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Strategies for improving backfill quality in cold temperature mines

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Abstract

One of the key factors for good cemented backfill performance is proper cement hydration. By understanding the factors that influence cement hydration, improved backfill performance in subzero conditions can be achieved. The authors report on the results of a laboratory test program comparing various cements and an additive, over a range of subzero to plus zero conditions. Several mix designs were investigated to show strength development including a variation with a thawing period. This paper documents the results and applies the findings in the form of strategies to improve cemented backfill strength in permafrost conditions, and follows a paper presented at the May 2014 CIM conference held in Vancouver BC titled 'Effect of low temperature on backfill quality in permafrost condition' (Lin et al. 2014).

1 Introduction

As mining in more remote locations increases, mining conditions that were once considered extreme are becoming more common. With respect to mine backfill, cold temperatures can have a negative effect on cemented backfill strengths due to slow cement hydration. Remote mining locations have additional cost pressures resulting from their location. Consequently, it is essential to minimise costs related to delays in the mining cycle, ground instability and dilution. A good quality backfill can make a significant contribution to minimising these costs and increase production reliability.

Working in permafrost conditions requires knowledge of how cement works in subzero temperatures. Since cement hydration is retarded in cold temperatures, strategies are required in order to extend the use of cements in subzero environments. To gain a deeper understanding of how to approach the challenge of improving the strength of cemented mine backfill in permafrost conditions, an understanding of cement hydration is one place to start. Cement hydration is an exothermic chemical reaction in which the magnitude of the heat generation is determined by the cement chemistry (tricalcium silicate and dicalcium silicate content) in the presence of water. The rate of heat generation is affected by:

- The fineness of the cement.
- The mixing temperature of various batch components.
- The chemical composition (gypsum content).
- The amount of water added.
- Admixtures.

In cemented backfill, as in concrete, the increase in strength with age requires the following:

- Unhydrated cement to be present.
- The material to remain moist.
- The backfill temperature to remain favourable.

- Sufficient space available for hydration products to form.

Under these conditions, optimum and continuous curing is possible.

Application of this knowledge can be used as a guide to designers to produce a backfill that will have better performance in permafrost conditions. For example, high–early (HE) cement which consists of a finer grind (Blaine) than general use (GU) cement, is the only type of Portland cement which produces up to 6% more heat generation in the first seven days than GU (Kosmatka et al. 2011). In cold temperature conditions, the generation of heat is beneficial since it helps to maintain favourable curing temperatures. Consequently, HE cement is certainly a candidate as a backfill binder in cold temperature conditions. In fact, HE was the binder of choice at the Polaris Mine (Dismuke & Diment 1996) when it was operating in the High Canadian Arctic. Ambient underground temperatures at Polaris ranged between -7 to -10°C.

In the case of concrete, if it is frozen and kept frozen above approximately -10°C, it will gain strength slowly. However, below that temperature, the cement hydration and strength increase ceases (Lafarge North America 2014). In another example, concrete cast at 4°C and cured at -4°C achieved a seven day strength of 5 MPa and a 28 day strength at 11 MPa compared to the same concrete cast and cured at 23°C which had a seven day strength of 30 MPa and 28 day strength of 40 MPa (Klieger 1958). These examples not only illustrate the dramatic effect of temperature on strength, but they also illustrate the range of cold temperatures in which GU cement cures to achieve practical strengths.

This study aims to investigate the effectiveness of different strategies to improve backfill strength in mines operating in permafrost conditions. These strategies can be applied to rock, sand and/or tailings backfill. Since the chemistry and grain size distribution of backfill material is unique to each mine, strength testing specific to an individual orebody is required in order to verify the soundness of any particular strategy.

This paper does not look at the case of high sulphide mine tailings used in permafrost. This is a special case requiring a different approach. The scope of this paper is to offer understanding of how levers, such as additives, temperature and proper cement type selection, can be used effectively within in a framework of subzero temperatures.

2 Methodology

The materials used in this test program consisted of sand (in accordance with ASTM 20-30), GU cement, HE cement, silica fume blended cement (SF – silica fume is composed of 85% or more amorphous SiO_2 having a particle size of one micron or less), distilled water, and calcium chloride ($CaCl_2$ – an inorganic accelerating admixture). A sand suitable for ready mix was chosen because it is chemically inert and, although it generally has a wider range of grain size distribution than most tailings, it would likely produce a wider spread of strengths and thus be more sensitive to the severe conditions of the planned test program. Sand is used as backfill in several Canadian operations, particularly where the mine is located some distance from the nearest source of mill tailings.

A number of recipes were designed using different combinations of these materials. The sand was used as a standard fill material in all the trials carried out in this study. As aforementioned, the focus of this study is on the strategies for improving the binding of the backfill. By comparing the unconfined compressive strength (UCS) while keeping the solid concentration and sand quality constant (an average sample density of 1,750 kg/m^3) the effect of curing temperature, cement type and different binder-admixture recipes were compared.

The ambient temperature in the sample preparation room and the water temperature were held constant for all tests at 5°C to simulate the temperature in a backfill plant during cold weather conditions. A set of curing temperatures consisting of, -10, -5, 0, 5 and 10°C, were used to determine the effect of the curing temperature on cement hydration. The sand, cement, and $CaCl_2$ were adjusted to the specific curing temperature for each trial. This temperature simulated the outside temperature in which such products may be stored.

The binder content was 5% by weight of dry sand. The sand and cement were blended in a laboratory mixer and the water was introduced after a one minute premix. Upon completion of the mixing cycle, the slurry−sand mix was subsequently cast into six 5 cm cubes. The six cubes consisted of two sets (for 14 and 28 days) of triplicates (for reproducibility).

Once cast, the cubes were moved into the curing chamber which was adjusted to the designated curing temperature. The curing chamber for the samples at 0, -5 and -10°C was a Keep Rite walk-in freezer. The samples at 5 and 10°C were cured in a Hot Pack incubator. All the samples in both curing chambers were covered with a plastic bag during curing. After 24 h in the curing chamber, the cubes were stripped from the moulds. They continued to be stored in the curing chamber for 14 and 28 days before the unconfined compressive strength tests were conducted. One triplicate set of samples went straight to the UCS test, while another set was allowed to sit at 22°C for 16 h before the UCS test was carried out. The UCS device was manufactured by Crock House Engineering. A constant loading rate of 2 mm/minute is utilised for this machine when breaking low strength materials such as cemented mine backfill and cement stabilised soil.

Figure 1 Samples were prepared in a temperature-controlled (5°C) room

A control test was run at -10°C consisting of only sand and 5% water, the same water content as all the other mixes. The control would demonstrate the strength provided by the frozen water without the influence of a cement binder. Creep was not considered since the sample only had 5% water with 95% sand and was well mixed.

3 Data

Six recipes were examined; GU, GU with 10% silica fume blend, GU plus 2% calcium chloride, HE, HE with 10% silica fume blend and HE with 2% calcium chloride. Three cubes were tested until compressive failure with the average representing the reported unconfined compressive strength. The results are compiled in the following four charts.

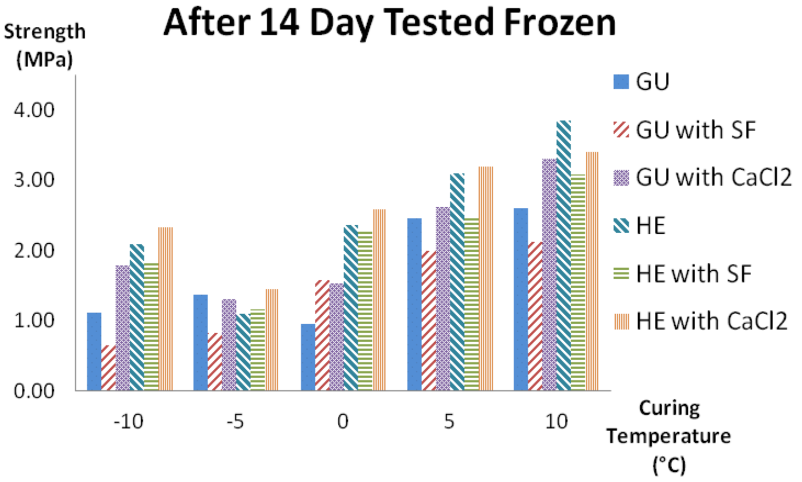

Figure 2 Samples cured for 14 days and tested frozen

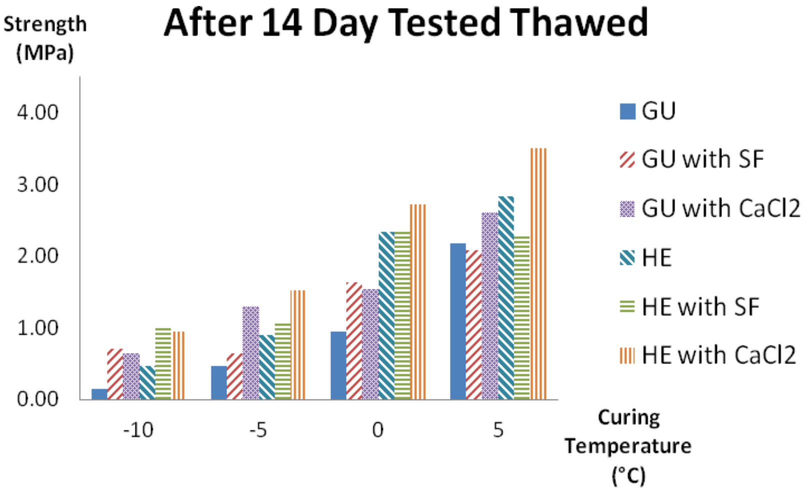

Figure 3 Samples cured for 14 days and tested after a 16 h thawing

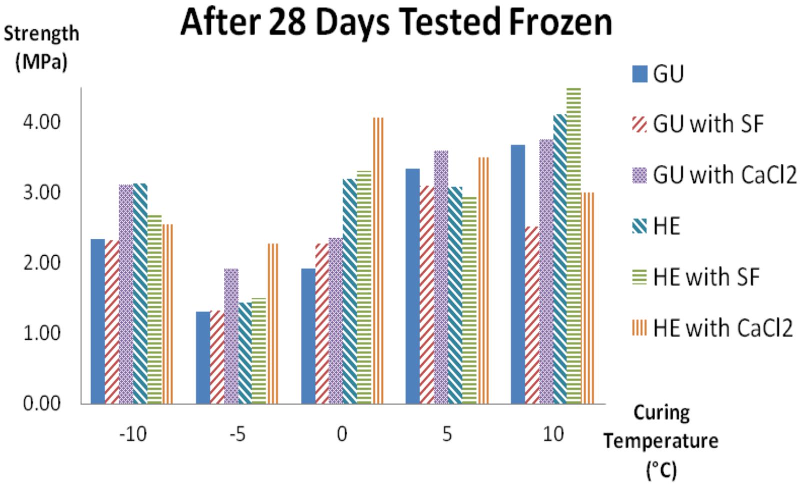

Figure 4 Samples cured for 28 days and tested frozen

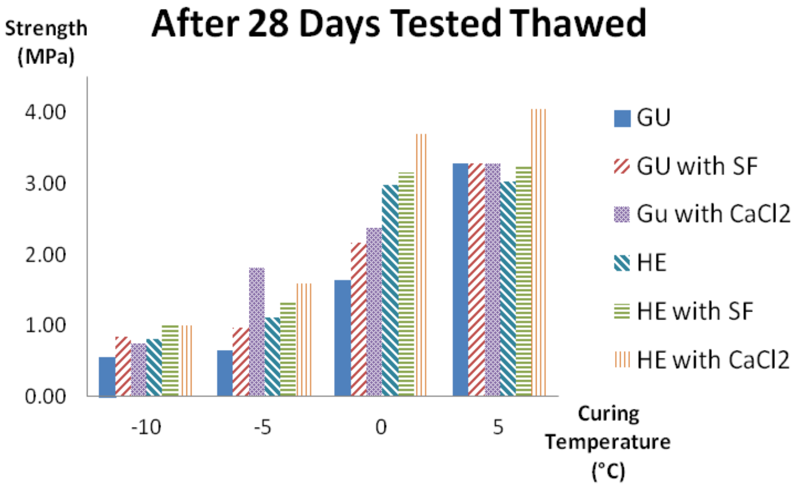

Figure 5 Samples cured for 28 days and tested after a 16 h thawing

4 Results

4.1 Effects of freezing on backfill strength

The control sample cubes, without binder, had broken apart while in the curing chamber before leaving the -10°C environment and therefore had zero strength. It was concluded that the 5% water addition was too low to bind the fill material together. The test was repeated with the exception that the water addition rate was increased to 20%. The average 28 day strength that resulted was 3.2 MPa, a strength that is comparable to strengths obtained using cement binders in the 5°C and 10°C temperature range.

As a strategy, when working with backfill in permafrost, water can be used as a binder. The strength is comparable in magnitude to strengths obtained with cement binders and which are adequate to maintain stability in most stopes. In fact, in the Canadian arctic, such a strategy was employed at the Polaris Mine and considered at the Raglan mine (Swan & Kazakidis 2010). During the later stages of mine life at Polaris the ‘ice stopes’ were replaced by rock fill bonded with HE cement and calcium chloride. The strategy of using ice to bind rock fill was abandoned because the stopes took longer than a year to fully freeze. The practice could no longer be accommodated within the production cycle.

Looking at Figures 2-4 there is generally an increase in UCS as the curing temperature increases, as is expected in concrete technology. However, two exceptions in the data are noted:

1. In Figures 2 and 4 the samples cured at -10°C are stronger than the -5°C cured samples.
2. Comparing Figures 2 with 3 and 4 with 5, looking at samples cured below zero, a higher compressive strength was observed in the samples that did not undergo the thaw. The samples cured at 0°C and higher had comparable strengths.

We know that ice bonding alone, in sand with low water content, did not play a role in the strength when no cement was present because the control sample had zero strength at -10C. There are two mechanisms working simultaneously:

1. A temperature challenged hydration reaction which decreases with decreasing temperature.
2. As ice gets colder, its UCS increases.

The combination of the cement and the 5°C colder curing temperature seems to have enhanced the -10°C sample strength relative to the -5°C samples. This phenomenon seems to result from the combination of partial cement hardening with ice bonding. There also appears to be no strength advantage when the curing of the thawed samples was increased to 22°C.

It is important to note that the added frozen strength phenomenon is easily demonstrated in the bench scale study because the sample dimensions are small enough to completely freeze within the 14 and 28 days. In practice, stope sizes are significantly larger and therefore typically take many months and up to years to freeze to the core. The rate of heat diffusion limits the extent to which the backfill benefits from the added frozen strength, i.e. if the stope takes 18 months before it is completely frozen it is likely that adjacent mining would start before the stope is completely frozen. To account for the freezing effect, the actual strength of the backfill is likely to fall in between the frozen and the completely thawed samples.

4.2 Effects of mix temperature on backfill strength

As noted in the Introduction, in the list of parameters that affect the rate of heat generation, the second point lists the mixing temperature of the batch components. A strategy that has long been adopted in the ready mix industry when working in cold weather conditions is to heat the water and in some cases heat the aggregates. Water represents about 20-35% by weight in paste backfill or hydraulic fill, and about 23 % in cemented rockfill. Water is relatively easy to heat up and distribute. Heating aggregates requires more effort. However, the aggregate represents such a large portion of the mass that, depending on the ambient temperature, heating the water alone may not adequately raise the mixing temperature. Heating the aggregate may also be required to eliminate ice chunks in alluvial sand or recovered tailings.

The Kidd Creek Mine in northern Ontario utilises paste backfill made from a blend of tailings and alluvial sand. Both sources are stockpiled in 20,000 t capacity domes and are kept warm enough to prevent the water in the aggregate from freezing. This is accomplished by circulating heated air in the dome. In addition, the mix water is heated in the winter months (McGuinness & Bruneau 2008). At the Polaris Mine, both water and aggregates were heated. In addition, after mixing, its rockfill was heated while being trucked for placement to a stope. Both examples demonstrate the practice of heating materials to elevate the temperature during the mixing cycle in cold weather environments as a means of improving backfill quality.

To summarise, two significant points concerning the effects of freezing and mix temperature on cemented backfill strength are:

1. Temperatures below -5°C can assist strength, less from cement hydration but more from the water freezing as a result of the increasingly cold temperatures however lab scale strength results, in a freezing environment, overestimate strengths.
2. Although not demonstrated in this paper, the well known practice of heating aggregates and or water is a proven strategy to extend the use of cement in freezing temperatures.

4.3 Effects of adding silica fume or $CaCl_2$ on backfill strength

Using the 100% GU mix as the benchmark, in the temperatures below zero, the silica fume addition to the GU demonstrated no strength benefit. Likewise, using the 100% HE mix as a benchmark, the silica fume addition was only marginally better in strength at -5°C and weaker at -10°C. Overall, the 10% silica fume addition was shown to have no benefit to mixes in a below zero environment.

On the other hand, the 100% GU mix showed a significant strength improvement at both -10°C and -5°C with a 2% $CaCl_2$ addition to the mix. The 100% HE mix showed no benefit with the 2% $CaCl_2$ at -10°C but a clear benefit at -5°C. It should be noted that in the below zero cures, the top mix designs either incorporated HE with or without 2% $CaCl_2$ or GU with 2% $CaCl_2$. Based on strength, the HE with or without $CaCl_2$ appears to have a modest advantage over the GU with $CaCl_2$. However, HE cement carries a premium over the price of GU cement and $CaCl_2$ is a common and low cost additive. The premium on HE is variable from market to market, pending on:

- If the HE and GU come from the same plant or not.
- The distance (freight costs) in getting the cement to the mine i.e. sometimes there is so much freight cost in getting the cement delivered that the price of the cement is secondary.

- Energy costs, HE is more energy intensive to produce and energy prices vary from jurisdiction to jurisdiction.

Consequently, the GU with 2% $CaCl_2$ offers efficiency in terms of value per cubic metre of backfill placed.

4.4 Effect of the thawing period

The time allowed for the samples to thaw was arbitrarily chosen to be 16 h. This length of time was estimated to be sufficient for the frozen samples to thaw. The thaw was meant to simulate a possible seasonal rise in temperatures experienced underground. The results showed that the samples that were cured at below zero temperatures and allowed to thaw, lost strength relative to the samples that did not undergo the thaw. In other words, the thaw reduced the strength.

In hindsight, the authors should have had an extra set of cubes to determine if the strength of the cubes would have increased due to continued hydration if they were thawed longer than 16 h, as would have been expected.

5 Summary and conclusions

Guided by the factors that affect the rate of heat generation in cement and practices reported in literature, the following guidelines of processes and products have been found to improve the strength of backfill in a permafrost environment:

- Heating the water, rock, sand or reclaimed tailings can extend the temperature range that cement will hydrate at, leading to improved backfill strength.
- Frozen backfill without binder can make effective backfill if several months of freezing are permitted before the mining of adjacent stopes. Even with binder, temperatures below -5°C have been shown to enhance strength.
- Cement type plays a key role in the strength of the fill.
- GU with additive offers better value per cubic meter of backfill placed compared to HE with additive.

In conclusion, GU cement in combination with calcium chloride was reported to be the most cost effective backfill binder tested. HE cement with or without calcium chloride in some circumstances can produce better strengths than GU with calcium chloride. The use of 10% silica fume in either GU or HE showed no benefit to strength in freezing temperatures.

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References

Dismuke, S & Diment, T 1996, ‘The testing, design, construction and implementation of cemented rockfill (CRF) at Polaris’, *CIM Bulletin*, vol. 89, no. 1005, pp. 91-7.

Klieger, P 1958, ‘Effect of mixing and curing temperature on concrete cement’, *Research Department Bulletin RX103*, Portland Cement Association.

Kosmatka, S, Kerkhoff, B, Hooton, RD & McGrath, RJ 2011, *Design and Control of Concrete Mixture*, 8th Canadian edn, Cement Association of Canada, Ottawa, Ontario.

Lafarge North America 2014, *Cold weather concreting plain facts and common sense*, Lafarge North America, viewed 1 April 2014, http://www.lafarge-na.com/wps/portal/na/en/3_A_11_2-Cold_Weather_Concreting:_Plain_facts_and_Common_Sense

Lin, B, O’Hearn, B & Ting, B 2014 ‘Effect of low temperature on backfill quality in permafrost condition’, *Proceedings of the CIM May 11-14, 2014 Conference*.

McGuinness, MA & C, Bruneau 2008, ‘Pastefill operation at Xstrata Copper – Kidd Mine’, *Proceedings of the Maintenance Engineering/Mine Operators' Conference*, Canadian Institute of Mining, Metallurgy and Petroleum, Westmount, pp. 50-8.

Swan, G. & Kazakidis, V, 2010, ’Evaluation of frozen backfill for open stope mining in permafrost conditions‘, *Proceedings of the Maintenance Engineering/Mine Operators' Conference*, Canadian Institute of Mining, Metallurgy and Petroleum, Sudbury.