Engineering Backfill Fiber as an Environmental Solution to Cost-Reduce and Improve Paste Backfill

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ABSTRACT

This paper discusses the paste design and the experimental results of using an environmentally benign additive known as engineering backfill fiber (EBF), which can potentially and significantly reduce of the cost of paste backfill. It was found that paste with EBF produced less bleed water and developed higher strength. The improved high early strength allowed a more flexible mining and backfill schedule. EBF may also be used for managing the risk of liquefaction and improve safety. The tailings, binder, and water used in this series of experiments were collected in a real world mining process.

INTRODUCTION

A properly designed paste backfill allows appropriate tailings disposal and stabilizes the underground. A paste is made of tailings, binder, and mix water and is often backfilled in a pipeline or by trucks. When mining in close proximity to the fill is required, relatively high binder content is used to produce high early strength and high long term strength. On the other hand, low binder content may be used in applications where the strength requirement is low. Often, the decision to reduce the binder content is driven by cost. However, depending on the geometry of the stopes, backfill schedule, and the properties of the tailings, this 'low' or minimum binder content may vary. When the paste is not meeting the minimum specification, there is a risk of inadequate ground support or liquefaction.

Besides binder dosage, using different types of cement produces different rates of strength gain in the paste backfill. For example, high early strength (HE) cement can be used when rapid strength gain is required. While using slag in the mix cement tends to have a slower strength development, it produces higher long term strength than of ordinary Portland cement (OPC). [1]

A well-designed paste backfill should meet the strength requirement within a given time, such that the time it takes for the paste to gain strength does not become the bottleneck of the mining process. At the same time, the cost per tonne of backfill should be kept low. This motivates the study of engineering backfill fiber (EBF). Paste backfill, like concrete, is strong in compression and weak in tension. Delaying crack formation and propagation is one of the strategies to improve the strength of paste backfill. Analogous to using steel and glass fiber to reinforce concrete, EBF is specifically designed to reinforce paste backfill. It is designed such that it is environmentally benign, low cost, and effective in reinforcing paste backfill. This approach is first looked at in as early as the 1980s by Mitchell, Stone et al 1985. [2] In

Mitchell and Stone's work, equilibrium analyses and laboratory tests were carried out. It was concluded that reinforcing techniques are effective and may save a substantial amount of binder. Saving cement binder is important as it may not only save cost, but also significantly reduces the carbon footprint for mining backfill.

DEVELOPMENT

In a project where EBF was tested, the backfill system required two recipes for producing 28-days UCS strengths of 100 kPa and 250 kPa. The tailings used in this project were reclaimed from a tailings pond and dry stacked. The tailings had an average of 30 – 35% passing 20 micron. A screen was employed to selectively remove clay, and the screened tailings had approximately 25% passing 20 micron. Prior test programs indicated that 90/10 slag/Portland cement was the most effective and economic choice of binder. At 2% binder, the paste developed 350 – 450 kPa after 28 days, allowing a factor of between 3 to 4 for the 100 kPa requirement. When 5% binder was used, 28-day UCS exceeded 1MPa. As the project continued, the tailings particle size distribution (PSD) contained even more fine particles. The binder content was increased to 3% to maintain the factor of 3.

The low binder content and high slag content in the recipe caused a slow hydration and therefore relatively low early paste strength. The backfill schedule needed to be managed carefully to prevent liquefaction. Particularly when filling against a fill barricade, the paste was allowed to cure between 2 to 5 days.

It was evident that a solution for increasing the early strength of this low binder content paste could eliminate the delay in backfill. In other words, the flexibility to backfill with minimal curing time was highly desirable. The objective for developing EBF was to improve early strength, and to improve safety by reducing the chance of liquefaction.

PROCEDURE

To understand the effect of EBF on the paste backfill, three types of paste were produced, as shown in Table 1 below.

Table 1. Binder and EBF content in the three types of paste (as a percentage of tailings)

	Binder	**EBF**
Paste	3%	0%
Paste + EBF-A	3%	0.3%
Paste + EBF-B	3%	0.3%

The base paste contained tailings and binder (3% by weight of tailings), with approximately 74 weight percent (wt%) solid. Slag with Portland cement (90/10), 3% by weight of the tailings, was used as the binder. Three buckets of paste were collected from the backfill plant. A slump test was performed on the paste with no EBF, the base paste, and measured 9" slump. Cylinders (3" x 6") were casted with the base paste. EBF-A and EBF-B, 0.3% by weight, of the tailings was added separately and thoroughly mixed into the other two buckets of paste. Cylinders were then casted with EBF-A and paste with EBF-B. After 24 hour, bleed water was removed from the cylinders, and the samples were stored in heat sealed bags.

OBSERVATION

After EBF was added to the paste and was thoroughly mixed in, the paste appeared to reduce its flowability. Some fibers were visible in the paste during mixing but the fiber did not seem to segregate from the paste. As shown in Figure 1, the paste with EBF (right 4 piles) retained the shape better and appeared less flowable.

Figure 1. Paste without EBF (left most pile) and with EBF (right 4 piles)

After 24-hour curing, paste without EBF produced on average 4% bleed water, using the definition outlined in ASTM standard C232. On the other hand, samples with EBF produced no measurable bleed water. It appeared the water was retained in the paste.

UCS testing was performed on the samples after 7, 21, 56, and 285 days. A set of three cylinders were tested for each test. The results were recorded and the average of each set was calculated. As expected, samples with no EBF had pieces break away and detach from the cylinder as shown in Figure 2. On the other hand, samples reinforced with EBF fractured without little fragments detaching from the sample after the UCS test.

Figure 2. Base (without EBF) paste had broken pieces falling off from the sample after UCS testing was completed

Figure 3. EBF-B paste after UCS testing showed cracks but the broken pieces remained attached to the cylinder

ANALYSIS

The average UCS results of the base paste samples, samples reinforced with EBF-A, and EBF-B are summarized in Table 2 and plotted in Figure 4. Paste reinforced with EBF developed significantly higher 7-day UCS than of the paste with no EBF (Base). Respectively, EBF-A and EBF-B improved the 7-day UCS by a factor of 4.5 and 2.5. As discussed in the Development section, this improvement in early strength is particularly useful in backfill in preventing liquefaction and delays in backfill.

Table 2. UCS of the samples

	Average UCS (kPa)		
Days Cured	**Base**	**EBF-A**	**EBF-B**
7	21.3	97.3	53.7
21	190.3	379.3	223.3
56	424.0	712.7	498.3
285	526.7	916.7	698.3

After 21 and 56 days, all samples gained more strength as cement hydration continued. EBF-A had the most dramatic increase while the difference between EBF-B and Base narrowed as illustrated in Figure 4. With the same cement content, paste with EBF developed higher UCS. In operation, this improvement in UCS can reduce the binder consumption, as less binder would be required to achieve the strength specification. By decreasing the binder consumption, it not only saves cost but also significantly reduces the carbon footprint in backfill.

After 285 days, paste with EBF continued to exhibit higher strength than that of base paste (with no EBF). This suggested that EBF was stable and did not degrade.

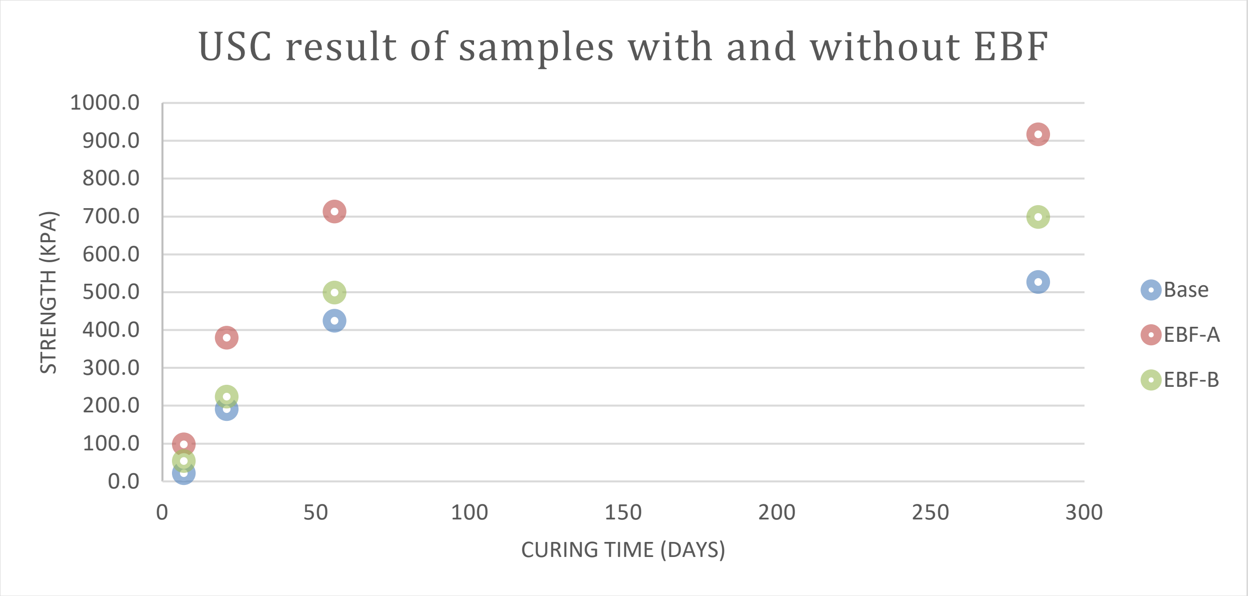

Figure 4. **USC results of base paste, paste with EBF-A and EBF-B**

One theory for the enhancement in UCS was that EBF helped retain the moisture in the cylinders. The base paste generated bleed water, which was removed, whereas EBF samples produced no visible bleed water. There was more water available for hydration in the EBF samples. However, this did not explain the difference between EBF-A and EBF-B. More likely, EBF provided reinforcement in tensile strength that concrete and paste backfill typically lack. This delayed crack formation and propagation. The material and mechanical differences in EBF-A and EBF-B resulted in different level of enhancement in UCS.

After the paste backfill fractured, the fragments remained attached to the sample as noted in the Observation section. In operation, this may reduce dilution and therefore improve the efficiency of the operation. More importantly, when the reinforced paste backfill failed, the fracture was gradual and not a catastrophic failure. This is an improvement for the underground safety.

In the QA/QC program for this particular backfill operation, most samples were tested after 7, 14, and 28 days. A few were done after 2, 3, 4 and 5 days to study the early strength of the paste. Unfortunately, the results presented in this paper were obtained after 7, 21, 56, and 285 days. While it is obvious EBF showed potential to improve the paste backfill, the misalignment in test days made it impossible to compare these results to a large set of QA/QC program data that were collected.

It is worth noting that there is potential to further improve EBF. EBF-A and EBF-B represented only a few parameters that were varied in the effort to optimize the material for paste backfill. Currently, the design of EBF is such that it is most suited for improving low binder content paste backfill. When the binder content is high, the effect of using current EBF design becomes insignificant. It would also be useful to understand how EBF would perform in paste with a very different particle size distribution (PSD) or different mineralogy. Furthermore, addition of EBF changed the flowability of the paste. To properly design paste with the use of EBF, the effect of EBF should be studied to account for the increased head loss in the paste distribution system.

CONCLUSION

An environmentally benign material, EBF, was experimented as the additive in paste backfill. In the backfill system where the test was carried out, slag/OPC (90/10) cement was used. The low binder dosage and the high slag percentage in the binder caused a slow paste strength development. It was found that the use of EBF complimented the original recipe in that it dramatically improved the early strength of the backfill. This characteristic allowed a more flexible backfill schedule and improved safety. Moreover, the enhanced strength can reduce the binder consumption. Lowering the binder consumption not only reduces the operating cost but also reduces the carbon footprint.

However, it was found that the current EBF is not effective in paste with high binder content. More tests using different tailings would be beneficial to understand how PSD and mineralogy may affect the EBF as an additive. Adding EBF changes the flow properties of the paste. Therefore, it is recommended that EBF to be studied in the early phase of the paste design in order to account for the difference in head loss for the underground distribution system

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