Proceedings of the 2nd International Conference on Civil, Structural and Transportation Engineering (ICCSTE'16)
Ottawa, Canada – May 5 – 6, 2016
Paper No. 139

Oxygen Consumption of Cementing Tailings: Effect of Curing Temperature

Z. M. Aldhafeeri
Department of Civil Engineering / University of Ottawa
161 Louis Pasteur, K1N 6N5, Ottawa, ON, Canada
zaldh048@uottawa.ca

Abstract **-** Among the different options for mine waste management, cemented paste backfills (CPB) have become important in mining operations around the world due to their technical, economic and environmental benefits. CPB is a heterogeneous material produced by mixing tailings with a solid percentage between 70% and 85%, water that is either fresh or mine processed, and a hydraulic binder. One of the key performance properties of CPB includes environmental performance. Oxidation of sulphide minerals in CPB belongs to the main environmental concerns of CPB. This is because the tailings used in the preparation of CPB can contain a significant amount of sulphide minerals (e.g., pyrite, pyrrhotite). The oxidation of these sulphide minerals within the CPB could result in the generation of acid mine drainage. This oxidation depends on the availability of oxygen within the CPB as well as on the temperature. This paper presents the results of an experimental study conducted to assess the influence of curing temperature on the reactivity (measured by oxygen consumption) of CPB. The results show that the reactivity of CPB is temperature-dependent.

Keywords**:** Cemented paste backfill - Tailings – Environment - Reactivity – Acid Mine Drainage

1. Introduction

Underground and open-pit mining involve a number of complex issues for the mining industry, such as ensuring the safety of miners and the public, maximizing the recovery of ore reserves, the safe and cost-effective management of the mine wastes. The development in the end of seventies of cemented paste backfill (CPB) technology and its application have allowed, among other benefits the preservation and improvement of several mining operations and mine waste management [1-2]. Since this date, the use of CPB technology has been worldwide accepted in the modern mining industry today as an attractive method for minimizing these engineering and environmental challenges commonly associated with mining operations [3-4]. The CPB is an engineered mixture of thickened and filtered tailings from the processing operation of the mine, water and hydraulic binders. CPB contains (often) between 70 and 85 % solids by weight depending on the desired consistency. The components are combined and mixed in a plant usually located on mine surface and transported (by gravity and/or pumping) to the underground openings (mostly) or to the surface, where the CPB is used for underground mine support and/or tailings disposal.

CPB offers significant advantages beyond the obvious rock support and regional stability. Indeed, CPB is an effective means of tailings disposal and management, since underground storage of CPB can allow reducing the volume of tailings stored at the surface by up to 60 % [1-5]. It also minimizes the need for constructing large tailings dam at the surface and thus reduces significantly the costs associated with surface tailings management. Moreover, when stored underground, the CPB may also be a hydraulic barrier to groundwater flow, thereby reducing generation of a potentially environment-hostile and onerous leachate [6-7].

A key environmental performance property of CPB is its chemical reactivity, which is related to the oxidation of some tailings used in CPB. Oxidation of sulphide minerals in CPB belongs to the main environmental concerns of CPB. This is because the tailings used in the preparation of CPB can contain a significant amount of sulphide minerals (e.g., pyrite, pyrrhotite). The oxidation of these sulphide minerals within the CPB could result in the generation of acid mine drainage [6-7]. This oxidation depends on several factors, such as the availability of oxygen within the CPB and the temperature (CPB curing temperature, mine ambient temperature).

During the past fifteen years, few studies have been performed on understanding the reactivity (by oxygen consumption of CPB) of CPB. Despite the tremendous progress that has been made by the aforementioned studies in understanding the reactivity or oxygen consumption of CPB, almost all the previous studies were conducted on CPB cured at room temperatures. The effect of different curing temperatures on the reactivity of CPBs was ignored. There is a need to acquire sufficient understanding of the effect if curing temperature on the reactivity or oxygen consumption of CPB since the CPB is subjected to various curing temperatures in the field.

2. Sources of Heat in Tailings Backfill Operations

Every single underground mine or backfill structure is unique with respect to its temperature conditions [4]. These conditions can largely vary with (i) the depth of the mine and geological conditions, (ii) the geographical location of the mine, (iii) the heat produced by the backfill hydration and/or transport, (iv) the self-heating of the rocks and/or the hardened backfill, and (v) other human-induced temperature variations as described below [4]. Detailed information about the sources of temperature in mines and backfill operations are published in Fall et al. [4]. The recent trend of progressive depletion of ores at shallow depths compels the mining industry to consider alternative resources located at greater depths. The excavation of ores located at 3500-5000 meters from the earth surface will increase the heat load of the mining site due to geothermal gradient [8]. Rawlins and Philips [8] reported the variation of temperature with depth in an investigation carried out in a South Africa gold mine. According to this investigation, it is found that the temperature at 2000 meters is 37°C, 48°C for 3000 meters and 70°C for 5000 meters. In addition, the geographical location of the mine is also a non-negligible factor that can affect the temperature of open-pit mines and mines situated at relatively shallow depths. The temperatures of these mines are strongly influenced by the climate of the region [4]. The heat generated by binder hydration is one the most important sources of heat in CPB technology [4]. The reaction between cement and water is exothermic and produces a significant quantity of heat. Due to the large size of CPB structures, the generated amount of heat cannot dissipate immediately, therefore resulting in noticeable increasing heat within the CPB structure (depending on binder type and quantity) [4]. Moreover, mine fires and the self-heating of rock masses that are sulfidic due to the oxidation of sulphide minerals are other reasons for high temperatures in mining activities. In addition, transportation of fresh backfill through pipelines from the surface to underground working areas produces heat as well. Moderate heat can be added to the CPT system during its preparation to increase its early age strength [9-10].

3. Experimental program

3.1. Materials used

The materials used include binder (Portland cement type I), water (tap water) tailings and pyrite. The grain size distribution of the tailings is shown in Figure 1. A commercial pyrite powder (FeS$_2$; M.W. = 119.98) was used to synthesize the pyrite-bearing tailings (or sulphide bearing tailings). This commercial pyrite has grains with a size similar to that of pyrite minerals commonly found in the natural tailings of hard rock mines. The pyrite-bearing tailings with a pyrite content of 45% wt. were prepared by mixing ST with the appropriate amounts of pyrite powder.

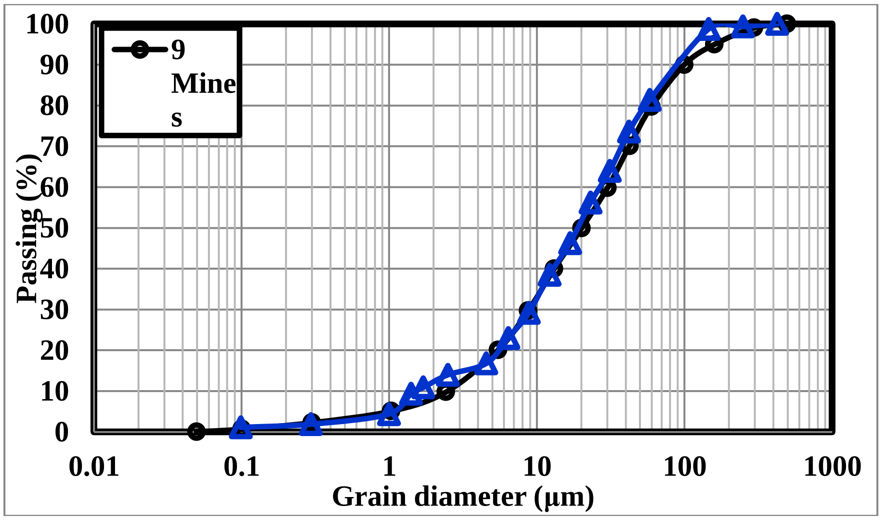

Fig. 1: Grain size distribution of tailings (ST) used and average grain size distribution of tailings from nine Canadian mines.

3.2. Specimen preparation

Several CPB specimens were prepared by mixing for 7 min (using a food mixer) the tailings (with various pyrite contents) with a constant binder content (4.5 wt. %) and water-cement ratio (w/c=7.6) until obtaining a homogeneous paste. After the mixing process, the CPB mixtures were poured into plastic cylinders (cylinders were then sealed with wax to avoid evaporation of water) with a diameter of 5 cm and height of 10 cm and then cured at various curing temperatures (20 and 50°C) until the time of conducting oxygen consumption tests to study the reactivity of the samples.

3.3. Oxygen consumption and MIP tests

The oxygen consumption (OC) test is most preferred method to measure the reactivity of sulphidic tailings because it is simple, inexpensive, fast and accurate. Nicholson et al. [11-12] studied the theoretical basis for controlling the oxidation rates based on the diffusion of oxygen from the atmosphere onto the tailings surface. They pointed out that the oxidation process of sulfide minerals is oxygen consuming. Therefore, calculating the amount of oxygen in a sealed vessel where the reaction is taking place results in obtaining information about the oxidation rate [11-12]. OC testing was propounded for the first time by Elberling et al. [13] and Elberling and Nicholson [14] as a new method to assess the oxidation rate of sulphide mine wastes. This method is utilized to measure the reactivity of acid generating tailings by applying Fick's and the conservation laws. The amount of reduction in the oxygen rate in a fixed volume of container is considered as the rate of sulphide oxidation [11-12]. In this process, the reactivity of the tailings material and the rate of oxygen diffusion control the reaction [11-12]. The main assumption behind this test is that during whole testing process, a steady state condition will be maintained. Figure 2 illustrates the experimental setup adopted in this study to conduct OC testing on CPB samples. Oxygen sensors (model SO-210, Apogee Instruments, Inc.) were used to measure the reactivity at various ambient (testing) temperatures because this type of sensor has an operating range that is relatively close to the ambient temperatures (-20 to 60°C).

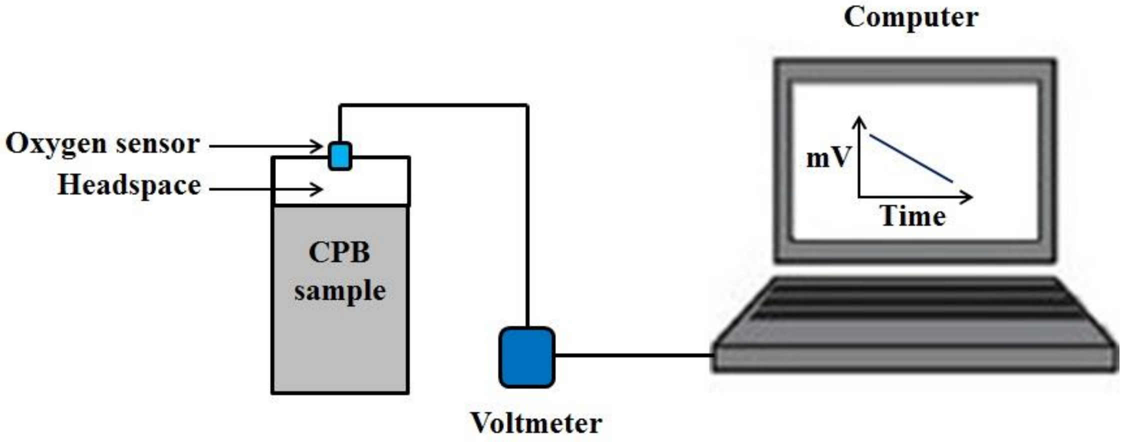

Fig. 2: Experimental set up for oxygen consumption test.

Furthermore, mercury intrusion porosimetry (MIP) tests were conducted on selected CPB specimens to investigate their pore structure. The MIP tests were performed by using a Micromeritics Auto Pore III 9420 mercury porosimeter in accordance with ASTM D4404-10.

4. Results and Discussions

Fig. 3 shows the mean and standard deviation of the reactivity of the CPB specimens made of tailings that contain 45% pyrite cured at different temperatures (20°C and 50°C) and plotted as a function of curing time. From this figure, it can be observed that the curing temperature has a significant influence on the reactivity of CPB. The samples cured at 50°C depict lower reactivity than the samples cured at 20°C. This reduction of the reactivity of CPB at 50°C is due to the improvement in the microstructure of the CPB (refinement of the pore structure) due to the acceleration of the cement hydration caused by increased curing temperatures. This improvement, in turn, results in the restriction of oxygen diffusion into the CPB.

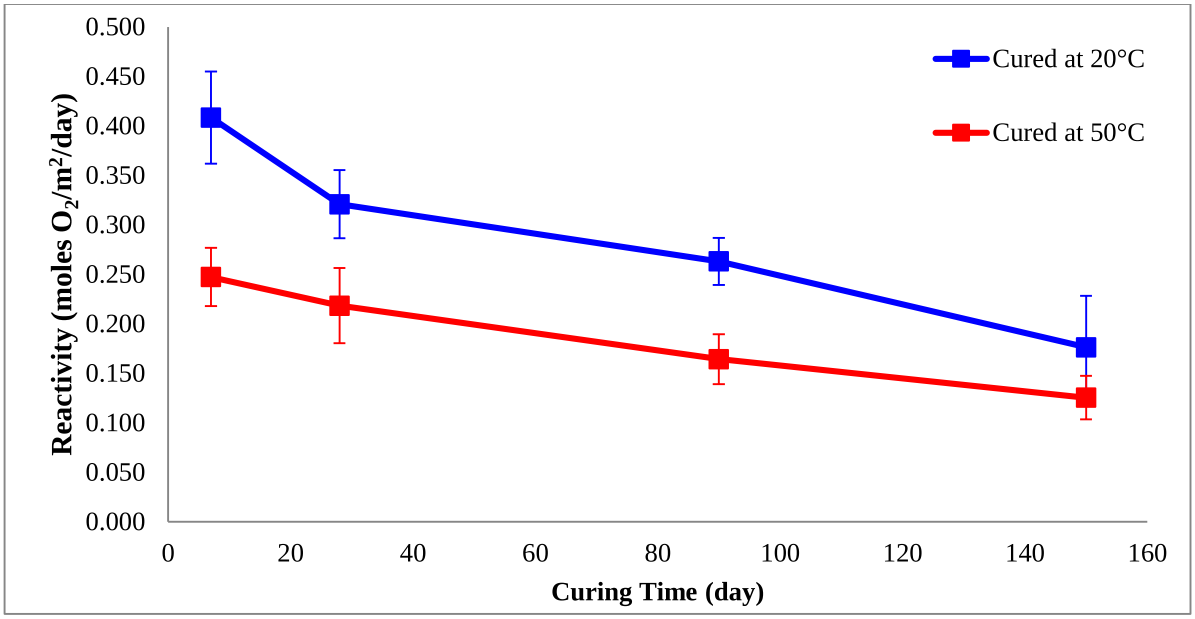

Fig. 3: Effect of curing temperature on the reactivity of CPB-ST-Py.45% for different curing times.

The results obtained from the MIP tests, as shown in Fig. 4, support this argument with respect to the refinement of pore structure induced by the acceleration of the cement hydration. Fig. 4 illustrates the differential pore size distribution of 90-day CPB-ST-Py-45% Py. specimens cured at 20°C and 50°C. It can be observed that as the curing temperature increases, the threshold pore diameter decreases, thus indicating a refinement of the pore structure of the cementitious material.

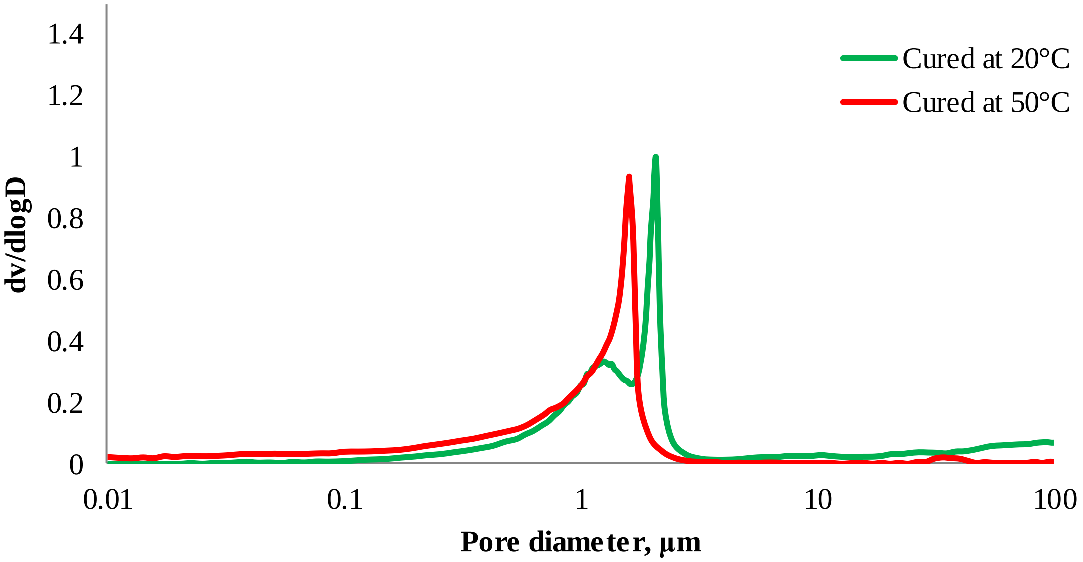

Fig. 4: Differential pore size distribution curves of 90 day CPB specimens (w/c=7.6) cured at temperatures (20°C, and 50°C).

5. Conclusions

Laboratory experiments are performed to investigate the reactivity of CPB systems under various thermal load conditions. The reactivity of CPB depends upon the curing temperature. CPB containing 45% of pyrite and cured at 50°C shows a lower degree of reactivity than those cured at room temperature (20°C). This lower degree of reactivity is attributed to the refinement of the pore structure of the CPB cured at 50°C because of the acceleration of the cement hydration at higher curing temperature. Further studies should be performed to better understanding the effect of curing temperature on the reactivity of CPB.

References

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

[2] 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.

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

[4] 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.

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

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

[7] M. Fall and M. Pokharel, “Coupled effects of sulphate and temperature on the strength development of cemented tailings backfills: Portland cement-paste backfill,” *Cement Concrete Composite*, vol. 32, pp. 819–828, 2010.

[8] C. A. Rawlins and H. R. Philips, “Reduction of mine heat loads,” in *Proceedings of the 7th International Mine Ventilation Congress*, 2001, pp. 381–389.

[9] N. Abdul-Hussain and M. Fall, “Unsaturated hydraulic properties of cemented tailings backfill that contains sodium silicate,” *Engineering Geology*, vol. 123, pp. 288-301.

[10] A. Ghirian and M. Fall, “Coupled Thermo-Hydro-Mechanical-Chemical Behaviour of Cemented Paste Backfill in Column Experiments. Part I: Physical, hydraulic and thermal processes and characteristics,” *Engineering Geology*, vol. 164, pp. 195-207, 2013.

[11] G. Nicholson, R. V. Elberling, B. Williams, “A new oxygen consumption technique to provide rapid assessment of tailings reactivity in the field and the laboratory,” in *Proc. Sudbury ‘95-Mining Environ.*, 1995, vol. 3.

[12] R. V. Nicholson, R. W. Gillham, and E. J. Reardon, “Pyrite oxidation in carbonate-buffered solution: 1. Experimental kinetics,” *Geochim. Cosmochim. Acta*., vol. 52, pp. 1077–1085, 1988.

[13] B. Elberling, R. V. Nicholson, E. J. Reardon, and R. Tibble, “Evaluation of sulphide oxidation rates: a laboratory study comparing oxygen fluxes and rates of oxidation product release,” *Can. Geotech. J.*, vol. 31, pp. 375–383, 1994.

[14] B. Elberling and R. V. Nicholson, “Field determination of sulphide oxidation rates in mine tailings,” *Water Resour. Res.*, vol. 32, pp. 1773–1784, 1996.