Laboratory investigation of using foam grout as micro-trench backfilling material in cold regions

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Abstract

Micro-trenching, an innovative method for fiber optic cables installation, involves creating a narrow trench in the road pavement to place a cable or conduit; the trench is normally narrower than 40 mm wide and shallower than 300 mm deep, depending on the size of the used conduit and trencher. After cutting the pavement, the next step is cleaning the area and placing the cable or conduit inside the trench, followed by backfilling. The quality of the backfilling plays an important role in both the sustainability of the installed cable or conduit and the cut pavement; using unsuitable materials or improperly installing cable or conduit can significantly decrease pavement life. The trench dimensions are very small, so for a successful procedure the backfilling material should be self-compacted and flowable enough to penetrate and completely fill the whole trench depth. As it has been investigated before, using traditional backfilling material such as play sand is not appropriate for Canadian cold regions; hence, it is recommended to stabilize the conduit inside the pavement's granular layer using a material similar to a cement grout. Alternatively, foam grout is a mixture of cement, water, and pre-formed foam; the foam considerably reduces the density of the blend by adding air, which consists of more than 25% of the mix. As a result, using this foam grout technology reduces the amount of cement required significantly and could be a cost effective solution for backfilling. The objective of this paper is to assess foam grout as a backfilling material for micro-trenching in cold climates. For this purpose, foam grout samples were prepared in a laboratory and their compressive strengths before and after several freeze and thaw cycles were investigated. Different mix-proportioning ratios were also studied in an attempt to create a more reliable method and assess variations in compressive strength and cost along with density.

Key Words: foam grout, freeze and thaw conditioning, compressive strength, mix proportioning.

INTRODUCTION AND BACKGROUND

Micro-trenching is a cable installation method that presents a reliable technique to the telecommunication industry due to its low cost, fast-paced execution, and more environmentally friendly aspects [1]. This cable-installation method is a cost-effective solution to time-consuming and disruptive traditional trenching methods, like open-cut [2], especially when considering the logistics of the last 200 meters of fiber optic deployment, known to service providers as fiber-to-the-home (FTTH) [3]. Using this technique, a trench no wider than 40 mm and between 120-300 mm deep is created alongside the edge of the road; trenching closer to the curb is preferable in order to avoid direct load caused by vehicles in their wheel path [4]. The trench is then cleaned and cables are laid inside. The most important step of this method is backfilling. The pavement must be – as much as possible – reinstated to its original condition. However, the size of the trench poses a great challenge to this process. Materials used as backfill must secure the cable inside the trench and be self-compact, flowable, stable, properly bond with the existing structure, and prevent water penetration [5]. It is important to note that the cut normally affects more than one layer of the pavement. Therefore, more than one material is usually applied as backfill. Figure 1 presents the three-step procedure for micro-trenching including cutting the trench (a), laying the cable (b) and backfilling (c).

Figure 1: Micro-trenching Procedure. (a) Cutting the trench. (b) Laying cable. (c) Backfilling

Micro-trench backfilling in cold regions presents a new challenge due to the unpredictable freeze and thaw cycles during changing seasons. With these extreme conditions, traditional materials like sand may not be suitable for backfilling purposes; for example, a pilot study investigation located in Edmonton, Alberta, Canada, used sand as a backfilling material in two different micro-trench techniques, and discovered that the cables had moved significantly [6]. With the first method, the 9 mm wide and 80 mm deep trench was completely filled with sand after the cable installation and covered with a hot sealant. With the second method, a 15 mm wide and 23 mm deep trench was filled with sand from the bottom to the interface of soil and pavement layers, and cold mix asphalt added on top. Monitoring the micro-trenches using ground penetrating radar (GPR) revealed considerable movements in the cables after a few months of installation [6]. Alternatively, in order to stabilize and protect the conduit inside the soil layer, cement grout was suggested as a replacement for sand. The setting time of the cement grout can be adjusted by changing the water temperature; additionally, the use of fast-setting cement will accelerate curing to less than 1 hour [7]. The use of cement grout as backfilling material has some drawbacks, as grout compressive strength can be as high as 28 MPa after the first day of curing and may increase to 40 MPa after 28 days. These high compressive strength values compared to soil may lead to stress development on the interface of the existing material and the reinstatement product. In addition, the high cost of cement may make this solution uneconomical. To decrease the strength and lower the price of backfilling material, foam grout can be presented as reliable substitute.

Foam grout

Foam or aerated grout is basically a mix of cement, water, and foam. In foam grout, the air bubbles produced will act as a temporary wrapping material for the mortar [8]. Foam can be generated by directly adding a foaming agent to the mix or it can be pre-formed in a separated recipient. In the dry method, a solution of water and foaming agent is forced through a series of high density restrictions by injecting compressed air into the mix recipient. The result is a thick foam similar to shaving foam [9]. The density of the mortar can be controlled by the amount of foam added. Density ranges from 300 to 1,800 kg/m^3 can be obtained [8, 10]. However, care should be taken towards the material specification, as any decrease in density will directly decrease the compressive strength of the grout after curing [8, 10, 11, 12, 13]. There is no defined mix proportioning for foam grout [8, 11, 12, 13]. The material specification is determined by collecting samples after each foam addition and controlling the density or strength [14]. The material is also very fluid, which provides an excellent load spreading and the ability to fill inaccessible areas without any compaction requirements [8]. Other advantages of foam grout are that it does not settle, can be produced in-situ, and has great thermal insulation properties. All listed advantages guarantee successful applications for different purposes such as trench reinstatement, void filling, road sub-base, building construction, and roofing insulation [8, 11].

Many projects have been conducted using foamed concrete as a construction material. In July 2006, 13,379 m^3 were used as a fill to elevate the playing field of the Mets Stadium in New York about 1.5 to 1.8 m above the grade of the old parking lot. A 465 kg/m^3 and 0.55 MPa mix was applied at productivity rate of 765 m^3 per shift, which provided a fast paced solution and direct savings of more than $500,000 [15]. In 2003, 7,951 m^3 of wet cast foamed concrete was applied in a full depth reconstruction – along with drainage improvements and curb installation – of the 3 km, four-lane Central Road in Schaumburg, Illinois, USA. The area was facing ongoing settlement due to a soft organic underlying soil (peat) located 3 to 5 m under the roadway. The 480 kg/m^3 material was produced onsite at a rate of 600-650 cm/day and resulted in a cost and time effective solution to the problem in the area [16]. In a similar manner, both a 500 mm and a 650 mm layer of material was applied in an intersection of the City of Victoria in 2007-2008 and in a 120 m rural highway in 2009, respectively, to solve differential settlement caused by peat sub grade [17, 18].

OBJECTIVES AND SCOPES

The objective of this paper is to complete and review a laboratory evaluation of foam grout minimum requirements for use as micro-trench backfilling material in cold regions. For this purpose, a mix design was prepared considering the material density and compressive strength. To evaluate the resistance of foam grout to freeze and thaw cycles, samples were conditioned and their compressive strength measured. To further prove the benefits of using foam grout as compared to regular cement grout, a cost analysis was prepared along with research and laboratory results.

Foam grout mix design

The mix proportioning method was developed by mixing 20 kg of Portland Cement Type GU at 1:2 water/cement ratio. Pre-formed foam with 5% protein-based foaming agent was added to the grout in small batches of 2 L (150 g). This value represents 0.17% in mass of the entire mix. After each addition, density was measured and three cylindrical samples were collected for compressive strength tests. The molds used have a 75 mm diameter and 150 mm height. Before the samples could be measured for density and tested for compressive strength, they were cured for 28 days inside a humidity chamber and the end grinded off. The procedure of preparing foam (a), mixing (b) and pouring (c) is shown in Figure 2.

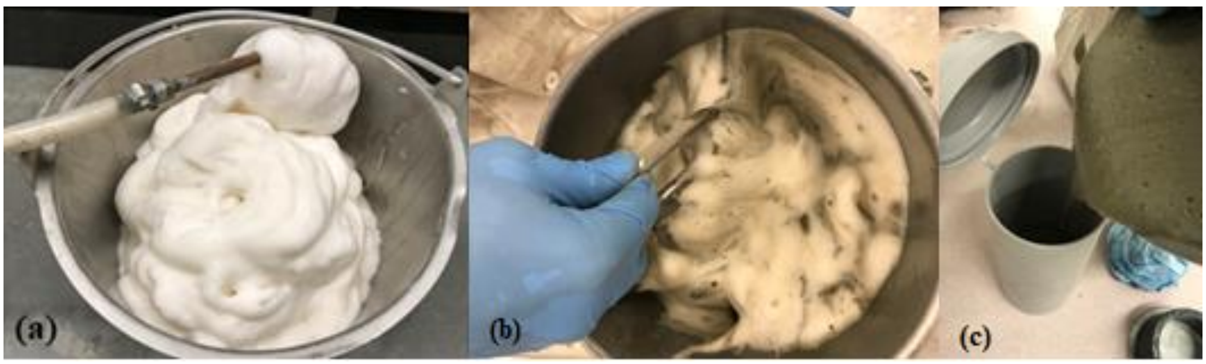

Figure 2: Sample Preparation. (a) Pre-formed dry foam. (b) Mixing. (c) Pouring in the molds

The recommended grout strength after curing is 1-3 MPa [19]; in this research, to be on the safe side, the target compressive strength was selected between 3 and 5 MPa. After several tests, the corresponding density to this strength was calculated as 850 kg/m^3. The density values obtained after each foam increment are presented in Figure 3.

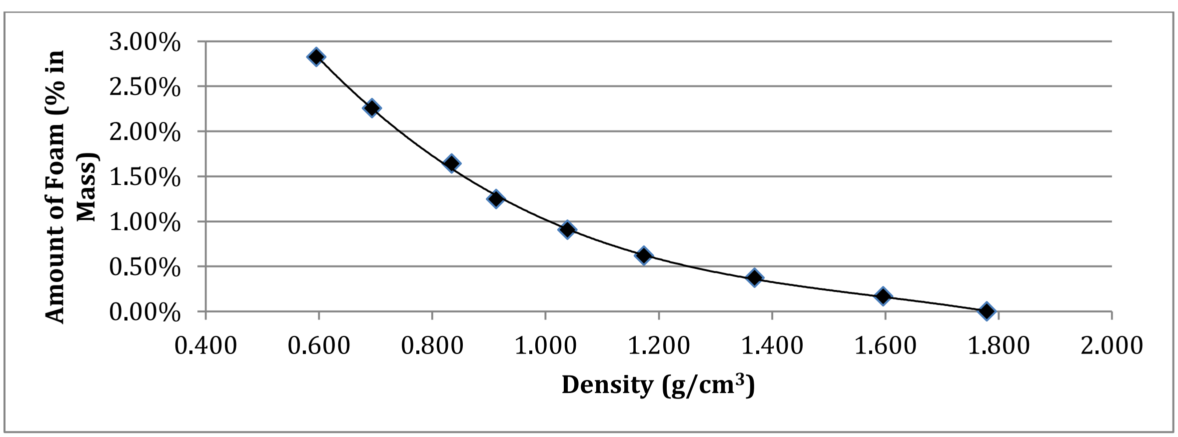

Figure 3: Mix Proportioning Curve

Figure 4 demonstrates the decrease in compressive strength obtained after decreasing the density of the foam grout mixture. As mentioned before, in foamed grout the air bubbles formed by the foam behave as aggregates in the mortar. Any increase in foam volume means more air inside the mortar and consequently, a lower density; that fact alone explains the compressive strength behaviour as air has no measurable strength.

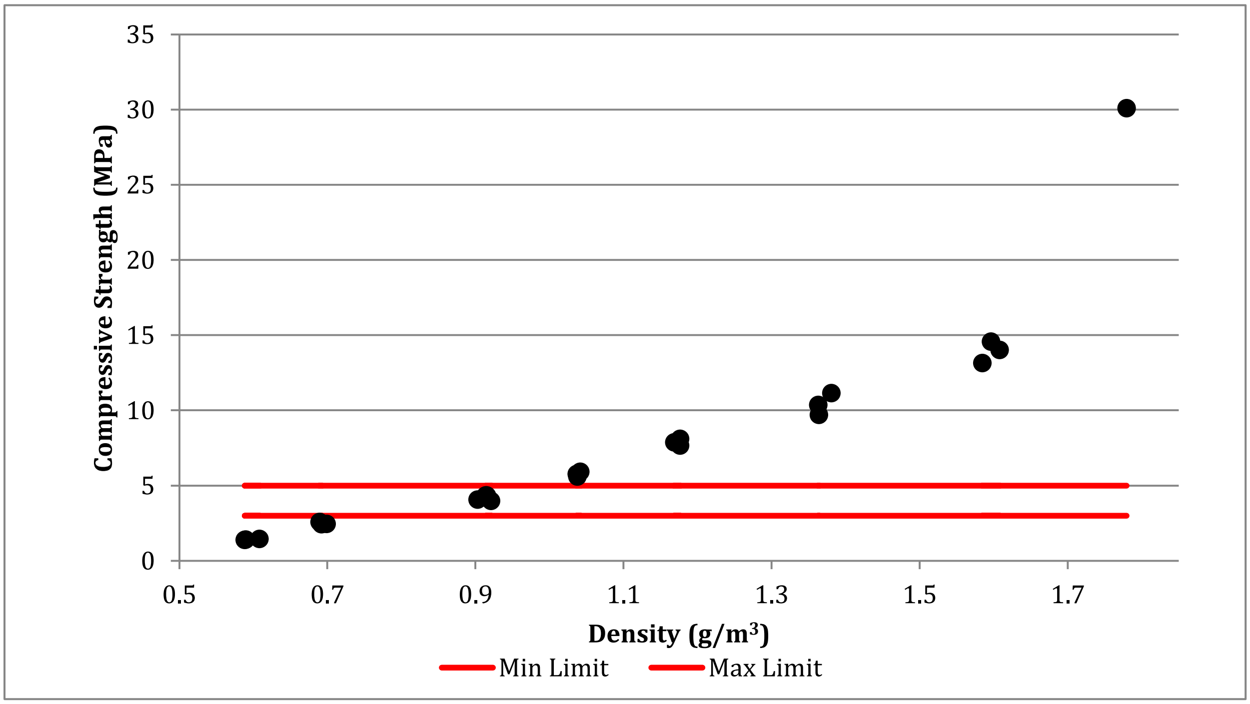

Figure 4: Compressive Strength Variations with Density

Another interesting observation is that the simple addition of foam in any amount results in a plunge in compressive strength. For this experiment, adding 0.17% of foam in mass to regular grout caused the compressive strength to drop from 30 MPa to 14 MPa. Note that this reduction becomes way less steep after the first increment.

Freeze and thaw testing on foam grout

To evaluate the effects of density and freeze and thaw cycles in compressive strength, ASTM C39 [20] procedure was followed. For the test, 62 foam grout samples with the density of 850 kg/m^3 were prepared. Samples were cured in a moist room for 3, 7, 14, 28, and 56 days and submitted to freeze and thaw cycles. According to Kearsley and Mostert [12], foam concrete continues to gain strength after 28 days of curing. Therefore, this curing period was added to investigate if the same happens for foam grout. Freezing cycles consisted of wrapping the samples in a plastic bag to prevent moisture loss and placing them inside an environmental chamber at -18˚C for 24 hours. For thawing, frozen samples were removed from plastic bags and submerged under water at 20˚C for 24 hours. Samples were conditioned to 0, 7, 14, and 25 freeze and thaw cycles for each curing period. After conditioning, samples were leveled using ASTM C 617 - 98 [21] method and crushed in the compressive strength machine.

Figure 5 shows the compressive strength results after exposure to multiple freeze and thaw cycles. After 3 days of curing, the ideal target of 3 MPa for compressive strength was obtained. A steady increase in strength for 7 and 14 cycles was observed for all tested samples, reaching a maximum of 4.63 MPa for samples cured for 28 days and conditioned for 14 cycles; however, for cycle 25, a very clear distinction appeared between the samples cured for 3 and 7 days and the samples cured for 14 and 28 days. It was observed that in the early stages of curing, when the material is still building strength, the increase in density counter-balanced the deterioration caused by conditioning. Characteristically, in the last stages, the harsh environment prevails and the specimens begin to lose strength. The significant presence of air voids can be explanation for such a long period before those effects were noticeable in the samples. The crushed samples did not have a plain and clean cut typical of cementitious material, which could be indicative that foam grout might be able to stop, at a certain level, the progression of cracks. Further comparison with regular grout samples is suggested as a base point for this analysis.

In either scenario, an unexpected increase of strength was observed for all samples after conditioning, which demanded further investigation for a clear understanding. A deeper analysis of the specimens before and after conditioning revealed an increase in density, as observed in Figure 6. For each testing condition, identified as days of curing and freezing/thawing cycles, the results of the 3 samples were plotted in the graph. The circle and square points in the vertical direction represent the same sample before and after conditioning, respectively. Consequently, as observed in the previous test, once the samples become heavier, their compressive strength also increases.

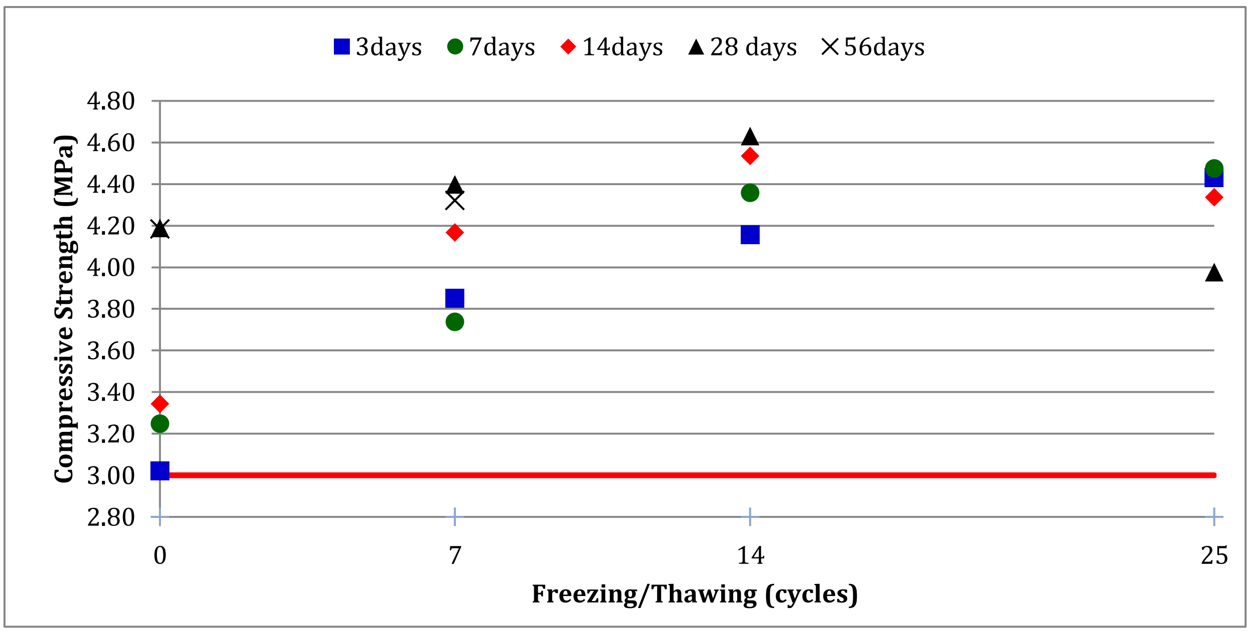

Figure 5: Compressive Strength for Regular and Conditioned Samples

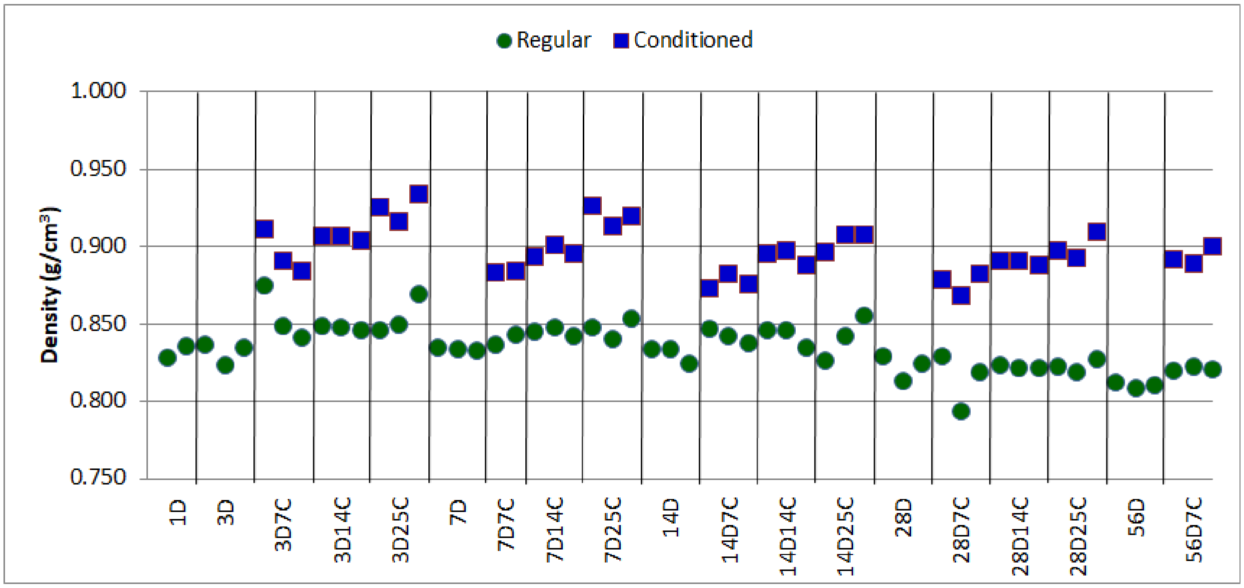

Figure 6: Sample Density

Future tests need to be conducted to closely evaluate the reasons behind this increase in density. Considering that every specimen was measured before and after conditioning and no difference was observed, the logical assumption would be that water is being absorbed by the samples and replacing the air within them. If water absorption is the sole test done to explain this density effect, then the results create a rather uniform pattern with the sample characterization. Figure 7 shows the percentage increase in mass of each group of conditioned samples. These groups were selected based on the number of days the sample was cured (first number, e.g.: 3D) and the number of freezing/thawing cycles (second number, e.g.: 1C).

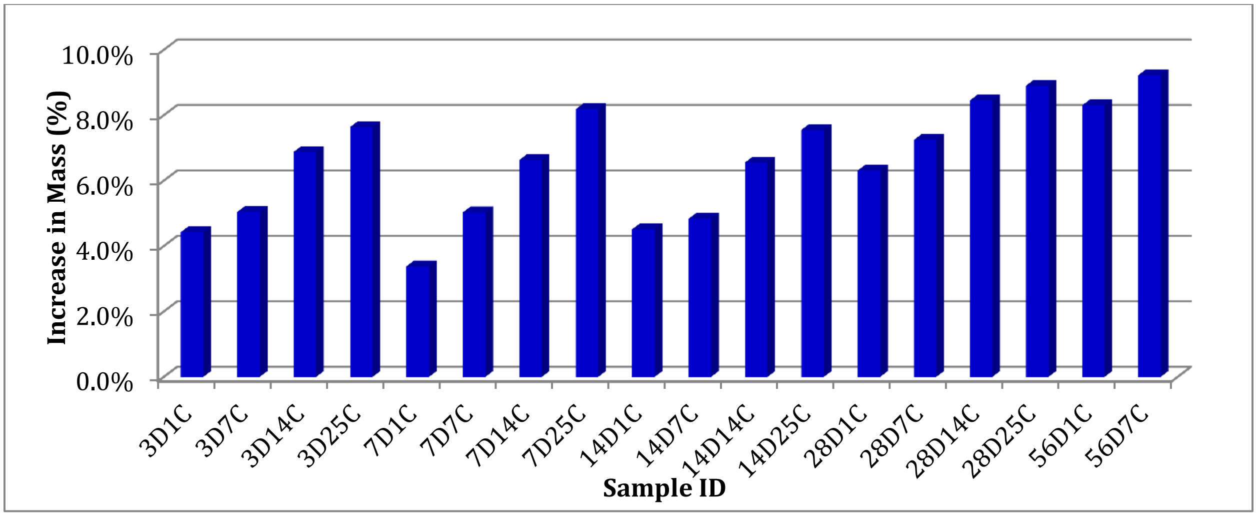

Figure 7: Water Absorption

Corroborating with this theory, Figure 8 presents a distinct color difference between a sample that was submitted to freeze/thaw cycles (on the left) and one that was not (on the right). The darker gray shade clearly indicates the presence of water within the conditioned sample, despite the fact that the outside surface is bare dry. Additionally, the dimensions of each sample were measured before and after they were conditioned and no apparent differences were detected; hence, density increment could be a result of the sample's water absorption.

Figure 8: Water Absorption Samples Before (right) and After Conditioning (left).

Cost analysis of using foam grout

To prove the benefits of using foam grout, a cost effectiveness analysis of the material was conducted. Table 1 presents the savings obtained in regards to material cost with the foam addition and the corresponding density of the sample piece. For backfilling applications, the target compressive strength of 3 MPa can be obtained with a density range between 0.8 g/cm^3 (6th increment) and 0.9 g/cm^3 (5th increment). In this range, around 50% of cement costs can be reduced by foamed grout utilization in comparison with regular grout (blank).

TABLE 1: Cement Cost Saving with Foam Addition

Foam content (% in mass)	**0**	**0.17%**	**0.37%**	**0.62%**	**0.90%**	**1.24%**	**1.64%**	**2.26%**	**2.82%**
Average Density (g/cm^3)	1.780	1.596	1.369	1.174	1.039	0.913	0.834	0.694	0.596
Average Cost Savings (%)	0.0%	10.3%	23.1%	34.0%	41.6%	48.7%	53.1%	61.0%	66.5%

The results of this study prove that the foaming agent is inexpensive when compared to the cost of cement. In order to produce the first 2 L of foam, 1.25 g of the water/foaming agent mix was used. Considering the 5% ratio applied, the total amount of foaming agent was 62.5 mg. In other words, 1 L of foaming agent is enough to produce 20 L of water/agent mix, 800 L of foam and, consequently, 1.2 t of foam grout at 850 kg/m^3 density. For perspective, foaming agent can be purchased in North America for an average of $10 USD/L [22].

CONCLUSIONS AND FUTURE STEPS

Conclusions obtained from the study are summarized as follows:

1- As previous literature stated, there is a direct proportional relationship between density and compressive strength.
2- The simple addition of foam causes a considerable decrease in compressive strength that becomes less evident as the quantity of foam increases.
3- The addition of foam can significantly decrease the cost of other materials in any application.
4- Regarding foamed grout, freezing and thawing conditioning results in an increase in density, followed by a compressive strength increase after each cycle.
5- For short curing ages, this same increase in strength overcomes the deterioration of the material when submitted to freezing/thawing conditions.

Based on the above conclusions, it is advisable as next steps for the research to further investigate the reasons behind the increase of density after freeze/thaw cycles. Water absorption can be considered as a reasonable start point to conduct observations. In order to draw a comprehensive cost effectiveness study of the technique, production costs and productivity analysis can be conducted in field applications. Additionally, the existence of test sections like the one in Edmonton, Alberta represent a great source of information to assess long term performance of the application.

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