

Preliminary Evaluation of Concrete-Rock Interface Behavior Under the Action of Freeze-Thaw Cycles

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Abstract. The most common source of failure for tunnelling occurs at the excavated surface due to a high frequency of freeze-thaw cycles and cold weather that significantly drop the strength of the interface between the rock and the concrete. A preliminary experiment was conducted to confront the problems associated with cold weather effect on concrete and the adhering connection between the concrete and the excavated rock surface. A series of composite specimens made of sandstone rocks and concrete with the three types of surfaces (smooth, semi-rough, and rough) were prepared in the Materials Laboratory of Northern Arizona University. All specimens were undertaken up to 180 Freeze-thaw cycles using an ASTM C666 apparatus with modifications on molds and dimensions of specimens. Tensile splitting tests of the interface between concrete and three types of rock surfaces were performed with respect to the bonding strength. The purpose of the research was to (1) evaluate the effect of freezing and thawing cycles on the bonding strength/interface behavior of the composite specimens and (2) to determine the rate at which adhesion strength is lost when undergoing cold weather environment. Based on the test results, the concrete-rock specimens prepared with rough surface show higher bonding strength than the other two surface treated specimens (smooth and semi-rough surface treatments).

1 Introduction

The concrete-rock composite structure has been used dramatically in engineering design and construction projects, such as tunnels, dams, mining facilities, etc. The interface behavior of the concrete-rock has a significant impact on the determination of the properties of the composite. Krounis et al. (2016) indicated that the shear strength of the concrete-rock interface has a substantial influence on the sliding stability of concrete gravity dams founded on rock [1]. Fishman [2] analyzed three failure mechanisms of concrete retaining structures situated on rock foundations and concluded that several factors (rock excavation, spread grouting, drainage cutoff, etc.) occurred during the rock foundation construction that should be taken into consideration for design and analysis. Tian et al. (2015) indicated that the shear behavior of cemented concrete-rock joints is a key factor affecting the shear resistance of dam foundations, arch bridge foundations, rock socketed piles and rock bolts in rock engineering [3]. Numerous studies using laboratory experiments and numerical analyses have been studied to help understand the performance of the concrete-rock structure such as drilled piers socketed into rock, rock anchors, and dam foundations [4,5,6,7,8]. Many research works focused on the application of concrete-rock in the construction of dam foundations while only a few examples of the concrete-rock structure is on tunneling

construction. Similar with the design of dam foundations, the interface behavior of the concrete-rock structure appeared to be a prominent factor that influences the mechanical properties of the composite in both tunneling and underground mining [4]. Particularly, the finishing surface between the interface of the concrete and the rock would result in a significant impact on the properties of the composite. Siange et al. (2005) further expressed that the rock surface preparation and the geometry of the rock surface on which the shotcrete is applied have been found to affect adhesion strength quite significantly [4]. However, the impact of freeze-thaw cycles on the interface behavior of the concrete-rock has not well studied, particularly how the strength of the composite material would change under the action of freeze-thaw cycles.

The paper presents a recent project that focused on evaluating the interface properties of the concrete-rock structure using sandstones finished with three surface textures (smooth, semi-rough, and rough) of the rock samples to be adhered with concrete. All concrete-rock specimens were prepared in the Construction Materials Laboratory of Northern Arizona University, USA and all concrete-rock specimens were undertaken a series of freeze-thaw cycle tests starting from 0, through 60, 120 and 180 cycles.

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2 Sample Preparation

2.1. Specimen design

In order to create a representation of tunnel lining, 5"x5"x5" (12.7 cm x 12.7 cm x 12.7 cm) cubic specimens consisting of a 2.5" (6.4 cm) layer of concrete poured onto a 2.5" (6.4 cm) layer on sandstone. A model of the specimen can be seen in Figure 1. The sandstone was shaped into three types of rock surfaces: smooth, semi-rough, and rough defined by no saw cuts, cuts at 1/2 inch (1.27 cm) in spacing, and 1/4 (0.64 cm) inch in spacing, respectively seen in Figure 2.

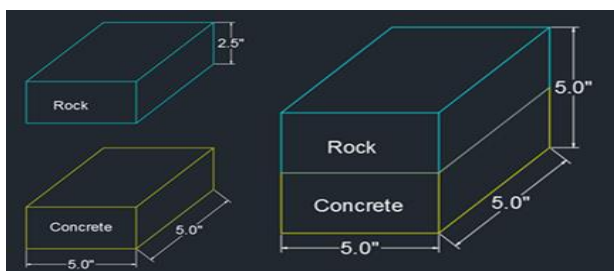


Fig. 1. Model of Specimen Design



Fig. 2. Sandstone surfaces: rough (left), semi-rough (middle), smooth (right)

The concrete mix was set to be used as conventional Portland cement mixed with water, aggregate, admixture (AKKRO-7T a liquid bonding mixture), and fiber. The mix design is shown in Table 1.

Table 1. Concrete mix design

(%) by weight	Mix component
25	Cement
62	Aggregate
12	Water
0.94	Admixture
0.04	Fiber

2.2 Specimen preparation

All sandstone rocks including smooth, semi-rough, and rough surface were placed in a fabricated concrete form (Fig. 3a). All materials indicated in Table 1 were

thoroughly mixed in a concrete mixer and then the concrete pastes were poured in to each box of the concrete form to be adhered with each rock specimen (Fig. 3b). After concrete pouring is completed, all the concrete-rock specimens were covered by a moist fabric and placed on top of the table at a room temperature for 7 days of curing.

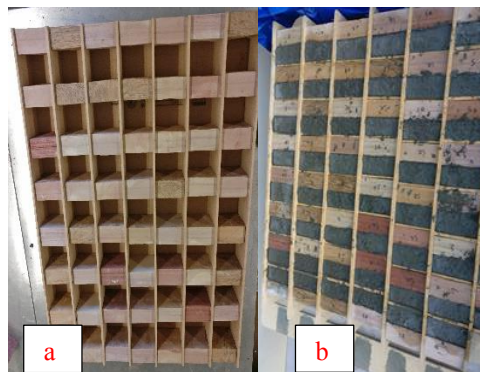


Fig. 3. concrete-rock preparation before and after concrete pouring

2.3 Cold weather simulation: freeze-thaw cycles

In order to simulate a cold-weather environment, the concrete-rock specimens were subjected to a series of freeze-thaw cycles following the modified American Society for Testing and Materials (ASTM) C666 standard: Resistance of Concrete to Rapid Freezing and Thawing. The ASTM C666 standard is specifically used for previous concrete (Fig. 4 top) (the dimension of mold: 16.5" x 3.5" x 4.6", or 42 cm x 8.9 cm x 11.7 cm; L x W x H). To ensure that the concrete-rock specimens could be undertaken freeze-thaw cycles, the modification of the procedure derived from the dimensions of the specimens and the bins needed to be changed to accommodate for the shape of the specimens. Thus, the dimension of a mold was refabricated to 20" x 7" x 6" or 51 cm x 17.8 cm x 15.2 cm (L x W x H) (Fig. 4 bottom). The freeze-thaw procedure was designed at 0, 60, 120, and 180 cycles at temperature ranges of 4° C to -18° C according to the ASTM C666 standard [9].



Fig. 4. ASTM C666 apparatus (a) and with a modification of molds (b)

3 Test Results and Discussions

3.1. Splitting tensile test

As previously mentioned, the direct shear test was primarily used to evaluate the interface behavior of the concrete-rock specimens. Given the objective of the research is to evaluate the strength along the interface between the original rock and the concrete, a splitting tensile test was considered as a better option to evaluate the adhering capacity along the interface between the concrete and the rock. The specimens were subjected to a splitting tensile test after the intervals of 60 freeze-thaw cycles: 0, 60, 120, and 180. A modification of the ASTM C496 Splitting tensile Strength of Cylindrical Concrete Specimens was used with extensometers placed on both sides of the specimen (Fig. 5).

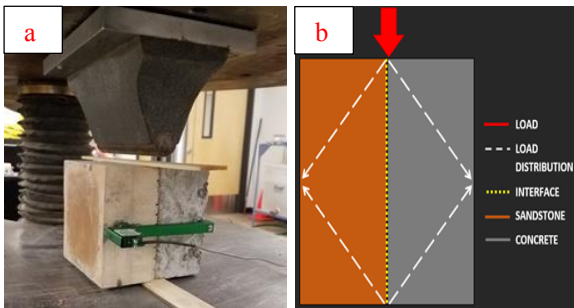


Fig. 5. Specimen, before test, with placed extensometers on each side (a) and illustration of loading distribution along a specimen (b)

After undergoing the ASTM 666 freeze-thaw testing at the designed cycles (60, 120, and 180), the specimens were removed from the mold and undertaken a splitting tensile test. During testing, load-displacement readings were recorded and then the ultimate/failure strength was identified. The examples of load-displacement curve for specimens with the three surfaces (rough, semi-rough, and smooth) tested at 120, and 180 freeze-thaw cycles were shown in Figure 6 and Figure 7. The peak point of the load-displacement curve is determined as the ultimate strength for a given specimen at the designed freeze-thaw cycles.

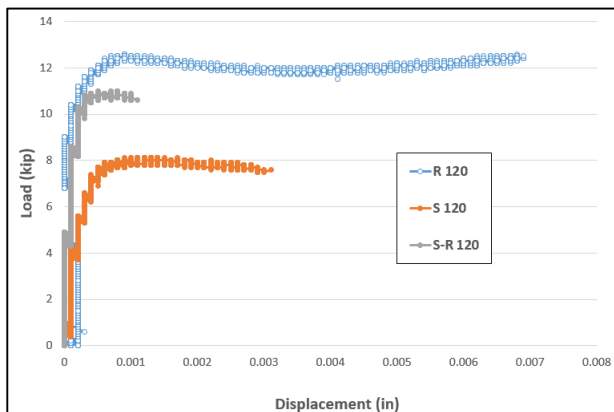


Fig. 6. Load-displacement curve for three types of specimens at 120 freeze-thaw cycles

Note: R, rough; S, smooth; S-R, semi rough

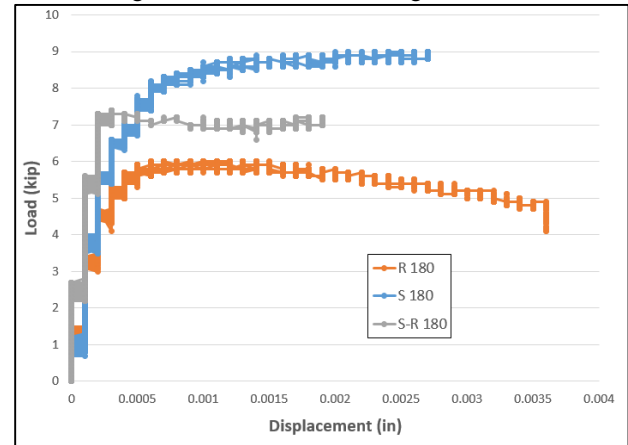


Fig. 7. Load-displacement curve for three types of specimen at 180 freeze-thaw cycles

Note: R, rough; S, smooth; S-R, semi rough

As can be seen in Figure 6 and Figure 7, rough treated specimens showed a better ductile ability than other two types of specimens, indicating that rough treated specimens would have better energy absorption when receiving loads. An example of specimens with three surface treatments after a splitting test was exhibited in Figure 8 and Figure 9. The comparisons on the failure between the interface of the concrete and the three surface treatments are also shown in Figure 9 and Figure 10.



Fig. 8. Close view of specimens with three surface treatments.



Fig. 9. Failure along the saw cut plane of a rough rock

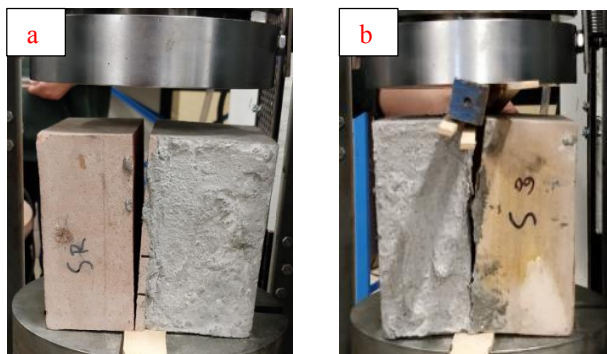


Fig. 10. failure along the saw cut plane of a semi-rough rock (a) and along the interface of a smooth surface (b)

From Figure 8 through Figure 10, it is observed that the failure occurred along the saw cut plane instead of the interface between the rock and concrete. This phenomena indicates the rough treatments improve the bonding strength of the composite material.

3.2. Results

After each designed cycle was completed, three specimens were removed and then tested for their splitting tensile strength. Thus, the average ultimate strength for each designed cycle was calculated. After all 180 freeze-thaw cycles were done, the average ultimate strength values of all concrete-rock specimens with three surface treatments were obtained and the results are displayed in Table 2. The trend of ultimate strength versus the increase of freeze-thaw cycles is not clearly observed in Table 2 along with Figure 6 and Figure 7, given the fact that all specimens including the rough, semi-rough, and smooth surfaces dropped from the 0 freeze-thaw cycle to 60 freeze-thaw cycles but adversely increased at 120 cycles and then dropped again at 180 cycles. It seemed that the effect of freeze-thaw cycles on the ultimate strength of concrete-rock specimens is not significant based on the tests. This could be possibly caused by testing operations, given the fact that after each designed F-T cycle (60, 120, and 180) specimens were left in the lab without immediately being tested for splitting strength. In addition, the bonding capacity during the concrete pouring might be a problem that needs further investigations.

Table 2. Ultimate strength of specimens

Surface condition/ultimate strength, Kips	Freeze-Thaw Cycles			
	0	60	120	180
Rough	7.6	7.6	11.0	8.3
Semi-rough	6.3	6.1	9.4	5.0
Smooth	7.1	5.7	8.5	7.9

In view of failures in Figure 8 through Figure 10, it showed that the rough and semi-rough surfaces have better bonding capacity along the interface than the

smooth surface, provided that the failures occurred on the rock specimens instead of the interface. The semi-rough and rough surfaces do provide greater adhesion properties along the interface. Even though, the ultimate strengths among all specimens did not show a trend on the relation between the interface behavior of the concrete-rock specimens, the failures through the rock specimens (Fig. 10) do bring a promising insight on the interface design for concrete-rock structures to be used in tunneling construction. Based on the above testing results, further tests have to be implemented to provide better understanding on the effect of freeze-thaw cycles on the interface behaviors of concrete-rock specimens. Nevertheless, the concrete-rock specimens with rough surface have appeared to have a higher ultimate strength than the two surface textures.

4 Conclusions

- (1) The ASTM C666 apparatus with modifications on specimen sizes is capable of testing concrete-rock specimens for their resistance to freeze-thaw cycles. The testing procedure can be adopted for future material testing under the action of freeze-thaw cycles.
- (2) The effect of freeze-thaw cycles on the interface behavior of concrete-rock specimens was not clearly understood in the study due to testing operation procedures. However, further tests must be implemented to investigate the interface properties of concrete-rock specimens.
- (3) The rock surface finished with rough textures appeared to have a higher ultimate strength than the two other treated surfaces. This is under expectation. However, surface finishing methods such as mechanical polishing can be taken in to consideration to further compare their ultimate strength.
- (4) The rough and semi-rough surfaces have better bonding capacity along the interface than the smooth surface, provided that fact that the failures occurred on the rock specimens.
- (5) While this is a preliminary experiment using the ASTM C666 standards with modifications, future research using the same apparatus should be continued to update the results done in the paper.

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