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Strength Development of Freezing Man-Made Soils that Contain Cement: Freezing Cemented Tailings

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Abstract **-** Cemented paste backfill, a mixture of man-made soils (tailings), water and cement is extensive used in underground mine operations for ground support and/or waste management. However, most of the previous studies involving CPB have been conducted at temperatures above 0°C. Knowledge of CPB in sub-zero environments is still lacking despite the increasing mining activities in permafrost or cold regions. For this reason, in this study the strength development of CPB cured in sub-zero environment is investigated. Uniaxial compressive strength tests were carried out on a series of freezing CPB (FCPB) samples and CPBs cured at room temperature (control samples). It has been discovered in this study that FCPB exhibits remarkable strength compared to CPB and, has a great resemblance to frozen natural soil.

Keywords**:** Cemented paste backfill - Tailings – Man-Made Soils - Permafrost – Temperature

1. Introduction

Ever since 1577, when the first mining operation was established by Martin Frobisher on Baffin Island, the mining industry has progressively become prominent across Canada. By the first half of the 20th century, Canada had already emerged as the world's leading producer of a large number of minerals. According to a recent report by the Canadian government, over 50% of the world's publicly listed exploration and mining companies are headquartered in Canada, accounting for more than 30% of global exploration expenditures in 2013 [1]. In terms of domestic contribution, mining and its related industries contributed more than 52 billion dollars to the gross domestic product (GDP) of Canada in the year 2012, ranking fourth out of all 18 Canadian industries. In total, it comprised 20.4% of the value of Canadian goods exported in 2012 [1].

However, underground mining produces a huge amount of voids and an even larger quantity of mine waste. Overlooking these voids could lead to the possibility of ground subsidence, as well as safety issues during mining operation; while ignoring the waste, could cause environmental pollution and significant suffering [2-5]. One solution to remedy both (the voids and the waste) is cemented paste backfill (CPB; Figure 1), which is a cemented man-made soil. It is gaining increased recognition in both the mining industry and academic research [6]. Transforming tailings into cemented paste, and transporting this back to underground stopes, not only negates these safety issues to a large degree, but also makes it possible to put waste to good use. CPB is an engineered mixture of thickened and filtered tailings (man-made soils) resulting from mineral pro- cessing, water, and binders (cement or pozzolans). Its solid content usually ranges from 70% to 85% by weight, depending on different requirements and needs. It is considered superior to other backfilling methods (e.g. dry fill, rock fill, and hydraulic backfill) for its success in minimizing engineering and environmental risks and challenges. Once transported underground, mine backfill is expected to gain strength as much and as quickly as possible to ensure safe and effective working conditions [6]. An unexpected mine backfill failure could not only lead to financial and environmental ramifications, but also be injuries and fatalities; many such incidents have occurred worldwide [7]. The reasons for failures are various; poor quality of prepared mine backfills, unstable surrounding environments, and inappropriate backfill operations can all result in a mining catastrophic disaster [5]. Therefore, it is vital to have an awareness of whether a given backfill meets the necessary mechanical stability requirements, as well as other information about its mechanical properties.

Extensive research on CPB (e.g., 3-4; 7-10) has been performed during the last 15 years in order to understand its strength development. Tremendous progress has been achieved in this area; however, most of these studies were carried out at temperatures above freezing. There is a persistent lack of understanding of the strength development of CPB in sub-zero environmental conditions. Former research related to CPB cured at temperatures above zero provides little help with this scenario. Mean-while, the demand for raw materials for construction and other industrialized activities is increasing; mining companies have started mining activities in Arctic areas, where temperatures remain below freezing all year round, to meet this need (see Figure 2). Considering the complexity of frozen soil as determined by countless prior studies, and this increase in sub-zero mining activities, a thorough understanding of the strength development of freezing CPB is necessary. For this reason, this paper investigates the strength development of CPB in sub-zero environment.

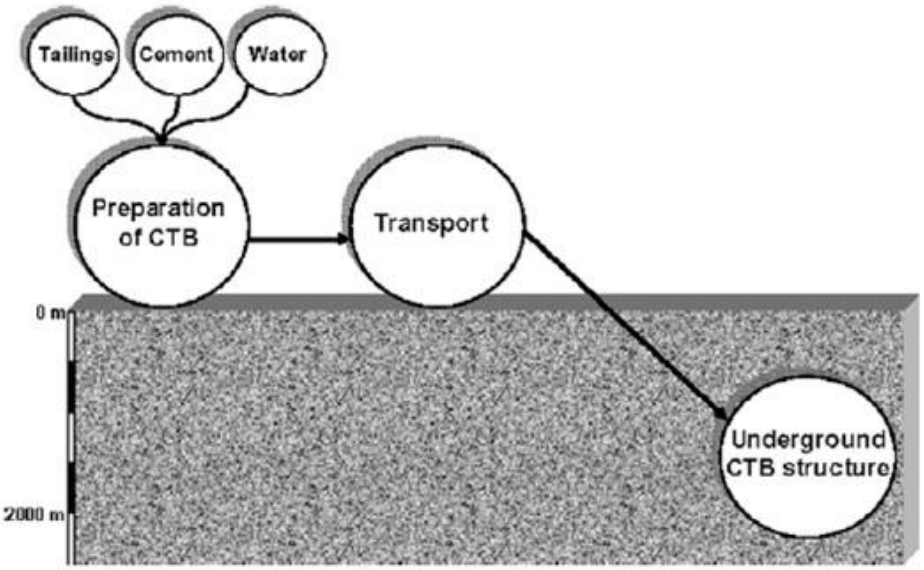

Fig. 1: Schematic presentation of the different phases of CPB technology: preparation, transport and underground placing of the CPB, where it is used to build a CPB structure [6].

Fig. 2: Canadian mining industry clusters.

2. Experimental program

2.1. Materials used, mix preparation and curing of samples

The materials used include binder (Portland cement type I), water (tap water) and tailings. The grain size distribution of the tailings is shown in Figure 3. Tailings materials, binders (4.5%) and tap water were properly weighed and mixed together using a mixer until a homogenous paste resulted. Then, the paste was poured manually into curing cylinders, which where 5 cm in diameter and 10 cm in height. The prepared CPB samples were then cured in a temperature-controlled cold chamber. The curing temperature was set at −6◦C. Freezing-time periods were 7, 28 and 90 days, respectively.

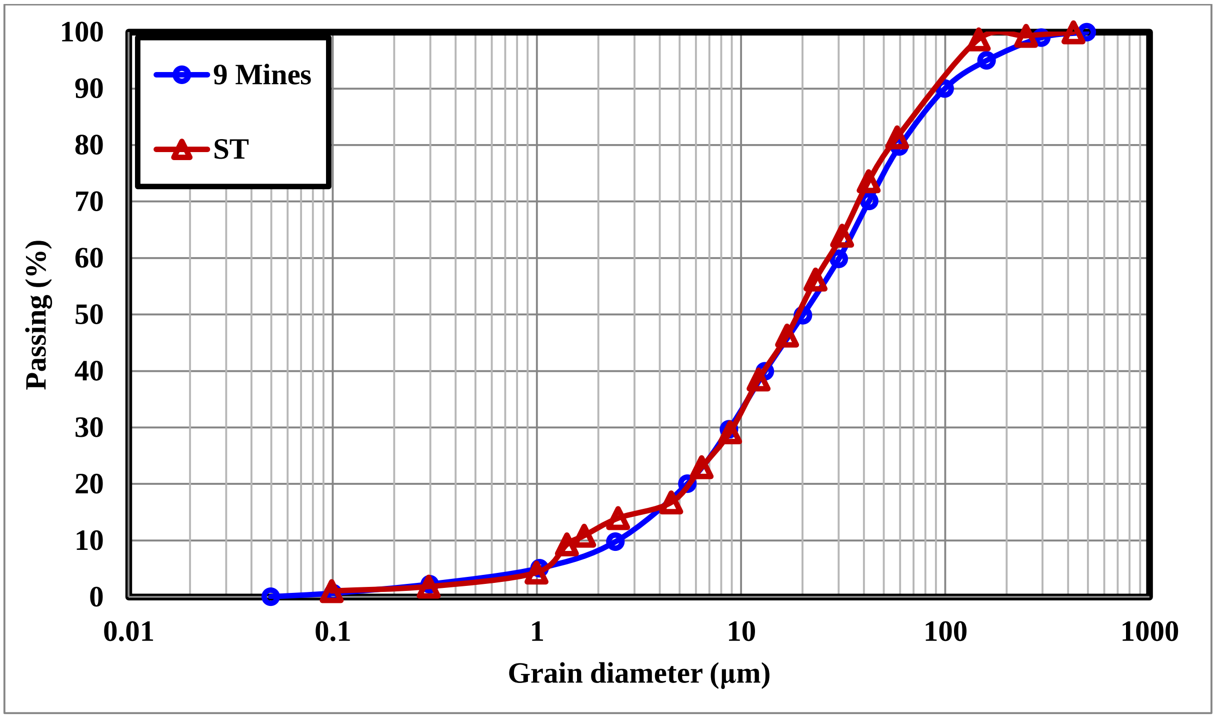

Fig. 3: Grain size distribution of tailings used and average grain size distribution of tailings from nine Canadian mines.

2.2. Mechanical tests on CPB specimens

Uniaxial compressive strength (UCS) tests (Figure 4) were conducted on the CPB samples in accordance with ASTM D7300-06, and repeated at least four times for each individual type of sample, to ensure valid values. The UCS machine was equipped with an environmental chamber to keep the temperature constant (e.g., -6°C) during the testing specimens. The deformation rate was set at 0.15 mm/min. Applied load, together with deformation information, were automatically logged by LabVIEW and stored in the computer. A stress- strain curve was developed and presented as the test proceeded. Peak strength of each sample was recorded as objective strength for this study. If no peak strength appeared due to the strain-hardening process, objective strength corresponding to a strain of 15% was selected as the peak strength of the FCPB.

3. Results and Discussions

Figure 5 shows the strength development of CPB samples cured at subzero temperatures (freezing CPB samples, FCPB) and those cured at room temperature (control samples, CPB) a function of curing time. FCPB specimens in general show rather desirable (higher) strength compared to CPB (CPB cured at room temperatures). CPB samples, which cured at room temperature (20◦C), reached a strength of around 300 kPa at the age of 7 days, then continued to grow stronger with time, eventually achieving a value of around 1200 kPa after 90 days of curing. The strength development of CPB has been explained in many articles [11-14], and is due to the binding effect produced by cement hydration. Whereas, for FCPB specimens that cured at sub-zero environmental conditions (-6°C), a precipitous growth of strength can be seen clearly from 7 to 28 days, and a relatively stable growth of strength followed until 90 days. The reason for such a remarkable increase in strength may be credited to the formation of ice within the FCPB. Indeed, once soil freezes, its strength, along with its other mechanical properties, changes dramatically. It is also interesting to learn from Figure 5 that the strength-gaining rate is faster in the first 4 weeks (28 days) than during the next 9 weeks. This can be explained by the fact that the strength developmemt of FCPB follows the process of ice formation rather than cement hydration, which continues gradually throughout the whole curing time. After 28 days of curing, most water has frozen, and so ceases to provide any ice content to increase its strength.

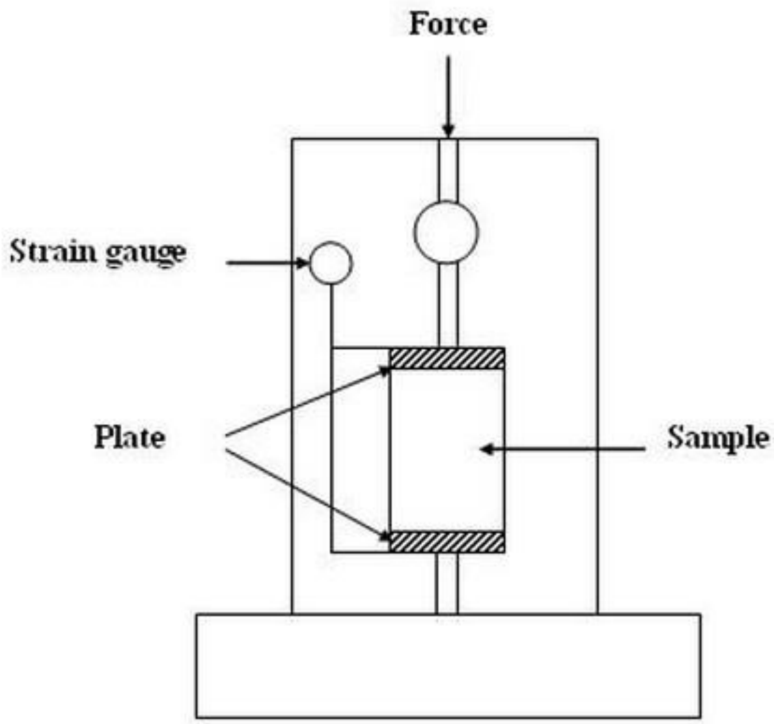

Fig. 4: Schematic configuration of an uniaxial compressive strength testing machine.

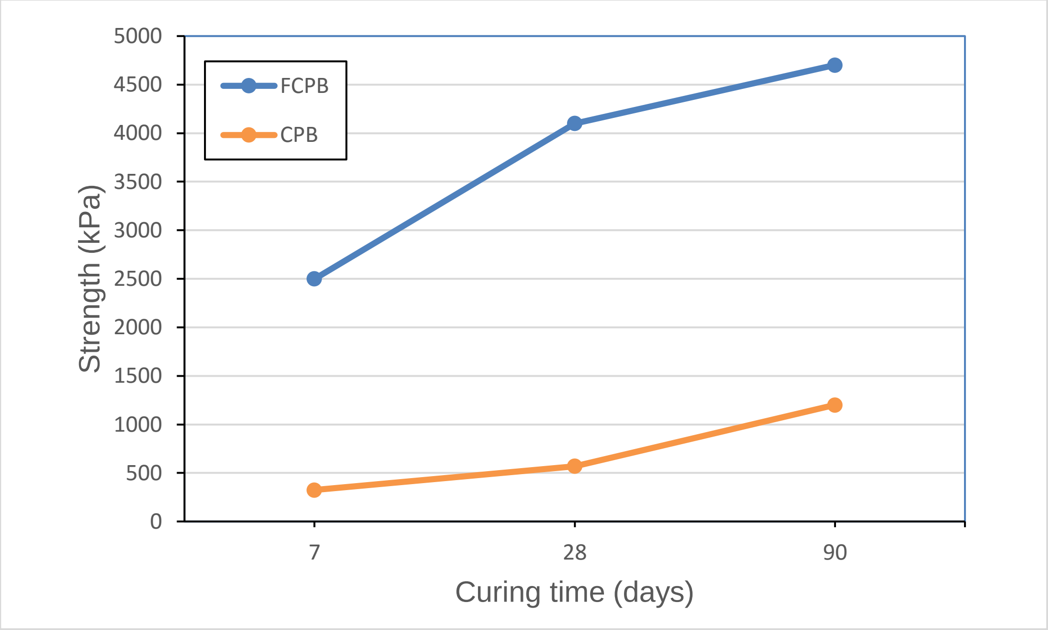

Fig. 5: Strength development of freezing CPB (FCPB) and CPB in room temperature as a function of the curing time.

4. Conclusions

Frozen CPB (FCPB) exhibits remarkable strength at advanced ages (> 90 days), which is nearly three to four times higher than that of CPB cured at room temperature during the same curing time. Furthermore, it gains strength rather quickly. Within less than one month since casting, FCPB achieved 90% of its total strength. The growth of compressive strength of FCPB with time is due to the increasing amount of ice.

References

[1] "Doing business the Canadian way: A strategy to advance corporate social responsibility in Canada's extractive sector abroad," Tech. Rep., 2014.

[2] A. Farkish and M. Fall, "Rapid dewatering of oil sands mature fine tailings using super absorbent polymer," *Minerals Engineering*, vol. 50-51, pp. 38-47, 2013.

[3] M. Fall, T. Belem, S. Samb, M. Benzaazoua, "Experimental characterization of the stress-strain behaviour of cemented paste backfill," *Journal of Materials Sciences,* vol. 42, pp. 3914-3922, 2007.

[4] M. Fall and S. Samb, "Pore structure of cemented tailings materials under natural or accidental thermal loads," *Journal of Material characterization*, vol. 59, no. 5, pp. 598-605, 2008.

[5] S. G. Vick, "Planning, design, and analysis of tailings dams," *BiTech*, 1990.

[6] M. Fall, M. Benzaazoua, and E. Sae, "Mix proportioning of underground cemented paste backfill," *Journal of Tunnelling and Underground Space*, vol. 23, pp. 80-90, 2008.

[7] Y. Potvin and E. Thomas, *Handbook on mine fill*. Australian Centre for Geomechanics, 2005.

[8] M. Fall and O. Nasir, "Mechanical behaviour of the interface between cemented tailings backfill and retaining structures under shear loads," *Journal of Geotechnical and Geological Engineering*, vol. 26, no. 6, pp. 779-790, 2010.

[9] O. Nasir and M. Fall, "Shear behaviour of cemented pastefill-rock interfaces," *Engineering Geology*, vol. 101, no. 3-4, pp. 146-143, 2008.

[10] A. Kesimal, E. Yilmaz, B. Ercikdi, I. Alp, and H. Deveci, "Effect of properties of tailings and binder on the short-and long-term strength and stability of cemented paste backfill," *Materials Letters*, vol. 59, no. 28, pp. 3703–3709, 2005.

[11] M. Fall, J. C. Célestin, M. Pokharel, and M. Touré, "A contribution to understanding the effects of temperature on the mechanical properties of cemented mine backfill," *Engineering Geology*, vol. 14, no. 3-4, pp. 397-413, 2010.

[12] A. Ghirian and M. Fall, "Coupled Thermo-Hydro-Mechanical-Chemical Behaviour of Cemented Paste Backfill in Column Experiments. Part II: Mechanical, Chemical and Microstructural Processes and Characteristics," *Engineering Geology*, vol. 170, pp. 11-23, 2014.

[13] D. Wu and M. Fall, S-J. Cai, "Coupling temperature, cement hydration and rheological behaviour of cemented paste backfill structures," *Minerals Engineering*, vol. 42, pp. 76-87, 2013.

[14] M. Fall, D. Adrien, J. C. Célestin, M. Pokharel, and M. Touré, "Saturated hydraulic conductivity of cemented paste backfill," *Minerals Engineering*, vol. 22, pp. 1307–1317, 2009.