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One-dimensional consolidation parameters of cemented paste backfills

Introduction

Each year, a vast amount of mine waste (mainly fine-grained tailings and coarse-grained waste rocks) is generated by mine and mill operations worldwide (Aubertin et al. 2002; Bussičre 2007; Yilmaz 2011). Fine-grained tailings are typically either discharged in slurry form to surface tailings dams or delivered in cementitious form to underground stopes as backfilling, while coarse-grained rocks are stored by depositing as a dry material in large dumps (Khalili et al 2007). The engineering design of surface tailings dams or underground mine stopes is often controlled by the high compressibility and low shear strength characteristics of fine-grained tailings. Saturated, fine-grained backfills can undergo major consolidation settlement during early curing ages [stages?].

When compared to other forms of backfilling, such as slurry and rock fills, cemented paste backfill CPB is a promising tailings management process for most modern mines because it provides a rapid rate of delivery and placement, and is made up of recyclable, fine-grained tailings. CPB is produced by mixing ever higher density dewatered tailings (65–90 wt% solids content) with a hydraulic binding agent (which can be a blend of two or more cements and mineral additives, 1–9 wt%) to provide mechanical strength and stability, and mixing water (e.g., lake, process, or tap water) to obtain the desired slump value (6–10") allowing the safe transport and placement of the final CPB material in the underground

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stopes (Hassani, Archibald, 1998; Benzaazoua et al. 1999). A few studies regarding the physico-chemical and mineralogical characteristics of CPB ingredients (i.e. tailings, binder, and water) on strength acquisition and microstructural properties have been conducted by focussing on interrelationships between grain size, solids concentration, binder type and proportion, curing age and temperature, and pore structure (Benzaazoua et al. 2004; Kesimal et al. 2005; Ouellet et al. 2007; Tariq, Nehdi 2007; Tariq, Nehdi 2007; Fall et al. 2008; Ercikdi et al. 2009; Belem, Benzaazoua 2008; Yilmaz et al. 2011). However, certain aspects linked with *in situ* properties and conditions that affect the performance of CPB are not well identified. Actually, the effects of during- and after-placement conditions on the quality and behaviour of fresh and hardened CPB cured under effective stress have not yet been sufficiently investigated (Belem et al. 2002, 2006; Yilmaz 2010).

It is common practice at most modern underground mines to place CPB in sequence (plug fill and residual fill), except for small-scale mines where backfill placement is continuous and governed by a constant filling rate based on the plant capacity. Overall, it is essential to pour an initial “plug-fill” of CPB and then let it cure under self-weight consolidation over a couple of days (2–7 days) in order to achieve a good cement bonding and to prevent barricade failure during subsequent residual filling. Due to gradual reduction in the void ratio after consolidation, the stiffness of backfilling increases over the curing time (Bussiere 1993; le Roux et al. 2002; Cayouette 2003; le Roux 2004; Belem et al. 2006; Hsu, Lu 2006; Helinski etal. 2007; Grabinsky, Bawden, 2007; Fahey et al. 2010). In some cases, a “continuous” filling application may damage cement bonds or yield barricade failures due to excess strain and stress developed within CPB during placement (Yumlu, Guresci 2007; Page 2009). Thus, it is of great importance to understand self-weight and surcharge load consolidation characteristics of fresh CPB materials.

In this study, a new laboratory consolidation apparatus named CUAPS (curing under applied pressure system) that allows one-dimensional consolidation testing of CPB materials was developed (Benzaazoua et al. 2006; Yilmaz et al. 2010). The originality of the present work is its focus on relations between the effects of curing, void ratio, and binder content on the quality and behaviour of CPB. More specifically, it addresses the effect of binder content and curing time on one-dimensional consolidation characteristics (e.g. coefficient of consolidation c_v, coefficients of compression index C_c, and recompression index C_r) as well as the resulting physical and geotechnical properties (e.g. void ratio e_f, degree of saturation S_f, water content w_f, settlement S_p, vertical strain ε_v, and specific surface S_s). Five binder proportions (0-control sample, 1, 3, 4.5, and 7 wt%) and four curing times (0, 1, 3, and 7 days) were considered during the experimental testing.

1. Material and Method

1.1. Tailings sample characterization

Sulphide-rich tailings were collected from the LRD mine in Quebec, Canada. Samples were received in sealed plastic containers to avoid any oxidation. The laboratory test results showed that the tailings sample had an average water content w of 23.4 wt%, a specific gravity G_s of 3.7, a specific surface S_s of 2170 m^2/kg, an optimum water content w_{opt} of 9.1 wt%, a maximum dry unit weight g_{dmax} of 24.9 kN/m^3, a relative compaction R_c of 91 wt%, a liquid limit w_L of 23 wt%, a plastic limit w_P of 18 wt%, a liquidity index LI of 1 wt%, a plastic index PI of 5 wt%, and a clay activity A (simply defined as the PI divided by the percent of clay-sized particles present, < 2 µm) of 1. The Atterberg limit results showed that the tailings sample would be designated as CL-ML, silty clay. A laser diffraction-type particle size analyzer (Malvern Mastersizer) was used to determine the tailings' particle size distribution (PSD). PSD results showed that the sample contained only 4.7% of clay-sized particles. Most of the PSD fell within the category of medium to fine sand and silt-sized particles. With the fines' (< 20 µm) content of 44%, the sample was classified as medium size tailings material (Landriault 2001). The uniformity coefficient ($C_u = D_{60}/D_{10}$) and curvature coefficient ($C_c = D_{30}^2/D_{60}D_{10}$) of the tailings sample were 7.9 and 1.1 respectively. Based on the USCS classification (Das 2002), the tailings material tested was a low plasticity silt (ML).

Table 1 tabulates X-ray diffraction (XRD) analysis and ICP-AES analysis results for the studied tailings sample. It can be concluded from XRD analysis that the sample contains a high proportion of pyrite (47.05 wt%), mainly responsible for the high G_s of the tailings (3.7). The other major minerals are quartz (31.6 wt%), chlorite (8.9 wt%), paragonite

TABLE 1

Chemical and mineralogical analyses results

TABELA 1

Wyniki analizy chemicznej i mineralogicznej

Element (ICP)	Grade [%]	Mineral (XRD)	Grade [%]
Aluminum, Al	2.8	Pyrite	47.05
Calcium, Ca	0.57	Quartz	31.6
Iron, Fe	27.4	Chlorite	8.9
Sodium, Na	0.3	Paragonite	7.31
Lead, Pb	0.1	Muscovite	2.92
Sulphur, S	20.6	Talc	1.34
Potassium, K	0.2	Gypsum	0.84
Zinc, Zn	0.35	Albite	0.04

(7.31 wt%), and muscovite (4.60 wt%). The ICP-AES analysis also indicates iron Fe (27.4 wt%) and sulphur S (24.9 wt%) are the most abundant elements identified within the tailings sample.

1.2. Binding agent

The binder used for CPB preparation was a blend of 20 wt% of ordinary Portland cement (type I or PCI) and 80 wt% of ground granulated blast furnace slag (Slag). Five different binder contents were considered for each test series: 0 (control sample), 1, 3, 4.5, and 7 wt%. Table 2 tabulates the chemical and physical properties of the binder used in the mixtures.

TABLE 2

Chemical composition and physical properties

TABELA 2

Skład chemiczny i właściwości fizyczne

Properties	PCI	Slag	PCI-Slag (20–80 wt%)
G_s	3.08	2.89	2.92
S_s [m²/kg]	1 580	3 540	2 840
Al_2O_3 [%]	4.86	10.24	8.39
CaO [%]	65.76	31.41	42.82
Fe_2O_3 [%]	2.44	0.55	0.64
MgO [%]	2.21	11.29	6.19
Na_2O [%]	2.11	2.01	2.03
SO_3 [%]	3.67	3.27	3.35
SiO_2 [%]	19.51	36.22	30.91
Hydraulic index	0.36	1.09	0.80

The hydraulic index ($[SiO_2 + Al_2O_3]/[CaO + MgO]$) values of the binders are 0.36 and 1.09 for PCI and Slag binders, respectively. Metallurgists classify slag as either basic or acidic – the more basic the slag, the greater its hydraulic activity in the presence of alkaline activators (Lea, Hewlett 2000). Physical characterization indicates that the specific surface area S_s and the specific gravity G_s for Slag binder and PCI are 3540 m^2/kg and 1.58 and 2890 m^2/kg and 3.08 respectively.

1.3. Mixing water

Two types of water, the recycled process water and tap water, were used for preparing CPB mixtures. Their chemical and geochemical compositions are listed in Table 3.

TABLE 3

Chemical and geochemical analyses results

TABELA 3

Wyniki analizy chemicznej i geochemicznej

Parameter	Recycled process water	Tap water
Al [ppm]	0.212	0.01
Ca [ppm]	559	40.9
Fe [ppm]	0.011	0.066
Mg [ppm]	1.83	2.27
Si [ppm]	0.891	0.901
SO_4^{2-} [ppm]	4 882.8	137.8
pH	9.41	7.82
EhN [mV]	146.6	430.7
EC [mS/cm]	7.42	0.274

The mine recycled process water is very highly aggressive with respect to sulphate content (4882.8 ppm) but also contains calcium Ca of 559 ppm because of the addition of lime during milling. Tap water used within the CPB mix contains a Ca concentration of 40.9 ppm and a magnesium Mg concentration of 2.27 ppm. A Benchtop pH/ISE meter Orion Model 920A coupled with a Thermo Orion Triode combination electrode (Pt-Ag-AgCl; Orion) was used for the pH, redox potential Eh, and electrical conductivity (EC) measurements. In addition, Table 3 gives the pH, Eh, and EC parameters for recycled process and tap waters.

1.4. Mixing, pouring, and curing of paste backfills

The required amounts of CPB ingredients such as mine tailings, cement, and water were prepared in a Hobart mixer (Model No D 300-1). The mixing procedure was as follows. In order to ensure the homogeneity of the final paste material, tailings – accompanied by a limited quantity of water – were first mixed by a rigid "B" stainless beater for 4 minutes at a low speed of 54 rpm (speed 1). The cement was then added and mixed by a floppy "D" wire whip for 4 minutes at a medium speed of 100 rpm (speed 2). Later, the remaining water was added to the premixed materials and mixed with the same beater for 4 minutes at a high speed of 183 rpm (speed 3). Accordingly, the total mixing time for CPB materials was 12 minutes. Each CPB mix had a typical water content of 28.2 wt% (corresponding to a solids concentration of 78 wt%) and diverse binder contents (0, 1, 3, 4.5, and 7%). CPB containing 1, 3, 4.5, and 7 wt% binders had a water-to-cement ratio of 27.8, 9.7, 6.5, and 4.3 respectively. Each CUAPS cell or apparatus was then poured with the CPB material into a Perspex transparent cylinder in three equal thickness layers of ~68 mm. Each layer was rammed with 25 blows using a 1/4" diameter steel rod in order to eliminate any large, trapped air

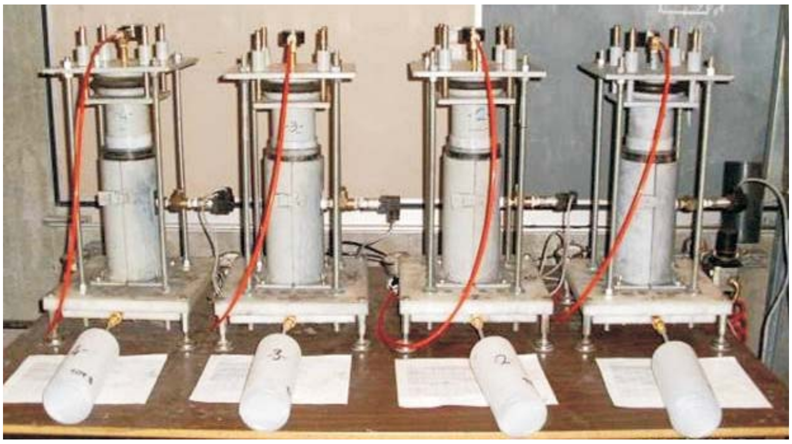

Fig. 1. A series of one-dimensional consolidation tests conducted on CPB samples being cured for 0, 1, 3 and 7 days

Rys. 1. Seria jednowymiarowych testów konsolidacyjnych prowadzonych na próbkach CPB po 0, 1, 3 i 7 dniach utwardzania

bubbles within the sample. After the paste was poured into cylinders, the top porous stone, the loading piston, and platen connected to a pneumatic pressure line were then placed (Fig. 1).

A total of 20 test samples (16 cemented tailings and 4 uncemented tailings as a control sample), having a 4" diameter and 8" height, were prepared and cured for 0, 1, 3, and 7 days at a room temperature of 20–25°C and relative humidity greater than 70%. It has been observed that, for a given binder content, the slump values measured by means of an Abrams cone (ASTM C143 standard) ranged between 165 mm and 254 mm. Slump in this range was suitable for safe placement without segregation as testified by a number of underground mines worldwide (Potvin et al. 2005).

1.5. One-dimensional consolidation tests

The one-dimensional consolidation tests, based on the ASTM D2435 and D4186 standards, were performed using CUAPS (curing under applied pressure system) cells in order to investigate the effects of binder content and curing time on the evolution of CPB microstructure and to simulate *in situ* placement of lab-prepared CPB. Basically, the CUAPS is a consolidometer having a polycarbonate cylinder as the CPB sample holder and a pneumatic pressure system, including porous stone discs, to cover the top and bottom ends of the backfill sample in order to enable pore water to escape from the CPB as compression is taking place. A complete description of the CUAPS employed in the experiments is beyond the scope of this paper. More information on this laboratory tool and some related works can be found in Benzaazoua et al. (2006) and Yilmaz et al. (2006, 2008) and Yilmaz (2010).

One-dimensional consolidation tests were carried out on CPB samples under time-dependent loading. Immediately after samples were placed into the consolidometer, a pre-contact pressure of 15 kPa was applied in order to put the piston and the top porous stone in contact. Then, the pressure sequence of 0.5, 25, 50, 100, 200, and 400 kPa was applied to the CPB material and vertical displacement was recorded following a time interval of 0, 2, 4, 6, 8, and 10 hours. The load increment ratio (LIR) was 1 ($\Delta\sigma/\sigma$, where $\Delta\sigma$ = increase in pressure and σ = pressure before the increase). Pressure was applied following this LIR until the maximum pressure of 400 kPa was reached. During consolidation tests, test data such as pressure, deformation, and time were concurrently and continuously recorded and stored in a data logging system. These data could be recovered and downloaded on a laptop for a total test duration of 7 days. In the tests, at first, samples were allowed to cure under self-weight consolidation until the predetermined curing time and, later, pressure was incrementally applied varying from 0.5 to 400 kPa to simulate time-dependent consolidation.

2. Consolidation Test Results

2.1. Effect of binder content on consolidation properties

Variations in the initial void ratio e_0 of uncemented tailings and cemented paste backfills during one-dimensional consolidation tests versus applied pressure (*log p*) are presented in Fig. 2. One can say from Fig. 2 that, in spite of the major difference in the magnitude, the overall trend of the variation in the void ratio (Δe) versus pressure is similar and decreases with curing time.

Table 4 summarizes the variation of the difference between the initial (e_0) and the final (e_f) void ratios for four binder contents and curing times. It can be observed that for a given

TABLE 4

Magnitude of variation of void ratio

TABELA 4

Wielkość zmienności wskaźnika porowatości

Curing time	$\Delta e = e_0 - e_f$			
	1 wt%	3 wt%	4.5 wt%	7 wt%
0-day	0.25	0.24	0.23	0.18
1-day	0.24	0.23	0.21	0.17
3-day	0.21	0.19	0.18	0.08
7-day	0.20	0.08	0.06	0.05

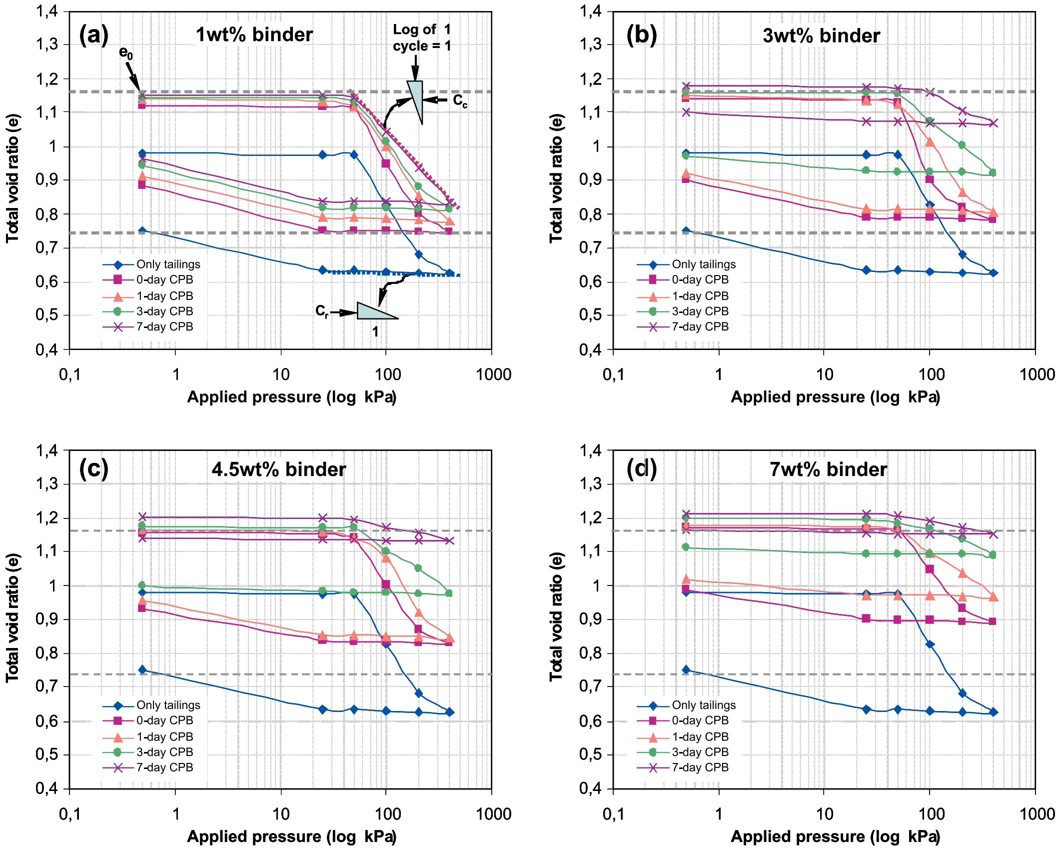

Fig. 2. Consolidation curves of CPB samples
a – 1 wt%, b – 3 wt%, c – 4.5 wt%, d – 7 wt% binder

Rys. 2. Krzywa konsolidacji próbek CPB; udział wagowy spoiwa
a – 1%, b – 3%, c – 4,5%, d – 7%

curing time, Δe decreases with increasing binder. For a given binder content, Δe decreases with increasing curing time. Let us consider Δe as «resistance to consolidation» of CPB material. Hence, a low Δe value means high resistance to consolidation, while a high De value means low resistance to consolidation. This resistance to consolidation is highest for the 7-day curing time, which can be explained by the strength gain because of the gradual formation of cement bonds during hydration.

2.2. Evolution of compressibility parameters

Compressibility parameters (i.e. compression index C_c, recompression index C_r, and coefficient of consolidation c_v) are obtained from the linear portions of one-dimensional consolidation curves in Fig. 2. The compression index C_c of the CPB material decreases in a non-linear fashion with the increase in curing time, regardless of the binder content (Fig. 3).

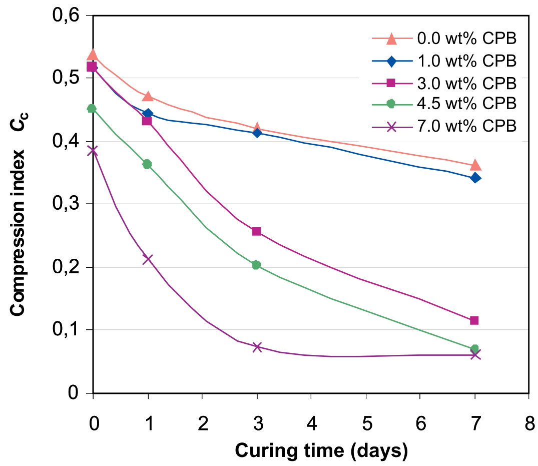

Fig. 3. Compression index vs. curing time

Rys. 3. Wskaźnik kompresji w funkcji czasu utwardzania

On the other hand, the rate of decrease in C_c with curing time is higher with the increase in the binder content because the CPB matrix becomes increasingly rigid. By increasing the binder from 0 wt% to 7 wt%, the C_c value is reduced by about 30% and 83% for 0-day and 7-day curing time respectively. For CPB with binder content of 7 wt%, the C_c value is reduced by 82%, while for the binder content of 1 wt% this reduction is about 34%.

Fig. 4 shows the variation of C_r with curing time for the samples tested. It can be observed that the C_r value decreases linearly with the increase in curing time, regardless of the binder proportion. This linearity seems to relate the evolution of C_r to the elastic properties of the CPB material. The calculated C_r values are very low compared to C_c values. This can be

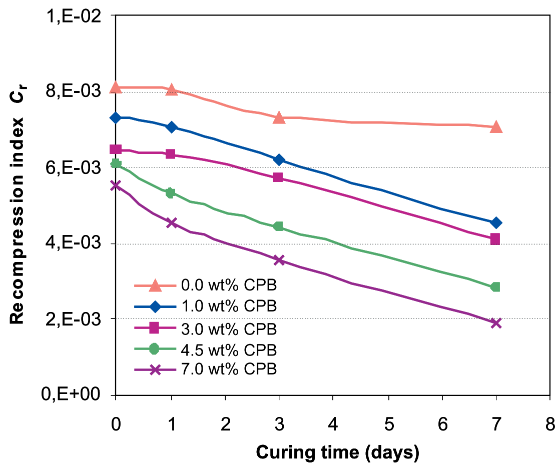

Fig. 4. Recompression index vs. curing time

Rys. 4. Wskaźnik dekompresji w funkcji czasu utwardzania explained by the fact that once the CPB is compressed (packed), the recompression phase affects its skeleton very little.

3. Discussion

3.1. Calculated coefficient of consolidation c_v

Fig. 5 shows the variation in the coefficient of consolidation c_v with curing time. Coefficient c_v was estimated from the square root of time or Taylor's method ($c_v = 0.848 \cdot \cdot H_{dr}^2/t_{90}$). It can be observed that the value c_v decreases with the increase in curing time, regardless of the binder content. Also, for a given curing time, the c_v value slightly increases with the increase in binder content.

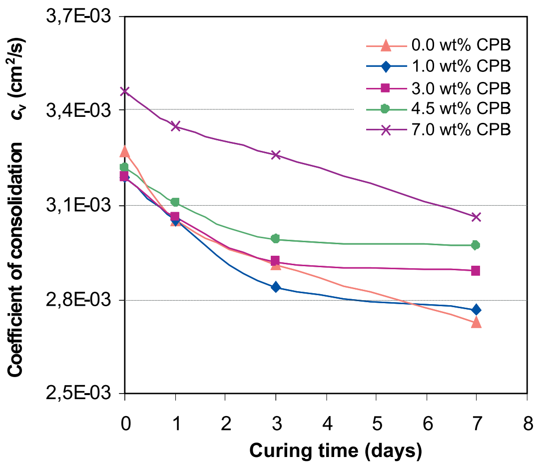

Fig. 5. Variation of CPB c_v with curing time

Rys. 5. Zmiana współczynnika konsolidacji c_v w zależności od czasu utwardzania

3.2. Calculated hydraulic conductivity k_{sat}

Fig. 6 shows the calculated CPB theoretical saturated hydraulic conductivity k_{sat} ($= c_v \cdot m_v \cdot g_w$) from values c_v and the coefficient of volume compressibility m_v (Taylor's method) values. The overall trend is similar to that of the variation in compression index (C_c) with curing time (see Fig. 4). It can be noted that for binder content varying from 0% to 4.5% by dry mass, the calculated k_{sat} decreases quasi-linearly with the increase in curing time. This k_{sat} decrease becomes non-linear when the binder content used in the CPB mix is of 7 wt%. Previous work done by Godbout (2005) showed that the measured k_{sat} decreases non-linearly with the increase in curing time, contrary to what was calculated in this study.

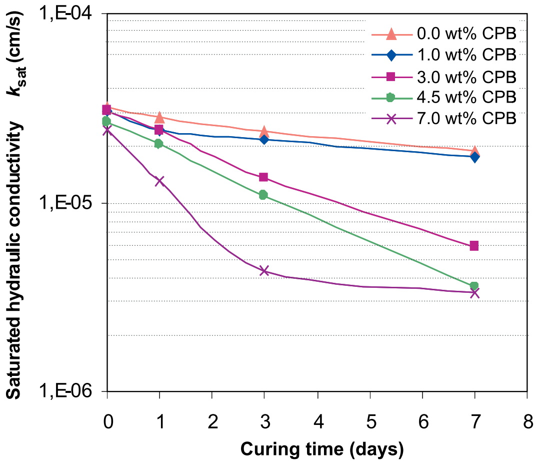

Fig. 6. Calculated CPB k_{sat} vs curing time

Rys. 6. Obliczona hydrauliczna przewodność k_{sat} w zależności od czasu utwardzania

However, data presented in Fig. 6 are overall in the same orders of magnitude as those obtained by Godbout (2005) for an identical binder type, binder content, and curing times even if they are slightly lower. However, in previous works it was stated that the calculated k_{sat} was lower than the measured k_{sat}. It should be noted that the samples tested in the study done by Godbout (2005) were not consolidated – in contrast to the samples tested in this present study.

3.3. Evolution of the physical parameters

Figs. 7–8 show the evolution of the final values of different physical index parameters calculated after 1-D consolidation tests performed on both tailings and CPB. Fig. 7a shows that binder content strongly affects the final void ratio e_f of consolidated CPB samples. Also, the increase in curing involves the increase in the final void ratio e_f. This is probably due to the precipitation and the formation of the hydration products within the CPB matrix. As an example, for 7wt% binder, e_f increases from 0.99 to 1.17 as curing time increases from 0 to 7 days. Fig. 7b also shows a variation in water content w_f with curing time. As the curing time increases from 0 to 7 days, CPB containing 1wt% and 7wt% binders reduces the w_f value from 23.5 wt% to 20.6 wt% and from 19.2 wt% to 14.1 wt% respectively. Knowing that the initial water content w_0 is 28.2 wt%, the first major drop in water content can be explained by water drainage due to stress application (0.25 to 400 kPa). In terms of the final degree of saturation (S_{rf}), this corresponds to a reduction in the initial degree of saturation (S_{ri} = 100%) by 10% for 1wt% binder and by 21% for 7wt% binder. The rest of the reduction (~7% and 15% for binder contents of 1 wt% and 7wt% respectively) can be attributed to binder hydration. It can also be noted that the binder type used (CP10-slag/20-80) – especially 7wt% binder – seems to support the mixture water drainage of fresh CPB.

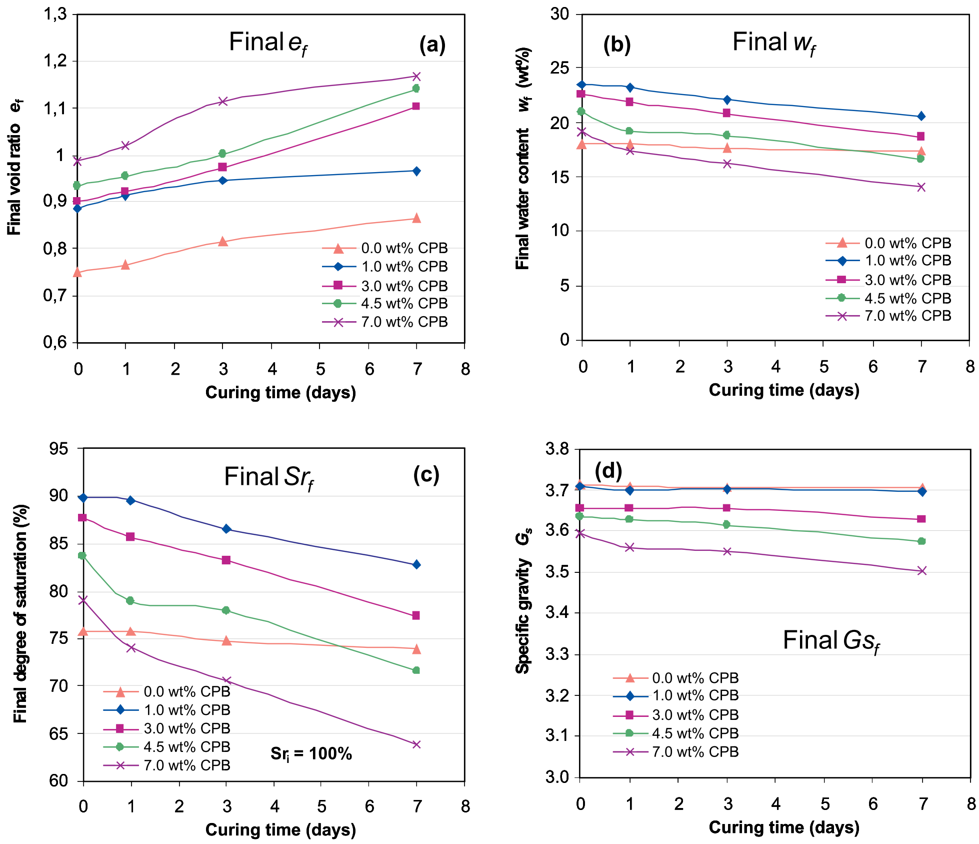

Fig. 7. Evaluation of the CPB final index properties as a function of curing time
a – void ratio, b – water content, c – degree of saturation, d – specific gravity

Rys. 7. Ocena końcowych indeksów właściwości próbek CPB w funkcji czasu utwardzania
a – wskaźnik porowatości, b – zawartość wody, c – stopień nasycenia, d – gęstość właściwa

The reduction in the paste backfill water by drainage, in fact, gives rise to a more dense structure (higher solids concentration) having a lower final degree of saturation S_r, as shown in Fig. 7c. It can be observed that, as the binder content increases from 1 to 7 wt%, S_r decreases from 98% to 72% for 0-day curing time and 79% to 64% for 7-day curing time. Fig. 7d shows that the specific gravity varies slightly and remains almost constant with curing time and binder content. After 7 days curing time, G_s decreases slightly from 3.7 to 3.64 when the binder content is increased from 0 to 7 wt%.

Fig. 8a shows that vertical strain Í$_v$ decreases with increasing curing time, depending substantially on the amount of binder used in the CPB mixture. This is because there is a progressive formation of cement bonds with curing time which develop the material's stiffness and prevent deformation. The exact same observations were made for the primary settlement (Fig. 8b). Fig. 8c shows the evolution of cumulative drainage water W_d as a function of time. It can be observed that for the vertical strain ε_v, the cumulative drainage

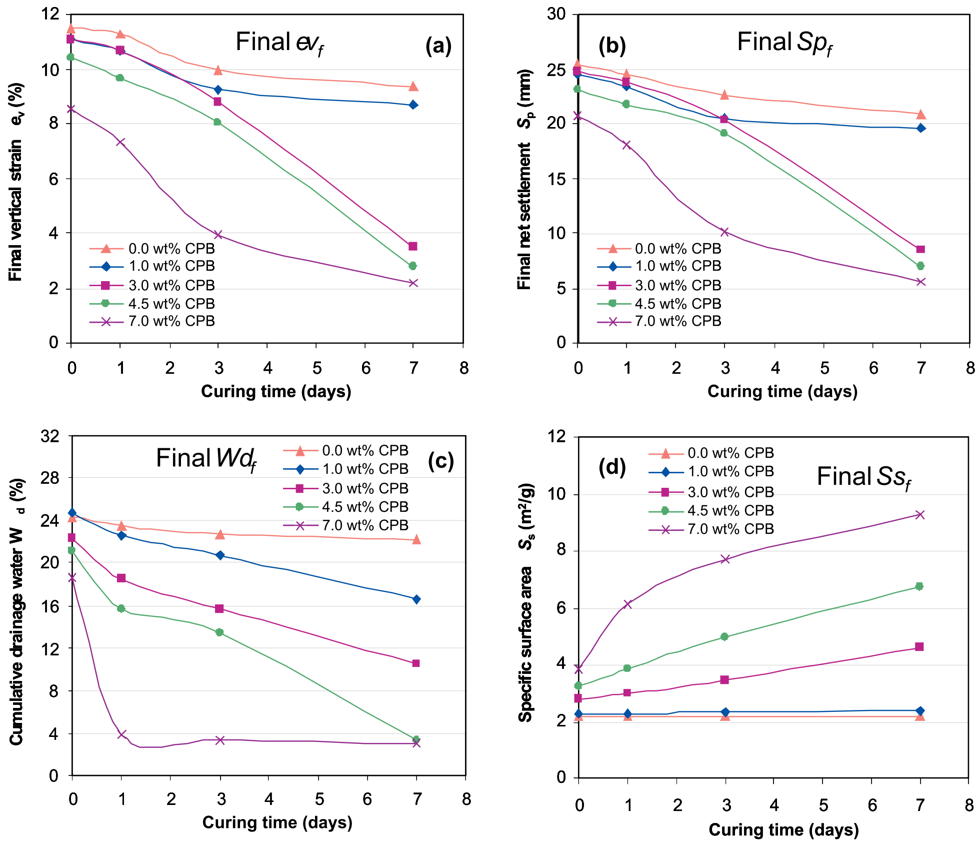

Fig. 8. Evaluation of the CPB final index properties as a function of curing time
a – strain, b – settlement, c – cumulative drainage water, d – specific surface

Rys. 8. Ocena końcowych indeksów właściwości próbek CPB w funkcji czasu utwardzania
a – odkształcenia, b – osiadanie, c – łączny odsącz, d – powierzchnia właściwa

water significantly decreases with the increase in curing time and depends greatly on the binder proportion. This is most probably due to the increase in CPB matrix stiffness with curing time, which allowed less drainage water volume to be collected once the pressure was applied (p = 400 kPa) and, at early ages (< 5 days), hydration reactions took place. For the CPB sample containing 7wt% binder, W_d decreases drastically from 18.6% to about 3% when the curing time increases from 0 to 7 days. Finally, the variation in the specific surface area S_s of CPB samples as a function of curing time is illustrated in Fig. 8d. The overall trend is that S_s value increases proportionally with increasing binder content because of the gradual formation of the cement hydration products which eventually filled the void space.

Conclusion

This study presents the effects of curing time and binder content on one-dimensional consolidation parameters and resulting hydraulic properties (e.g. saturated hydraulic conductivity k_{sat} and degree of saturation S_r) of early age CPB samples. The main conclusions from this work are as follows:

1. Coefficient of consolidation c_v is greatly affected by the CPB binder content as a function of curing time. The overall trend is that c_v increases with the increase in binder content and decreases with curing time.
2. Compressibility parameters such as compression index C_c and recompression index C_r decrease as the curing time increases.
3. The calculated saturated hydraulic conductivity k_{sat} (based on Taylor's method) and degree of saturation S_r decrease with increased curing time and are in agreement with the measured values from existing data.

Finally, this study has shown that the knowledge of 1-D consolidation of the CPB materials can effectively aid in the understanding of their placement and curing process during backfilling. More importantly, it brings to light the effect of consolidation on CPB properties, which can help operators to prepare a very efficient CPB design for underground hard rock mines.

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PARAMETRY JEDNOWYMIAROWEJ KONSOLIDACJI PODSADZKI W POSTACI CEMENTOWEJ PASTY

Słowa kluczowe

Odpady (szlamy), współczynnik konsolidacji, indeks kompresji, zawartość spoiwa (lepiszcza), okres utwardzania

Streszczenie

W procesach pozyskania i przeróbki węgla powstają duże ilości odpadów dwóch rodzajów: drobnoziarniste odpady (muły) i gruboziarniste – odpady skały płonnej. Odpady drobnoziarniste (muły) są odprowadzane jako zawiesina na stawy osadowe lub kierowane są do wypełnienia zrobów w podziemiach kopalń, natomiast odpady gruboziarniste zazwyczaj są składowane w postaci suchego materiału na hałdach. Składowiska tych odpadów, zarówno powierzchniowe jak i podziemne, wymagają częstych kontroli ze względu na dużą kompresję (ściśliwość) oraz płynięcie (ścinanie). Drobnoziarniste odpady nasycone cementem CPB (*Cement Paste Backfill*) mogą we wczesnych stadiach utwardzania ulegać konsolidacji w procesie osiadania w zrobach. Aby przygotować odpowiednią mieszaninę do wypełnienia zrobów konieczna jest dobra znajomość całkowitej wielkości i różnic w osiadaniu CPB utwardzanych w warunkach ciśnienia. Parametry konsolidacji CPB mogą być badane w warunkach laboratoryjnych z wykorzystaniem ulepszonego zestawu aparaturowego o nazwie CUAPS (*Curing Under Applied Pressure System*) – utwardzanie pod ciśnieniem. Taka konfiguracja jest w stanie symulować warunki utwardzania CPB, a więc pomiar parametrów konsolidacji przy efektywnych naprężeniach w zakresie od 0,5 do 400 kPa. W tym przypadku, seria jednowymiarowych prób konsolidacji prowadzona była na próbkach PCB, umożliwiających zbadanie wpływu rodzaju spoiwa i czasu utwardzania na właściwości kompresji (np. współczynnik konsolidacji C_v, wskaźnik kompresji C_c i wskaźnik dekompresji C_r) oraz końcowe właściwości geotechniczne (np. wskaźnik porowatości e_f, zawartość wody w_f i stopień nasycenia S_f). Wyniki pokazują, że ze wzrostem zawartości spoiwa, wzrasta odporność na konsolidację. Wartość współczynnika konsolidacji c_v maleje w miarę upływu czasu w wyniku zmiany mikrostruktury CPB wywołanej hydratacją.

ONE-DIMENSIONAL CONSOLIDATION PARAMETERS OF CEMENTED PASTE BACKFILLS

Key words

Tailings, coefficient of consolidation, compression index, binder content, curing age

Abstract

Each year, mine and mill operations generate enormous amounts of two waste types – fine-grained tailings and coarse-grained waste rocks. Fine-grained tailings are either discharged in slurry form to surface tailings dams or delivered in cementitious form to underground mine stopes as backfilling, while coarse-grained rocks are typically stored by depositing as a dry material in large dumps. The engineering design of surface tailings dams or underground mine stopes is often controlled by the high compressibility and low shear strength characteristics of fine-grained tailings. Cemented paste backfill CPB indicating saturated, fine-grained backfills can undergo major consolidation settlement during early curing stages. Thus, a better understanding of the rate and magnitude of both differential and total settlement of CPB cured under stress is essential for a proper backfill geotechnical design. The consolidation parameters of CPB can be determined from an improved lab setup called CUAPS (curing under applied pressure system). This setup is capable of simulating the CPB placement and curing conditions, and measuring the consolidation parameters of CPB cured under effective stresses ranging between 0.5 and 400 kPa. In this study, a series of one-dimensional consolidation tests were conducted on CPB samples allowing for examination of the effects of binder type and rate as well as curing time on the compression properties (e.g., coefficient of consolidation c_v, compression index C_c, and recompression index C_r) and the final geotechnical index properties (e.g., void ratio e_f, water content w_f, and degree of saturation S_f). Results showed that as the binder content increases, the initial resistance to consolidation increases. The c_v value decreases over the course of time due to evolution of the CPB microstructure generated by the hydration process.