission spectroscopy) in order to determine its main ionic elements: calcium (Ca), sulfur (S) and sulfate (SO\(_4\)\(^{2-}\)). Calcium is mainly related to the presence of a binder agent such as Portland cement. The presence of Ca in the collected water can indicate a loss of cement during backfill drainage and in which proportion. Another good indicator of the presence of cement in the collected water is the pH. If the pH is neutral to acidic \((5 \leq \text{pH} \leq 7)\) then the collected water does not contain cement. A basic pH \((\text{pH} \geq 12)\) indicates the presence of cement in collected water. The oxydo-reduction potential can also indicate Ca presence in water.
3.3 Geotechnical properties of loaded paste backfill

Tables 3a and 3b contain the physical and geotechnical parameters obtained from the drained (D-test) and undrained (U-test) paste backfill samples after a curing period of 28 days. These parameters are: the moisture content (w%), and volumetric water content (θ), the solid mass percentage (Cw,%) and water percentage (E%), the density (ρ) and dry density (ρd), solid particles density (ρs), the unit weight (γ) and dry unit weight (γd), the degree of saturation (S%), the porosity (n) and the voids ratio (e).

These parameters indicate a slight variation due to both water leaching and the load application. It is also evident that the voids ratio (e) of the drained control samples is lower than the one of the undrained control samples. These results also show that e slightly decreases with load increases in the case of the drained paste backfill (D-test) and slightly increases with the load increases for the undrained samples (U-test). In this last case, it appears that the load increased the pore water pressure within the backfill which prevented its skeleton from settling. Instead, this pore water pressure favored a gradual relaxation of its physical structure which allowed an increase in the amount of empty pore. This can also be seen by the lower unit weight value of the undrained backfill compared to the one of the drained backfill sample.

3.4. Mechanical behavior of loaded paste backfill

3.4.1 Compressive strength

Applied loads on the backfill and the backfill column height simulated by the addition of loads are presented in Table 1 in terms of mass (lb), weight (N and kN) as well as the corresponding applied pressure (kPa). The simulated height h corresponds to the ratio of the applied weight to the unit weight γ of the paste backfill which equals to 24 kN/m².

Results of uniaxial compression tests are shown in Table 4 for both drained and undrained paste backfill samples, loaded and unloaded control samples.

Table 3a. Physical and geotechnical parameters of drained and undrained paste backfill.

<table>
<thead>
<tr>
<th></th>
<th>Moisture content w (%)</th>
<th>Volumetric water cont. θ</th>
<th>Solid percentage Cw (%)</th>
<th>Water proportion E (%)</th>
<th>Density ρ (g/cm³)</th>
<th>Dry density ρd (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-test (control)</td>
<td>18.9</td>
<td>0.40</td>
<td>84</td>
<td>16</td>
<td>2.55</td>
<td>2.14</td>
</tr>
<tr>
<td>D-1@10 lbs</td>
<td>20.6</td>
<td>0.41</td>
<td>83</td>
<td>17</td>
<td>2.40</td>
<td>1.99</td>
</tr>
<tr>
<td>D-2@20 lbs</td>
<td>19.8</td>
<td>0.40</td>
<td>83</td>
<td>17</td>
<td>2.40</td>
<td>2.00</td>
</tr>
<tr>
<td>D-3@50 lbs</td>
<td>20.1</td>
<td>0.40</td>
<td>83</td>
<td>17</td>
<td>2.42</td>
<td>2.01</td>
</tr>
<tr>
<td>U-test (control)</td>
<td>21.5</td>
<td>0.43</td>
<td>82</td>
<td>18</td>
<td>2.44</td>
<td>2.01</td>
</tr>
<tr>
<td>U-1@10 lbs</td>
<td>21.1</td>
<td>0.42</td>
<td>83</td>
<td>17</td>
<td>2.40</td>
<td>1.98</td>
</tr>
<tr>
<td>U-2@20 lbs</td>
<td>21.5</td>
<td>0.42</td>
<td>82</td>
<td>18</td>
<td>2.39</td>
<td>1.96</td>
</tr>
<tr>
<td>U-3@50 lbs</td>
<td>21.3</td>
<td>0.41</td>
<td>82</td>
<td>18</td>
<td>2.36</td>
<td>1.95</td>
</tr>
</tbody>
</table>
Table 3b. Physical and geotechnical parameters of paste backfill (continued).

<table>
<thead>
<tr>
<th></th>
<th>Saturated unit weight $\gamma$ (kN/m$^3$)</th>
<th>Dry unit weight $\gamma_d$ (kN/m$^3$)</th>
<th>Degree of saturation $S_r$ (%)</th>
<th>Porosity $n$</th>
<th>Voids ratio $e$</th>
<th>Solids density $\rho_s$ (g/cm$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>D-test (control)</td>
<td>25.0</td>
<td>21.0</td>
<td>99</td>
<td>0.41</td>
<td>0.69</td>
<td>3.62</td>
</tr>
<tr>
<td>D-1@10 lbs</td>
<td>23.6</td>
<td>19.6</td>
<td>92</td>
<td>0.45</td>
<td>0.81</td>
<td>3.61</td>
</tr>
<tr>
<td>D-2@20 lbs</td>
<td>23.5</td>
<td>19.6</td>
<td>89</td>
<td>0.44</td>
<td>0.80</td>
<td>3.60</td>
</tr>
<tr>
<td>D-3@50 lbs</td>
<td>23.7</td>
<td>19.7</td>
<td>91</td>
<td>0.44</td>
<td>0.79</td>
<td>3.61</td>
</tr>
<tr>
<td>U-test (control)</td>
<td>24.0</td>
<td>19.7</td>
<td>98</td>
<td>0.44</td>
<td>0.79</td>
<td>3.61</td>
</tr>
<tr>
<td>U-1@10 lbs</td>
<td>23.5</td>
<td>19.4</td>
<td>93</td>
<td>0.45</td>
<td>0.82</td>
<td>3.60</td>
</tr>
<tr>
<td>U-2@20 lbs</td>
<td>23.4</td>
<td>19.3</td>
<td>92</td>
<td>0.46</td>
<td>0.84</td>
<td>3.62</td>
</tr>
<tr>
<td>U-3@50 lbs</td>
<td>23.2</td>
<td>19.1</td>
<td>90</td>
<td>0.46</td>
<td>0.85</td>
<td>3.60</td>
</tr>
</tbody>
</table>

Figure 8 shows the variation in paste backfill compressive strength as a function of applied load.

The first major observation is that compressive strength of the drained samples is always higher than the one of the undrained samples. It can also be observed that the UCS of drained backfill samples increase with increasing load while the UCS of undrained backfill samples decreases with increasing load (Fig. 8).

Table 4. Uniaxial compressive strength of drained and undrained paste backfill samples.

<table>
<thead>
<tr>
<th>Applied mass (lbs)</th>
<th>Applied load (kN)</th>
<th>UCS of drained sample (kPa)</th>
<th>UCS of undrained sample (kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>1 141</td>
<td>735</td>
</tr>
<tr>
<td>10</td>
<td>5.5</td>
<td>1 000</td>
<td>845</td>
</tr>
<tr>
<td>20</td>
<td>11.1</td>
<td>1 048</td>
<td>835</td>
</tr>
<tr>
<td>50</td>
<td>27.6</td>
<td>1 097</td>
<td>763</td>
</tr>
</tbody>
</table>

Load applications on the drained backfill samples lead to a more rapid drainage which favors the formation of hydrates caused by the saturation of hydration reaction, thus increasing mechanical strength. For the undrained paste backfill, load applications increase pore water pressure which can cause the break of cement bonds, thus favoring a reduction in mechanical strength. This reduction can also be due to the inhibition of the hydration reaction by the surplus of water in the backfill.

3.4.2 Stress-strain behavior of loaded paste backfill

Figures 9 and 10 present the stress-strain curves of the drained and undrained paste backfill samples, respectively. These figures show that when cured under loading conditions, this type of paste backfill exhibits an elastoplastic behavior, whether drained or not. These figures also show clearly the stress-strain curve of the control drained backfill sample is above the loaded samples curves. For each type of sample, these curves show that the loads do not have much influence on the deformability of the backfill (linear ascending part of the curves).

Figure 8. Variation in UCS with applied load pressure.

Figure 9. Stress-strain curves of drained paste backfill (D-test).

Figure 10. Stress-strain curves of undrained backfill (U-test).
3.5 Microstructural analysis of loaded paste backfill

Table 5 presents the values of specific surface area ($S_s$) of drained and undrained paste backfill samples. This parameter provides indirect information about the microstructure of paste backfill during the course of its curing. Indeed, by describing the degree of particle fineness, this parameter takes into account the binder agent hydrates formed. Consequently, the specific surface area can be related to the compressive strength of paste backfill.

However, when comparing the specific surface area values of both drained and undrained samples, there is a difference in favor of the undrained backfill samples.

<table>
<thead>
<tr>
<th>Applied mass</th>
<th>Applied load</th>
<th>$S_s$ (drained)</th>
<th>$S_s$ (undrained)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(lbs)</td>
<td>(kN)</td>
<td>(m$^2$/kg)</td>
<td>(m$^2$/kg)</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
<td>6547.2</td>
<td>6952.6</td>
</tr>
<tr>
<td>10</td>
<td>5.5</td>
<td>6668.0</td>
<td>7672.6</td>
</tr>
<tr>
<td>20</td>
<td>11.1</td>
<td>7076.5</td>
<td>7274.1</td>
</tr>
<tr>
<td>50</td>
<td>27.6</td>
<td>6416.9</td>
<td>6959.3</td>
</tr>
</tbody>
</table>

Figure 11 is a graphical representation of data in Table 5. One can note that contrary to the mechanical strength (Figure 8), the specific surface area of drained backfill is always lower than the one for undrained backfill. For the undrained backfill, $S_s$ increases from the unload state (control) up until the application of the first 10 lbs, 5 days after moulding of the samples.

The specific surface area then decreases after the application of the 20 lbs and the 50 lbs loads. For the drained backfill, however, $S_s$ increases slightly from the unload state to the point when the 10 lbs load was added and continuing to do so with the application of the 20 lbs load before decreasing under the application of the 50 lbs load.

4. DISCUSSION

Figures 12 and 13 show the variation in compressive strength of paste backfill and $S_s$ as a function of applied pressure for drained and undrained samples, respectively.

Previous work on undrained paste backfill (Benzaazoua et al. 1999) has provided evidence for the existence of a proportionality relationship between the specific surface area, $S_s$, and the binder agent proportion used in the paste backfill and consequently, its UCS value.

From the curves of Figure 12, there does not seem to exist a proportionality relationship between $S_s$ and compressive strength for the drained backfill samples. As a matter of fact, the highest UCS value is not associated to the highest $S_s$. From the drained water analysis, we know that there was not any loss of solid anhydrous cement or tailings particles. Moreover, assuming that drainage diminished the amount of pore water in the backfill, saturation of the hydration reaction of the binder agent should be favored, thus precipitating a significant amount of hydrates. These hydrates should generate strong cement bonds within the backfill and consequently, strong compressive strength (UCS). However, on Figure 12, the UCS varies in opposite direction of $S_s$. This has yet to be understood.
In contrast, the curves for the undrained backfill on Figure 13 suggest that the $S_s$ is proportional to the compressive strength. Indeed, the greatest value of the specific surface area is associated to the highest value of compressive strength.

5. CONCLUSION

This preliminary study has demonstrated that load applications have a significant influence on the strength development within drained and undrained paste backfill samples. Loading leads to an increase in mechanical strength when the paste backfill is drained, but a reduction of UCS when the paste backfill sample is undrained.

In the case of drained paste backfill samples, the chemistry of collected water showed a loss of a small proportion of anhydride cement (0.12%). The increase in mechanical strength is probably due to both the settlement of particles and the massive formation of hydrates. In the case of undrained backfill samples, the reduction in mechanical strength due to load application may be explained by the development of pore water pressure within the paste backfill. Microstructure analysis via $S_s$ seems to confirm these results, but further research is needed.

6. ACKNOWLEDGMENTS

This research was supported by the Fond de l'Université du Québec en Abitibi-Témiscamingue (FUQAT) under grant N3-2052397. The authors gratefully acknowledge their support. The authors would also like to thank our mining partner, Agnico Eagle (Laronde Division) and Aur-Novicourt-Teck (Louvicourt Mine) for their collaboration in the completion of this work. Also, thanks to Hugues Bordeleau, technician at URSTM, for performing the experiments.

7. REFERENCES


