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An investigation into the addition of sodium silicate into mine backfill, Gelfill

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Abstract

Physical and mechanical properties of cemented hydraulic backfill (CHF) made with and without sodium silicate are investigated in this paper. Sodium silicate is an alkali activator and has been successfully used to stimulate the reactions of pozzolanic materials such as fly ash and blast furnace slag (BFS). A series of CHF samples made with various concentrations of sodium silicate were prepared and cured over 28 days. The mechanical properties of samples were analysed by conducting uniaxial and triaxial compression tests. The microstructure of selected samples was also investigated by conducting mercury intrusion porosimetry (MIP) test and scanning electron microscopy (SEM).

The results demonstrate that CHF made with an appropriate amount of sodium silicate can have stronger mechanical properties in comparison to those without the additive. Moreover, the rate of strength gain in samples made with sodium silicate is faster than samples without sodium silicate over 28 days of curing period. However, an elevated amount of sodium silicate may have a detrimental effect on the strength of samples due to the increase of the total porosity. The MIP test shows that the total porosity and pore structure are different for the two types of backfills. The SEM micrographs taken from samples made with and without sodium silicate revealed that the addition of sodium silicate caused the formation of more calcium-silicate-hydrate (C-S-H) gel.

1 Introduction

(CHF mainly consists of tailings, water and binder materials, the latter being the most expensive component. Although sodium silicate has been used in concrete manufacturing, the use of this material in mine backfill is relatively new. Until very recently, there have been only a few isolated publications, mostly out of McGill University (Doucet & Tarr 2007; Razavi & Hassani 2007; Kermani et al. 2009, 2010, 2011). This new mine backfill was called Gelfill due to the formation of silica gel after the addition of sodium silicate to cemented backfill. These papers investigate the effect of different parameters namely mixing time, curing temperature and pulp density on the basic mechanical properties of sodium silicate fortified cemented mine backfill. However, the mechanism of those effects has yet to be understood. Therefore, the main objective of this study was to answer this main question of how and why the addition of sodium silicate to cemented backfill could enhance the mechanical properties of cemented mine backfill. For this reason a series of mine backfill samples were prepared with different sodium silicate concentrations, the mechanical properties of those samples were analysed by uniaxial and triaxial tests. The microstructure of the samples was then investigated by employing MIP and scanning electron microscopy.

2 Materials

2.1 Tailings

Tailings consist mainly of finely ground host rock. Physical properties of tailings, such as density, particle size, shape and surface texture of tailings, as well as chemical composition of tailings are among the most important factors that influence the mechanical properties of placed mine backfill (Benzaazoua et al. 2004; Kesimal et al. 2005). In this research, the classified tailings were obtained from a mine located in Sudbury, Canada. Using the x-ray diffraction technique (XRD), it was found that the mineralogical contents of tailings are mainly Quartz, Albite, and a small amount of Calcite, Muscovite, Chalcopyrite, Biotite, Pyrrhotite, Epidote and Chlorite. The particle size distribution of the tailings was determined by using the laser diffraction methods (ASTM International 1996). The result is presented and compared with the average size of 11 mine tailings from the province of Quebec and Ontario, reported by Ouellet et al. (2007) in Figure 1. It was found that the tailings are significantly coarser than the average size of 11 mine tailings. This is due to use of classified tailings in CHF.

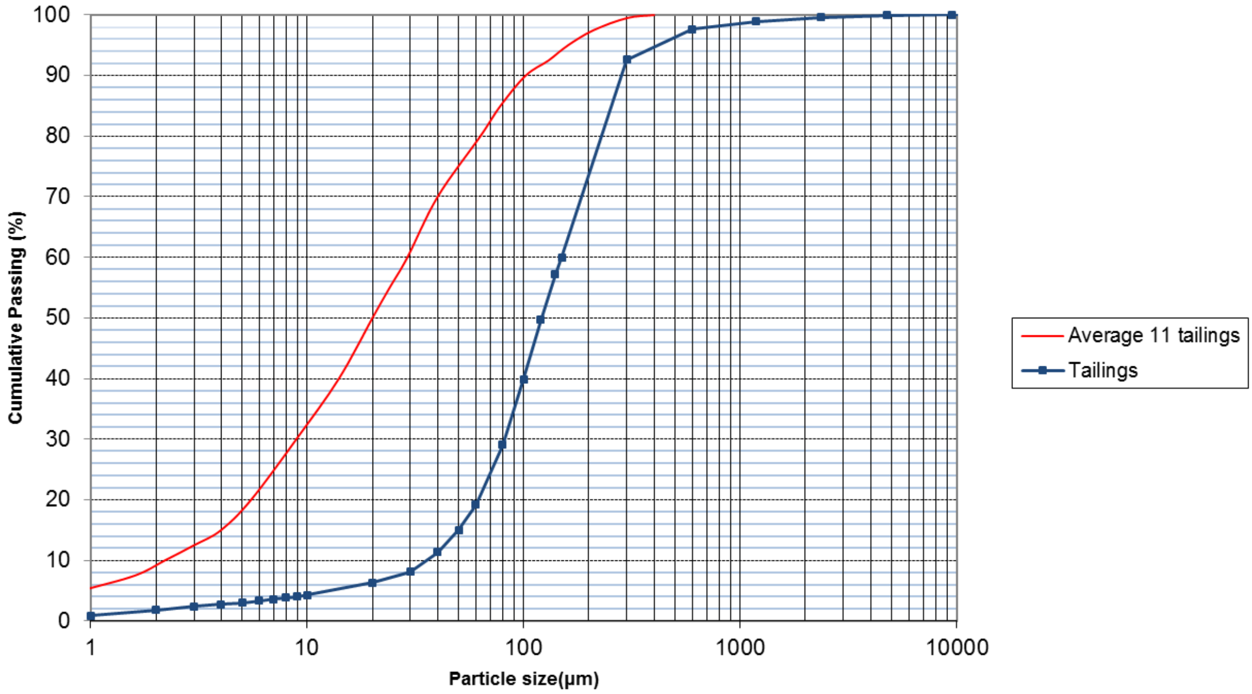


Figure 1 Particle size distributions of tailings and average size of 11 mine tailings

2.2 Binder

Different types of binders such as Normal Portland cement, fly ash and blast furnace slag have been largely used for mine backfill. In this research, a combination of 90% blast furnace slag and 10% Type 10 Portland cement, both provided by Lafarge Canada, were used as this combination is mainly used in the above mentioned mine. The densities of the slag and Portland cement used were 2.89 and 3.07 g/cm^3, respectively. The Blaine specific surface area of the slag and Portland cement were 5,998 cm^2/g and 3,710 cm^2/g respectively. The chemical compositions of the blast furnace slag and Portland cement are shown in Table 1.

Table 1 Chemical composition of the Portland cement and blast furnace slag provided by Lafarge

Chemical composition	Blast furnace slag (wt%)	Portland cement (wt%)
CaO	37.129	61.13
SiO_2	36.127	19.39
Al_2O_3	10.385	4.61
MgO	13.246	3.3
SO_3	3.362	2.27
Fe_2O_3	0.668	2.01
Na_2O	0.424	2.03
K_2O	0.489	0.71

2.3 Sodium silicate

The main application of sodium silicate in the mining industry and civil engineering is to accelerate the hydration rate of pozzolanic materials, such as slag and fly ash. Various types of sodium silicate are manufactured from varied proportions of Na_2CO_3 and SiO_2 by smelting the silica with the sodium carbonate at temperatures around 1,100-1,200°C. In this research, Type N® sodium silicate was used, provided by the PQ National Silicate Company. This type of sodium silicate is the most efficient activator for ground blast furnace slag. Table 2 shows the properties of the sodium silicate.

Table 2 The properties of sodium silicate (PQ National Silicate)

Sodium silicate properties	Standard	Maximum	Minimum
Na_2O	8.90%	9.10%	8.70%
SiO_2	28.66%	29.00%	28.20%
Weight ratio (SiO_2/Na_2O)	3.22	3.27	3.15
Specific gravity at 20°C	1.394	1.401	1.388
Viscosity at 20°C centipoises	177	213	141
Solids %	37.56%	38.10%	36.90%

3 Sample preparation and curing

In order to investigate the effect of sodium silicate concentration on the mechanical properties of CHF, different backfill mixtures with different mixture designs were prepared. The binder agent used for preparing the CHF samples was made of 90:10 blast furnace slag and Portland cement. The pulp density of the mixtures was kept constant at 70% using distilled water. Table 3 shows the mixture characteristics and samples' symbols. The mixtures were prepared in small batches in a five litre stainless steel bowl. A mixer with a stainless steel wire whip blade was used to mix the ingredients for five minutes. In order to cast the sample, PVC moulds (10 cm deep and 5 cm diameter) were used. The bottom of moulds were perforated by 25 uniformly distributed 1 mm diameter holes to simulate the drainage as would occur in the mines and a geotextile filter was installed to prevent the loss of fine particles. Those specimens were then cured in a curing chamber where the relative humidity was kept constant at 90 ± 2% and the temperature was adjusted to 25 ± 1°C. The specimens were then tested at seven, 14 and 28 days cure age.

4 Results and discussion

4.1 Effect of sodium silicate concentration on the CHF strength

In order to evaluate the effect of sodium silicate concentration on hydraulic backfill, eight mixtures and a total of 72 triplicate specimens were prepared. These specimens were cured for seven, 14 and 28 days and their uniaxial compressive strengths were measured.

Table 3 Binder mixtures characteristics of backfill samples made for unconfined compressive strength (UCS) and triaxial tests

	Slag BFS (wt%)	Portland cement (wt%)	Sodium silicate (wt%)	Curing temperature (°C)
CHF	4.5	0.5	0	25
GF .1	4.5	0.5	0.1	25
GF .2	4.5	0.5	0.2	25
GF .3	4.5	0.5	0.3	25
GF .4	4.5	0.5	0.4	25
GF .5	4.5	0.5	0.5	25
GF .7	4.5	0.5	0.7	25
GF .9	4.5	0.5	0.9	25

The results of UCS tests are shown in Figure 2. As expected, the UCS values increased with increasing curing time, due to the hydration of normal Portland cement and blast furnace slag. The results show that for a given curing time, UCS values increase by increasing the amount of sodium silicate up to 0.3% of the total dry weight (wt%). However, the UCS values decreased with any further increase of sodium silicate past this 0.3 wt% point. Moreover, the UCS values significantly decrease when the amount of sodium silicate surpasses 0.5 wt%. Thus, the optimum formula for Gelfill includes sodium silicate at 0.3 wt% for the samples made with 5wt% binder. The UCS of Gelfill made with 0.5 wt% sodium silicate was low after seven days of curing, but increased rapidly thereafter, whereas Gellfil at 0.7 and 0.9 wt% sodium silicate had no measurable strength within the first 14 days of curing and additional curing time increased UCS only a small amount.

The triaxial test results of CHF samples made with and without sodium silicate are summarised in Table 4. It can be observed that the cohesion of Gelfill sample made with 0.3 wt% sodium silicate is 45% higher than the cohesion of CHF samples with no sodium silicate. It could be the result of an increase in cementation caused by the addition of sodium silicate in CHF samples made with sodium silicate. On the other hand, the CHF samples have higher Young’s modulus and internal friction angle. It is important to note that the sodium silicate does create an amorphous crystal which could be a contributor (as a thin layer between and over the grains) to reducing the frictional properties. The lower modulus of elasticity of samples could be beneficial for a fill material due to the fact that it can better resist against vibrations induced by the blasts happened for the ore production.

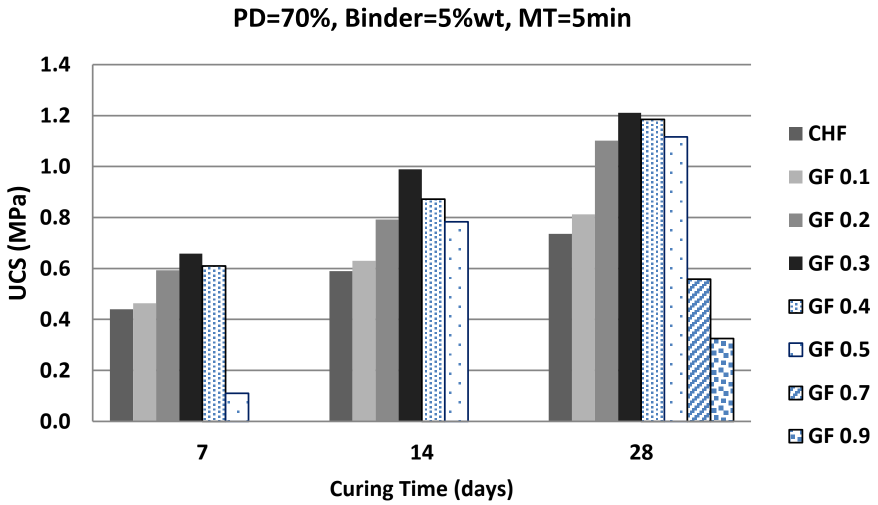


Figure 2 Effect of sodium silicate dosage on compressive strength of CHF

Table 4 Mechanical properties of Gelfill and CHF specimens cured for 28 days

	UCS (MPa)	Elasticity modulus (MPa)	Cohesion (MPa)	Internal friction angle (φ) (degree)
CHF	0.87	0.49	0.14	41
GF 0.3	1.28	0.38	0.23	37.5

4.2 SEM results

In order to study the effect of sodium silicate on the microstructures of CHF, four samples were separately made with four mixture designs (Table 5). In these series of samples, pure silica sand (99.8% SiO2) was used instead of tailings to mitigate the possible influence of chemical complexity and reactions of minerals in the tailings. Moreover, the size of pure silica sand was limited between 300-425 microns in order to clearly observe the effect of sodium silicate and hydration of binders. The samples were first freeze dried at seven and 14 days of curing, and then observed by taking SEM images (Figures 3 and 4). It can be seen that a coating material was developed around the sand particles in the specimens. The coating material could generally be a combination of C-S-H, portlandite and ettrengite which are the main products of hydration of binders (Kovacs 1993; Chang 2003); however, further investigation is in progress to clearly identify the coating material. The images also reveal that the coating materials were developed around and on the surface of sand particles in CHF specimens; however, the coating materials are less frequent and limited in CHF specimens with no sodium silicate. The same phenomena can be observed in specimens cured for 14 days. In fact, the observation is in full agreement with the result of MIP test which suggests that the total porosity decrease in CHF specimens made with 0.3 wt% sodium silicate.

Table 5 Binder mixtures characteristics of samples made for SEM analysis

	Slag BFS (wt%)	Portland cement (wt%)	Sodium silicate (wt%)	Curing temperature (°C)
CHF	4.5	0.5	0	25
GF 0.1	4.5	0.5	0.1	25
GF 0.3	4.5	0.5	0.3	25
GF 0.5	4.5	0.5	0.5	25

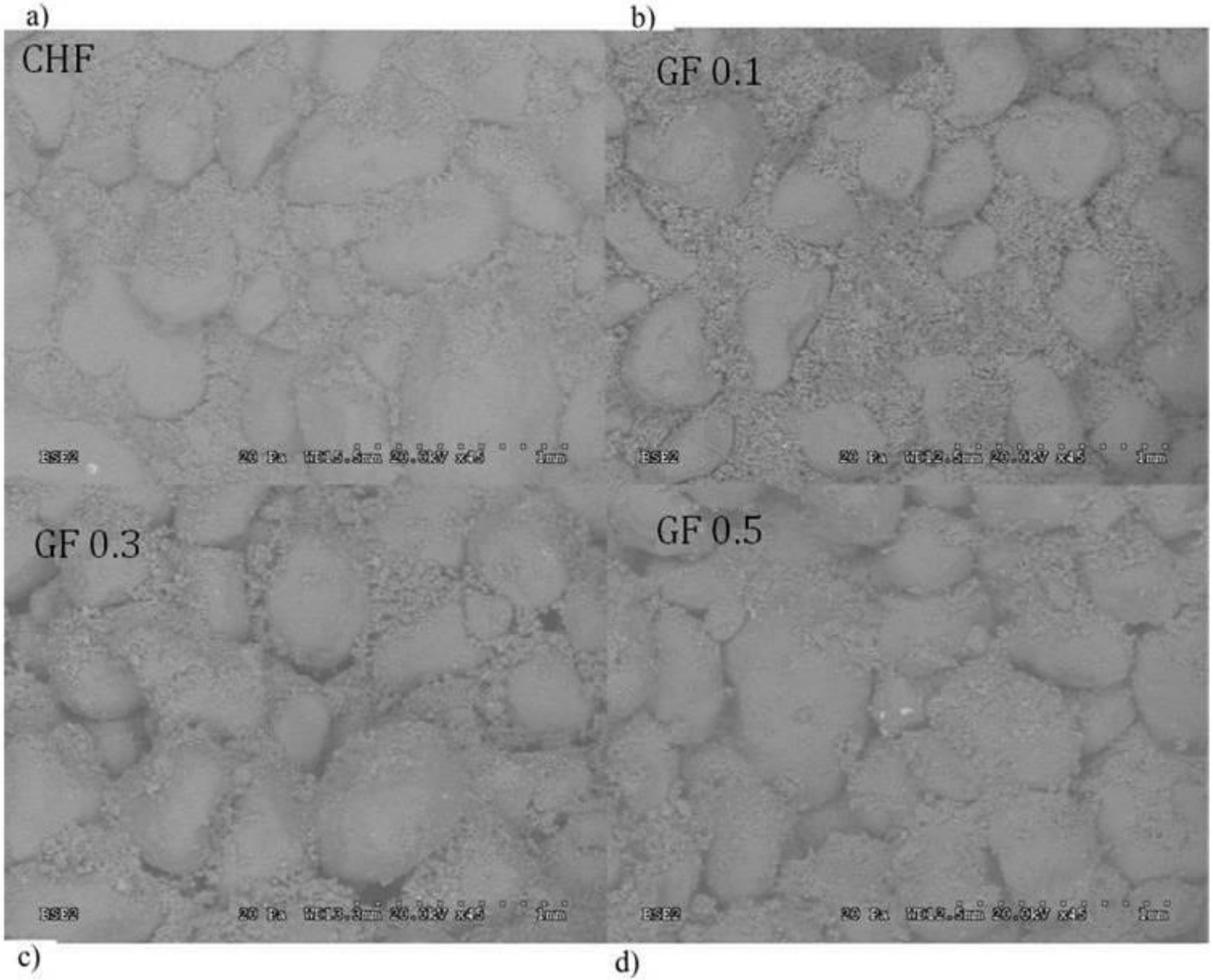


Figure 3 SEM photos (100× magnification) of CHF; (a) CHF made with 0.1 wt% sodium silicate; (b) made with 0.3 wt% sodium silicate; (c) made with 0.5% wt% after seven days of curing time

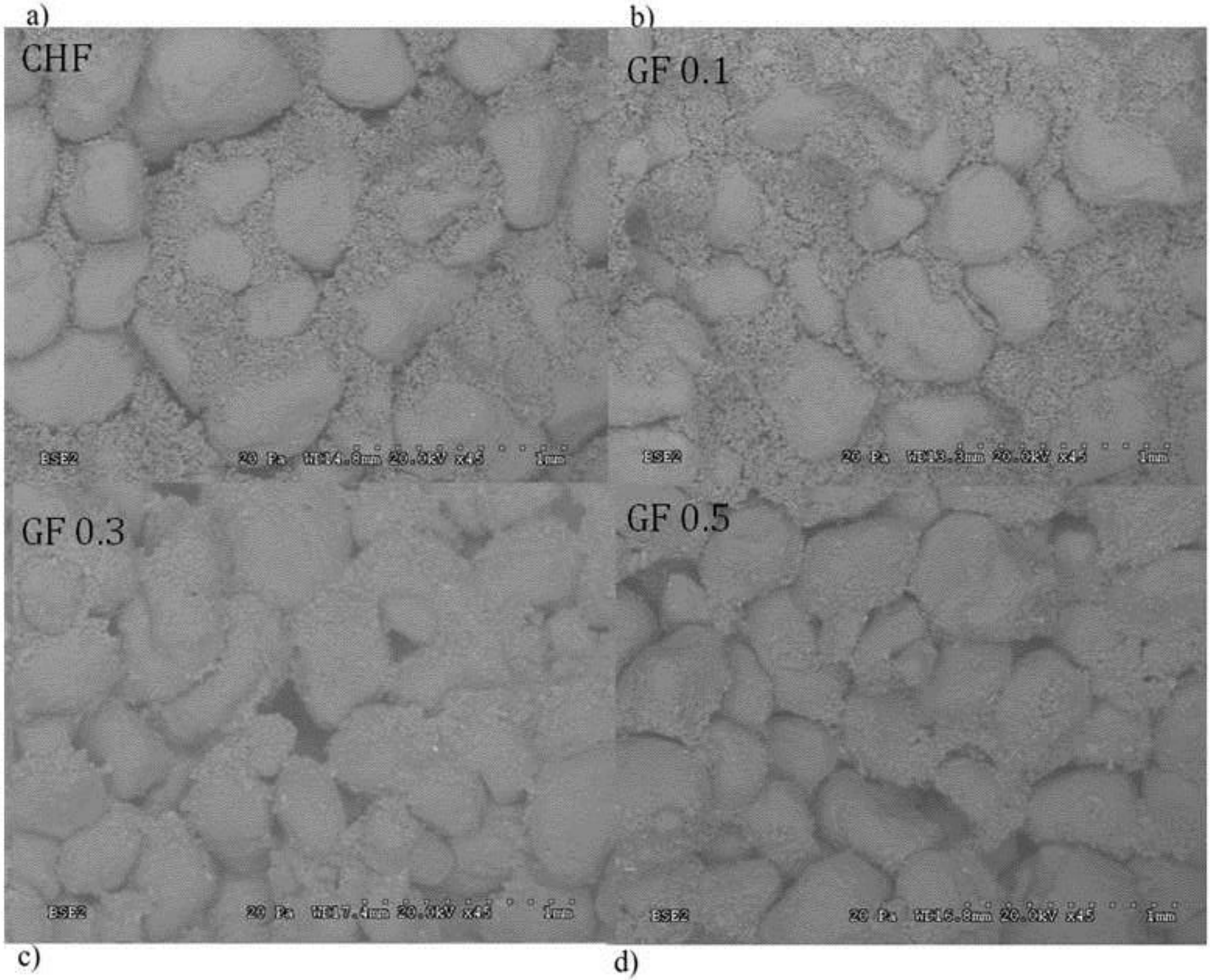
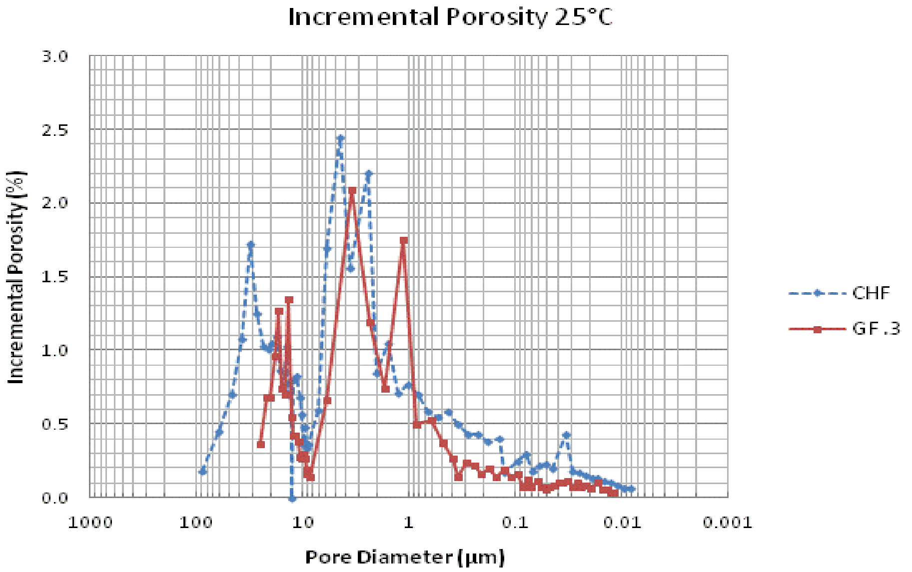


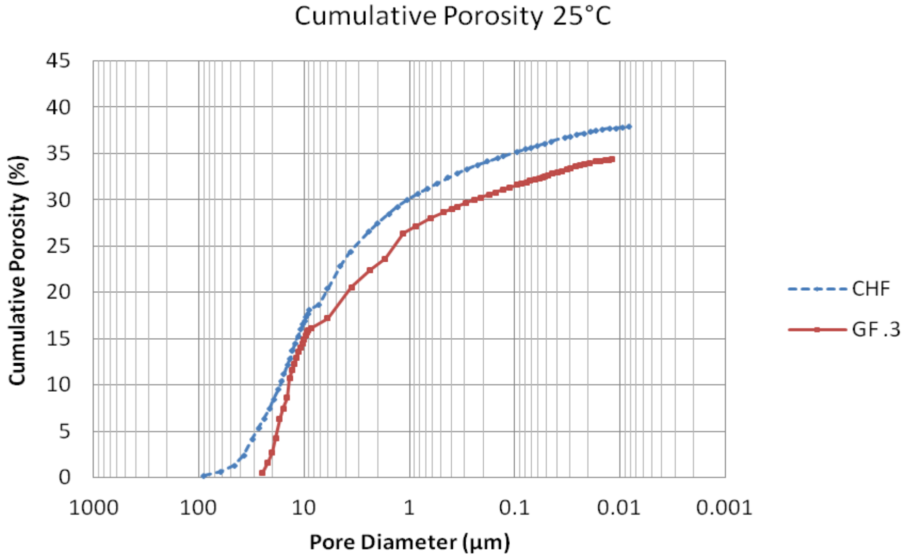
Figure 4 SEM photos (100× magnification) CHF; (a) CHF made with 0.1 wt% sodium silicate; (b) made with 0.3 wt% sodium silicate; (c) made with 0.5% wt% after 14 days of curing time

4.3 Mercury intrusion porosimetery results

In order to investigate microstructural properties and also to explain the results of UCS tests, MIP tests were performed on CHF and CHF samples containing 0.3 wt% sodium silicate (GF 0.3) cured for 28 days, and the results are shown in Figure 5. The total porosity of the CHF sample (38.93%) is higher than the GF 0.3 sample (34.11%). Moreover, both samples have two pore size families that dominate the pore size distribution, The size of pores reported in the GF 0.3 samples (between 20-0.1 µm) were smaller than the size of pores in the CHF samples (100 to 1 µm). These two differences can explain the higher UCS values and improved mechanical behaviour of the CHF samples containing 0.3 wt% sodium silicate over the CHF samples with no sodium silicate. In fact, for a given overall porosity of a sample, as pore size decreases, the distribution of an applied stress is more likely to be homogeneous and uniform (Li & Aubertin 2003).



(a)



(b)

Figure 5 Incremental pore size distribution; (a) and overall porosity; (b) of CHF and Gelfill containing 0.3 wt% sodium silicate after 28 days of curing

4.4 Effect of sodium silicate concentration on the drainage

One of the disadvantages of hydraulic fill is the introduction of additional water into the mine. The additional water may cause many problems underground. Therefore, the additional water has to be pumped out, which can be time consuming and costly. For that reason, the amount of released water and the drainage time are among the most important properties of mine backfill.

To study the effect of sodium silicate concentration on the drainage of CHF, five samples with different mixture designs were made. The mixture designs correspond to those already used for the study of the mechanical strength of CHF (Table 3). The water released from the bottom of the samples was collected and measured over the drainage period which lasted 22 hours. The amount of water collected for different mixtures is presented and compared in Figure 6. As expected, the quantity of collected water increases gradually with time; however, the rate of drainage decreases. The results show that drainage has ceased after 22 hours (1,320 minutes). It can be also observed that the quantity of collected water. Finally, it should be mentioned that the maximum volume of collected water at the end of the drainage period are 539.8 cm^3 for CHF and 481.85 cm^3 for CHF made with 0.3 wt% sodium silicate. The results could be positive due to the decrease of the amount of released water. Although the drainage was additionally decreased at higher levels of sodium silicate addition, the low compressive strength and low rate of strength gain do not make these appropriate choices for backfill.

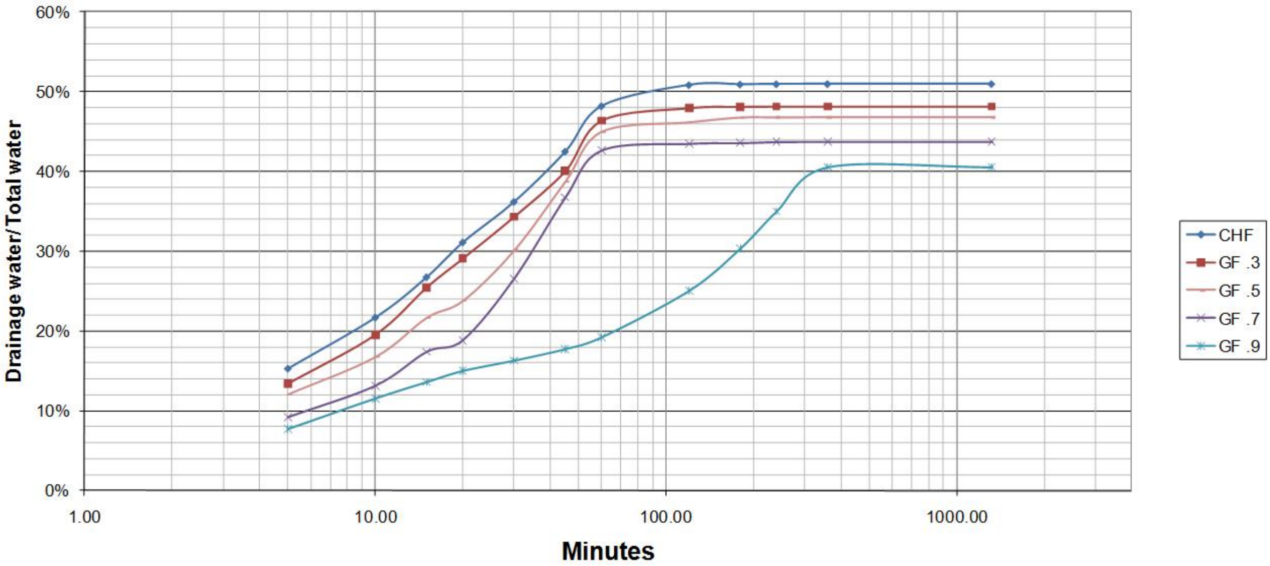


Figure 6 The effect of sodium silicate concentration on the drainage of CHF

5 Conclusions

The influence of a sodium silicate concentration on the mechanical and microstructural properties of CHF is presented in this paper. The investigation confirmed that for the materials tested by adding an appropriate amount of sodium silicate, the mechanical properties of CHF can be improved which can contribute to underground stabilisation and mine safety. Moreover, the results demonstrated that strength development of CHF can be accelerated with the addition of an appropriate amount of sodium silicate which could contribute to reduce the non-productive time of the mining cycle and to increase the mine production efficiency.

The research also shows that pore size distribution and total porosity of CHF samples were altered with the addition of sodium silicate which could contribute to better mechanical properties of specimens made with sodium silicate., the SEM analysis reveal that by adding sodium silicate to the CHF samples, more coating materials were developed within the samples. Finally, it was found that the addition of sodium silicate (0.3 wt%) caused an approximate reduction of 10% in the quantity of the drained water.

Acknowledgement

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