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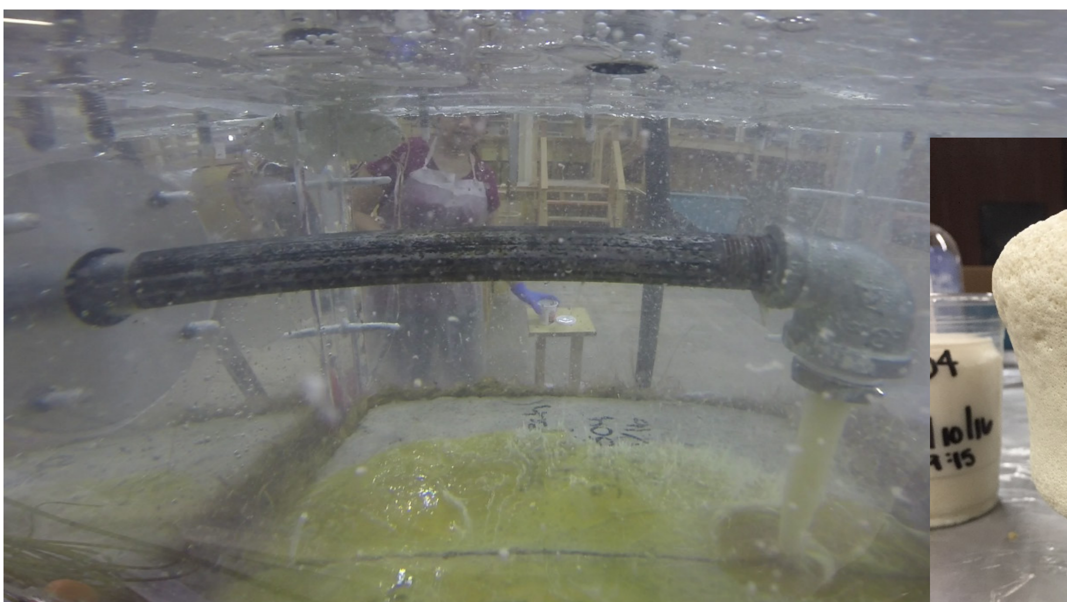
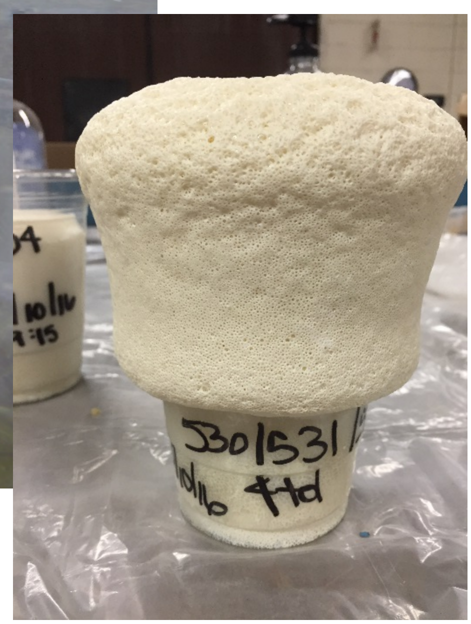
Report DSO-2016-04 (8530-2016-16)

Underwater Performance of a Hybrid Polymeric Repair Material to Seal Cracks in Concrete

Dam Safety Technology Development Program





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14. ABSTRACT

This research program evaluated the crack sealing performance of a combination of hydrophilic and hydrophobic polyurethane grout, using two proportions of two different manufacturer's grouts. The hybrid grouts were then injected underwater to determine if they could seal a crack in a concrete specimen. Successful performance of the hybrid polyurethane grout underwater consisted of sealing the crack, maintaining a 1 psi pressure, keeping the water clear during the injection phase, and having minimal floatation of the cured product. None of the hybrid grouts maintained the 1 psi pressure. However, the concrete specimens were qualitatively evaluated after the testing to determine how the grouts performed in the categories of penetration, number of gaps, adhesion, and shrinkage. The post evaluation also evaluated the final reacted product in the crack, characterizing the hybrid grouts as either flexible or rigid foams. Two of the four grout combinations were recommended based on the "good" rating they received in the post evaluation. Further study is recommended to determine if a hybrid polyurethane grout will fully seal cracks and sustain pressure underwater.

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Dam Safety Technology Development Program
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DSO-2016-04

Underwater Performance of a Hybrid Polymeric Repair Material to Seal Cracks in Concrete

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ACRONYMS AND ABBREVIATIONS

in.	inch(es)
ft.	feet
min.	minute
psi	pounds per square inch
CGSL	Concrete, Geotechnical, and Structural Laboratory
CAP	Central Arizona Project
F	Fahrenheit

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Page

Contents

TABLES

FIGURES

APPENDIX

ABSTRACT

This research program evaluated the crack sealing performance of a combination of hydrophilic and hydrophobic polyurethane grout, using two proportions of two different manufacturer's grouts. The hybrid grouts were then injected underwater to determine if they could seal a crack in a concrete specimen. Successful performance of the hybrid polyurethane grout underwater consisted of sealing the crack, maintaining a 1 psi pressure, keeping the water clear during the injection phase, and having minimal floatation of the cured product. None of the hybrid grouts maintained the 1 psi pressure. However, the concrete specimens were qualitatively evaluated after the testing to determine how the grouts performed in the categories of penetration, number of gaps, adhesion, and shrinkage. The post evaluation also evaluated the final reacted product in the crack, characterizing the hybrid grouts as either flexible or rigid foams. Two of the four grout combinations were recommended based on the "good" rating they received in the post evaluation. Further study is recommended to determine if a hybrid polyurethane grout will fully seal cracks and sustain pressure underwater.

KEYWORDS

Underwater, Concrete, Crack, Repair, Chemical Grout, Seal

EXECUTIVE SUMMARY

Many times, repairs to seal water leaks through concrete cracks and joints requires dewatering. Many of the products that are rated for underwater installation are epoxy based products that are rigid and thus not suitable for repairing cracks or joints that move. Using these products can crack adjacent concrete or crack the seal if there is movement.

Some polyurethane resin formulations result in cured grout products that are flexible and thus able to handle crack and joint movement. Because of this, a laboratory study was conducted in 2015 by the Concrete, Geotechnical, and Structural Laboratory in the Bureau of Reclamation. Results were very promising, but the study also found that injecting hydrophobic grouts underwater did not fully seal cracks. The products became buoyant as they cured, floating to the surface. They did, however react in such a way that the water remained clear. The same study found that hydrophilic grouts sealed the cracks, had limited floating cured product, but clouded the water so much that it was difficult to observe the application of the grout [1].

The objective of this new study was to see if premixing a hydrophilic grout with a hydrophobic grout would result in a product that would seal the crack, prevent production of a buoyant foam, and keep the water clear when used in an underwater application. Mixing hydrophilic and hydrophobic grout resins together prior to use is a somewhat novel concept that Reclamation staff have done, but only on a limited basis.

Grout products from Avanti and Strata-Tech were selected for this research project. Products from these same two manufactures were used in the 2015 study. Two mix proportions for each combination of grout were selected for testing based on cup test performance. The cup test products that produced a flexible foam with minimal shrinkage were selected for underwater testing. The proportions selected were 4 parts hydrophobic to 1 part hydrophilic (4:1) and 3 parts hydrophobic to 2 parts hydrophilic (3:2). The grouts were premixed and then tested in a custom test chamber that was designed and constructed in the Reclamation laboratory.

The test chamber contained a cracked concrete slab with water at a known pressure on one side and no pressure on the other side. Grout was injected through an injection nozzle near the crack opening in the concrete slab. Water flow through the crack would draw the grout mixture into the crack.

The grouts were initially evaluated based on their performance during the crack sealing phase of the project.

- Crack Sealed – Was the crack filled? Did the seal sustain the 1 psi pressure? Crack may have been completely filled, but some minor leakage may still be occurring.
    - Full Fill- the grout cured in the crack, went all the way thru, and had no gaps.
    - Fill – the grout cured in the crack, went all the way thru, but had a few small gaps.
    - Partial Fill – the grout only partially cured in the gap, large gaps remained, and/or poor penetration occurred.
- Visibility - Did the water remain clear during the testing?
- Workability - Did the product float as it cured underwater?

After testing was complete, a post testing inspection of the specimens was performed and evaluated the following characteristics:

- Penetration - Did the product penetrate all the way through the crack?
- Gap - Were there visible gaps along the length of the crack?
- Adhesion - Did the product appear to adhere to the walls of the crack? Was it difficult to pull grout out of the crack?
- Shrinkage – Did the product shrink back from the walls of the crack after drying?

Table 1 and Table 2 show the final results. Results of the final product performance was based on the post testing evaluation of the specimens where a qualitative inspection on product penetration, number of gaps in the seal, adhesion, and product shrinkage was conducted. A rating of “POOR” in 3 or more categories resulted in a final product performance of “POOR”. The product naming convention represents the part hydrophobic resin to part hydrophilic resin.

Example, Strata-Tech product testing using 4 parts ST-530 (hydrophobic) to 1 part ST-504 (hydrophilic) has a naming convention of 530/504 4:1. The "recommended" column notes which grouts are recommended for further study.

Table 1. Strata-Tech Final Results

Product Name	Crack Sealed	Visibility	Workability	Final Product Performance	Recommended?
Strata-Tech 530/504 4:1	FULL FILL	GOOD	POOR	GOOD	YES
Strata-Tech 530/504 3:2	PARTIAL FILL	GOOD	POOR	POOR	NO

Table 2. Avanti Final Results

Product Name	Crack Sealed	Visibility	Workability	Final Product Performance	Recommended?
Avanti 248/330 4:1	PARTIAL FILL	GOOD	POOR	POOR	NO
Avanti 248/330 3:2	FILL	POOR	POOR	GOOD	YES

The following conclusions resulted from the laboratory testing.

- The study found that two of the grout combinations filled or fully filled the crack.
- All the hybrid grout combinations had some floating foam as the grout cured due to the hydrophobic grout.
- An increase in hydrophobic grout content increased water visibility.
- Although the seals did not sustain a 1 psi pressure, a post evaluation of the specimens indicated the grouts may perform well in terms of penetration and adhesion and further study is recommended.
- Field studies should have extra grout pumps on site.
- Special attention is required to keep the supply bucket full of grout mixture to minimize delays in the injection process.

The following additional studies are recommended:

- Future lab tests should evaluate the effects higher grout temperatures and premixing water with the grout prior to injection would have on the sealing performance. The intent would be to see if the product would cure faster and have a better chance of adhering to the walls of the crack.
- Additional lab tests should be conducted using the products of other manufacturers.

INTRODUCTION

Previous Laboratory Study

The Concrete, Geotechnical, and Structural Laboratory (CGSL) has been studying underwater applications of polyurethane grout (also known as chemical grout). The underwater study began in the summer of 2015 where a custom test chamber was developed that simulated a 12 foot deep canal. The test chamber had an injection rod through the middle of the chamber that dispensed polymeric grout into a premade crack in a concrete specimen. The objective of this study was to see if the polymeric grout would cure underwater and seal the crack in the concrete specimen [1].

The 2015 study evaluated the performance of four different polymeric grouts, two hydrophilic and two hydrophobic grouts. Hydrophobic grouts require a catalyst and typically have a larger expansion than hydrophilic grouts. Hydrophilic grouts seek out water in cracks and usually form a flexible foam. The study rated the grouts based on the following criteria.

1) Crack Sealed – Was the grout able to seal the crack and sustain a 5 psi pressure?
2) Visibility – Did the water remain clear or did it cloud?
3) Workability – How easy was it to get the grout through the crack? Did the product become buoyant as it cured?

The results of the study found that the two hydrophilic grouts were the best at sealing the crack, but the two hydrophobic grouts were the best at keeping the water clear. The study also found that the hydrophobic grouts foamed and floated as they reacted with the water and cured. The study recommended that future studies be conducted where a hydrophobic and hydrophilic grout were mixed and applied underwater using the same methods as the 2015 project. The study authors hypothesized that the combination of the two grouts would create a product with less clouding of the water and better sealing qualities.

Field Demonstration

The success of the 2015 laboratory study drew the attention of the Phoenix Area Office and Central Arizona Project (CAP) staff. In February of 2016, CGSL staff traveled to Casa Grande, AZ to perform a field demonstration on the Pool 33 section of the CAP canal. The field demonstration used the two hydrophilic grouts that were used in the laboratory study on the crack in the CAP canal (Strata-Tech ST-504 and Avanti AV-330). The primary purpose of the field demonstration was to see if polymeric grout could be injected into the cracks in the concrete canal while the canal was still in service [2].

The main issue encountered in the 2015 laboratory study was the slow reaction of the grout with the water. There was a significant amount of product wasted because it passed through the crack before it could cure and adhere to the walls of the crack. This field demonstration also evaluated two new factors to see if they would decrease the curing time; mixing water with the grout at the point of injection by using a premixing nozzle (called an F-assembly) and mixing the grout with warm water (80 degree F to 180 degree F). CAP staff used a commercial diver to conduct all the underwater injection tests [2].

The following conclusions were drawn from the field demonstration [2].

1) Both ST-504 and AV-330 performed better using the F-assembly resulting in better adhesion and crack penetration of the grout. The F-assembly allowed water to be mixed with the resin just prior to injection.
2) Premixing the grout with heated water also helped the grouts set faster, which improved results.
3) Each grout had a different optimal water temperature to attain the best penetration and adhesion
    a. ST-504
        i. 120°F water mixed with grout
    b. AV-330
        i. Low canal flow condition – straight grout with no premixing
        ii. Higher canal flow condition – 80°F water mixed with grout
4) The 180°F temperature water was too high for both grouts. The grout set almost instantaneously and only had limited penetration into the cracks.

History of Hybrid Grouting at Reclamation

Mixing a hydrophilic and a hydrophobic grout is a novel concept that has been used sparingly by Reclamation. Gregg Day, a contractor and retired Reclamation concrete repair technician, performed polymeric grouting of the leaking cracks and joints in the upstream face of Gerber Dam in Oregon in December of 2014. The crew used a combination of Strata-Tech ST-504, Strata-Tech ST-524, and Strata-Tech ST-530 at a ratio of 1:2:2 by volume. The mix was catalyzed with Strata-Tech ST-531 to achieve a gel time of 2 to 2 ½ minutes. The trip report cited the combination of hydrophilic and hydrophobic grouts as having "good travel, strength, and flexibility." [3] However, the quantitative values for strength or flexibility were not documented.

For this project, Day was consulted to get more information about his experience with mixing hydrophilic and hydrophobic grouts. Recommendations were made to leave out ST-524 and that the ST-504 and ST-530 should be mixed at a 2:3 ratio by volume. In addition, the ST-504 could be catalyzed by the ST-531 if a faster reaction is desired.

Other Reclamation concrete repair projects, such as Jamestown Dam Spillway Crack Grouting, have used a hybrid application of polyurethane grout. However, those projects did not list specifics as to what proportions were used. Both the Gerber Dam and Jamestown Dam projects utilized traditional interception grouting methods and were not injected underwater.

Research Objective

The objective of this research was to evaluate the performance of hybrid polymeric grouts developed by mixing hydrophobic and hydrophilic polyurethane grouts. This study is very similar to the 2015 research study. Prior to starting testing of the grout in the water chamber, cup tests were conducted to determine what proportions should be used. The following are specific steps outlined to meet the objective:

1) Conduct cup tests to develop grout proportions so the resultant product will be flexible with little shrinkage during drying.
2) Develop a hybrid grout combination so that
    a. The water remains clear enough that the crack and injection rod remain visible at all times.
    b. The polymeric grout flows through the crack without curing before adhering to the concrete.
3) Apply polymeric grout underwater to successfully seal a premade crack in a concrete specimen.

CONCLUSIONS

The testing performed in this study found that mixing a hydrophobic grout with a hydrophilic grout did not perform as hypothesized by the author. However, the grout combinations performed well enough, that future study is recommended. Table 3 shows the results of the underwater application of the four grout combinations tested.

Table 3. Underwater performance

Product Name	Crack Seal	Visibility	Workability
Strata-Tech 530/504 4:1	FULL FILL	GOOD	POOR
Strata-Tech 530/504 3:2	FILL	GOOD	POOR
Avanti 248/330 4:1	PARTIAL FILL	GOOD	POOR
Avanti 248/330 3:2	PARTIAL FILL	POOR	POOR

Although none of the grout combinations resulted in a product that sustained pressure, several of the products performed very well in filling or fully filling the crack with cured resin. A post testing evaluation of the grouts indicated that issues related to the grout pumps and running out of material during testing may have had a negative impact on the performance of several of the grout applications.

Table 4 and Table 5 indicate which grout combinations are recommended for further study.

Table 4. Recommended grouts based on post testing evaluation

Product Name	Penetration	Gaps	Adhesion	Shrinkage
Strata-Tech 530/504 4:1	GOOD	GOOD	GOOD	GOOD
Avanti 248/330 3:2	GOOD	GOOD	GOOD	GOOD

Table 5. Not recommended based on post testing evaluation

Product Name	Penetration	Gaps	Adhesion	Shrinkage
Strata-Tech 530/504 3:2	POOR	POOR	VERY POOR	GOOD
Avanti 248/330 4:1	GOOD	POOR	POOR	POOR

This study showed that:

- Two of the grout combinations filled or fully filled the crack. However, none of the hydrophobic/hydrophilic grout combinations sustained pressure, indicating there were leaks in the seal.
- The higher the proportion of hydrophobic grout in the combination the better the visibility of the water.
- All four grout combinations yielded significant curing before adhesion resulting in floating of cured grout.
- Post evaluation of the specimens indicated that the final product may be suitable for underwater applications.
- Mechanical issues related to the grout pump may have affected the results.
    - During the Strata-Tech 530/504 3:2 testing, the pump lost its prime and a significant amount of time elapsed between grout applications over the crack. The grout that had been dispensed cured over the top of the crack, so additional grout could not be injected past the cured grout.
    - During the Avanti 248/330 4:1 testing, grout levels became low in the supply bucket and the pump lost its prime resulting in having to stop the testing. Perhaps the crack would have fully sealed had there been enough grout to perform more applications of grout.
- The grouts from the two manufacturers had different optimal mix proportions. The optimal mix proportions were based on how well the grout performed in the final evaluation. The two grout combinations listed below received a “good” rating in the categories of penetration, gaps, adhesion, and shrinkage.
    - Strata-Tech had optimal performance with the 4:1 ST-530 to ST-504 combination.
    - Avanti had an optimal performance with the 3:2 AV-248 to AV-330 combination.

- The Strata-tech final products were rigid to the extent that when compressed, the cell structure of the solid broke and there was no rebound in the solid. This final product should only be used when movement is required to be restrained.
- The Avanti final products were flexible and could be used when crack movement is anticipated.

TEST DESCRIPTION

Grout Optimization

Cup tests are performed by placing a small amount of prepared grout in a cup and observing its reaction including timing the period required for curing. Cup tests are used during traditional polymeric grouting operations for multiple reasons. They are used primarily to determine the gel time of the grout. If the grout is pumped a long distance, the grout operator needs to make sure that the grout does not gel too quickly. On the other hand, if the grout does not gel quickly enough, as is the concern with underwater grouting, the unreacted grout may pass thru the crack and not seal at the proper location. When using a hydrophobic grout, the percentage of catalyst can be adjusted so that the appropriate gel time is achieved. For grouts mixed with water at the injection nozzle, cup tests can provide evidence that the grout pump is delivering resin and water at the correct proportions.

The second use of a cup test is to perform quality control of the product. Cup tests should be performed with every new batch of polymeric grout used on a job. The gel time should fall into the range provided by the manufacturer. An experienced grouting contractor can tell if there is something off with the chemistry of the grout based on cup test performance. Figure 1 shows the cup test on a product that had expired. The chemical reaction was unstable and large gas bubbles formed. This product, if used, would not perform as designed due to the large void.

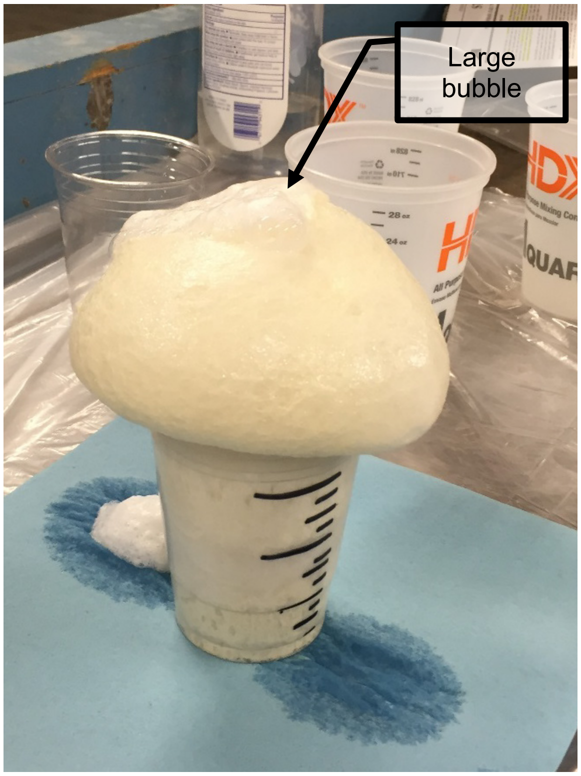

Figure 1. Cup Test of Expired ST-530

The purpose of the cup tests on this project were the following

1. **Gel Time-** Determine what the approximate gel time was of the product. The gel time of the cup tests were used during testing to determine when to inject more grout so that grout waste could be minimized.
2. **Quality Control-** A cup test was performed on the individual products as well as the combined products to make sure that the combination of the different grout types would react to form a quality product.
3. **Determine Product Proportions-** There is very little documentation about the characteristics of the final product when hydrophilic and hydrophobic resins are mixed together. After performing several cup tests, it became apparent which combinations would perform the best. The final product should have good strength, flexibility, and minimal shrinkage. Cup tests were performed on Avanti products, and the best two combinations were used in testing of both Avanti and Strata-Tech products. Cup tests were also performed on Strata-Tech products using the predetermined proportions from the Avanti cup tests.

Sample Preparation

Concrete Specimens

The concrete specimens used in this research project were 1 ft. × 1 ft. × 3 ½ in. thick. Similar to the 2015 underwater grout research project, the 3 ½ in. thickness was selected to match the typical thickness of a concrete lining in a concrete lined canal. The specimens were made out of a 4500 psi pea gravel concrete mix that was supplied by a ready mix supplier. [1]

The concrete specimens were notched with a ¼ in. deep groove. The groove was provided during casting so the specimen would crack at the predetermined location. The specimens were split into two separate pieces by performing a three point bend test and loading it to failure using the Instron Universal Testing machine. The specimens simulate a full depth crack in a concrete canal that needs repair [1].

Polymeric Grout

The grout had to be pre-proportioned before testing could begin. The hydrophobic resin (AV-248 or ST-530) was measured and poured into a five gallon bucket. The catalyst (AV-249 or ST 531) to the hydrophobic resin was measured second and poured in with the hydrophobic resin. Avanti recommends a maximum of five percent by volume of catalyst to the resin. Strata-Tech recommends a minimum of three percent and a maximum of nine percent by volume of resin of catalyst. The team selected the high range percentage of five percent catalyst by volume of the hydrophobic resin so that the resin would react as quickly as possible. Five percent was used for both products to try to keep the gel time constant. The grout was mixed for approximately one minute to completely mix the catalyst with the hydrophobic resin. Finally, the hydrophilic resin (AV-330 or ST-504) was measured and poured in with the catalyzed hydrophilic grout. The combined grout was mixed thoroughly for another minute. The final product was covered until it was time to inject the grout.

The grout was not mixed until the testing was completely set up and the grouting procedures were ready to begin. The team wanted to make sure that the grout remained completely mixed prior to injection. It was important to cover the grout as soon as possible because the grout reacts with moisture in the air and leaves a reacted film on the surface of the grout.

Equipment

Test Chamber

The test chamber was custom built so that a constant water pressure could be applied to top of the concrete specimen during testing. The system used an inlet in the top of the test chamber to apply the hydraulic pressure and an outlet at the bottom so that water could be drained out of the chamber. Figure 2 shows the test chamber prior to placing the concrete specimen in the chamber or attaching the top and bottom lids of the chamber.

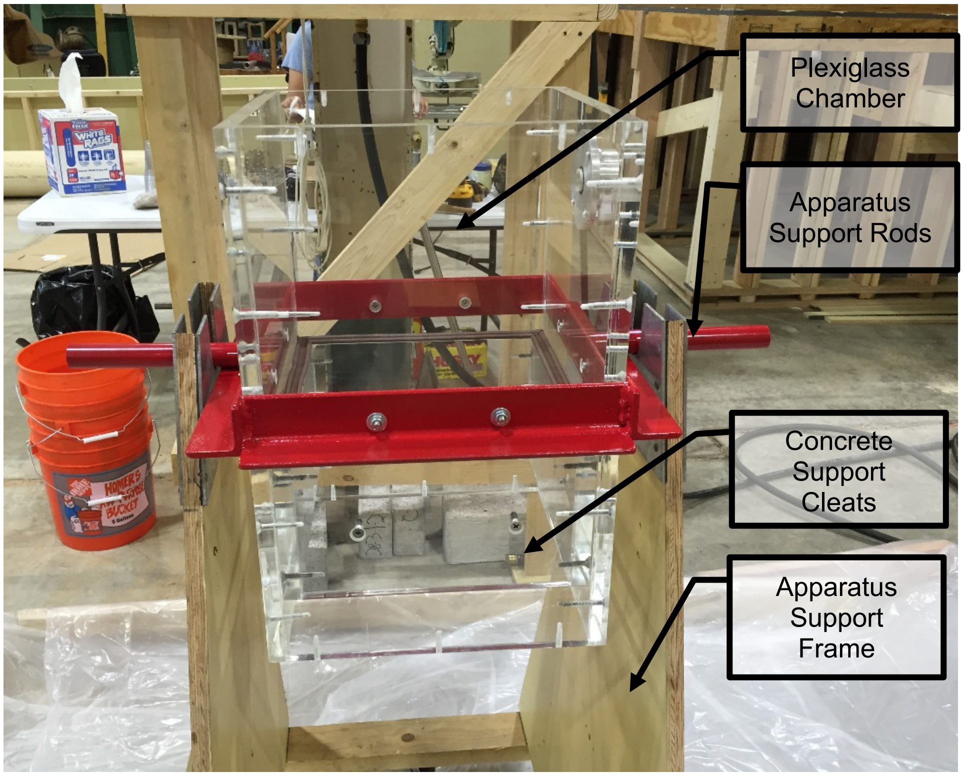

Figure 2. Test Chamber- Empty

The plexiglass was ¾ in. thick and the test chamber had the following inside dimensions: 12 ½ in. × 12 ⅝ in. × 1 ft. 9 in. tall. The inside dimensions were selected based on experience from the 2015 research. This year, the team built a new custom chamber that allowed only a ¼ in. gap on each end perpendicular to the crack and ¼ in. gap each end parallel with the crack. The crack width was held to ⅛ in. on all specimens by the use of a ⅛ in. rubber spacer. The injection rod was located so that the tip of the injection nozzle was directly over the top of the crack.

The plexiglass chamber was supported by four welded L2 × 2 × ¼ steel angles and attached to the plexiglass using bolts. Two steel rods were welded to the angles to serve as lifting handles and support axles for rotation. The support axel allows the chamber to be turned upside down as required. However, care was taken when doing this because the concrete specimen could fall out.

The concrete support in the chamber was constructed out of plexiglass that was glued and bolted to the inside of the plexiglass chamber. A rubber seal was attached to the top of the concrete support cleats to prevent water from leaking around the outside of the specimen.

Figure 3 shows the test setup prior to attaching the inlet hose to the top of the test chamber. The concrete specimen has not been put in place yet to clearly show all the components of the test system.

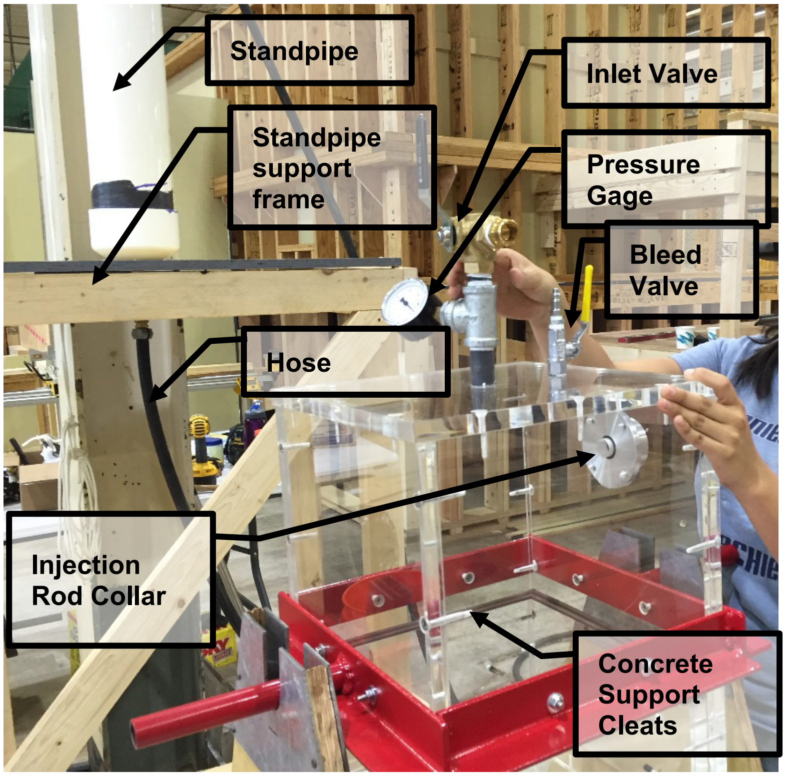

Figure 3. Test Chamber- Prior to hose hookup

Setup

Figure 4 shows the process for placing the concrete specimen inside the test chamber. The top and bottom lids of the test chamber are removed. The test chamber is placed over the top of a concrete specimen support frame. The concrete specimen with the pre-made crack is placed on the concrete support frame. The test chamber is lifted up around the concrete specimen until the specimen engages the concrete support located towards the bottom of the test chamber. The specimen is now loaded into the test chamber. The chamber is lifted onto the chamber support frame using the support rods as shown in Figure 5. Note that Figure 5 shows the concrete specimen in the test chamber prior to attaching the lid of the test chamber.

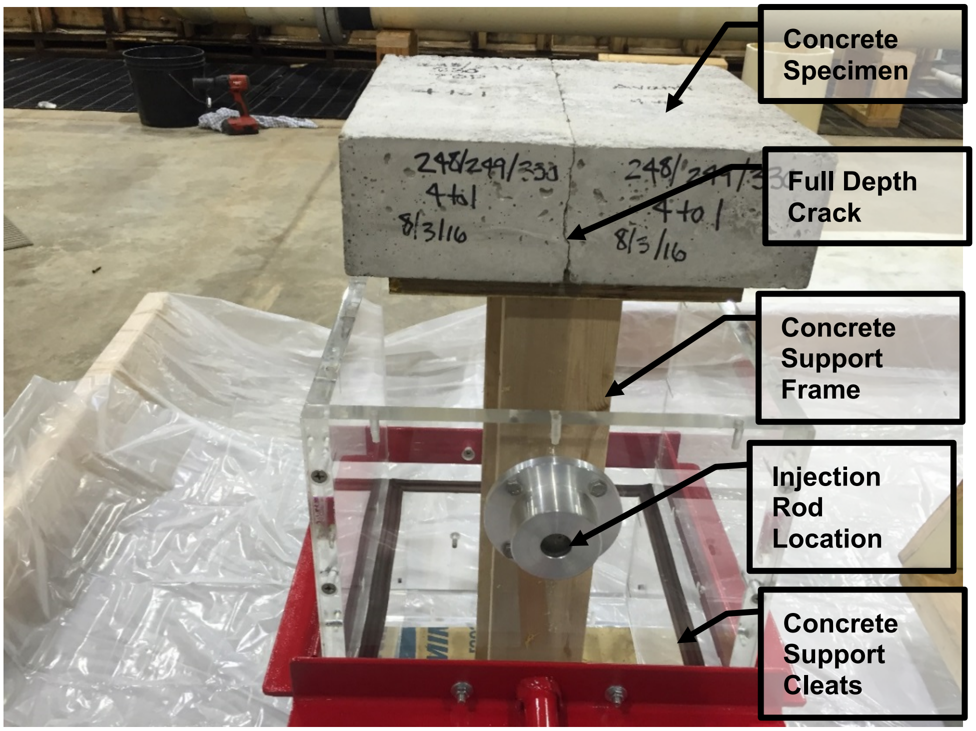

Figure 4. Specimen Installation

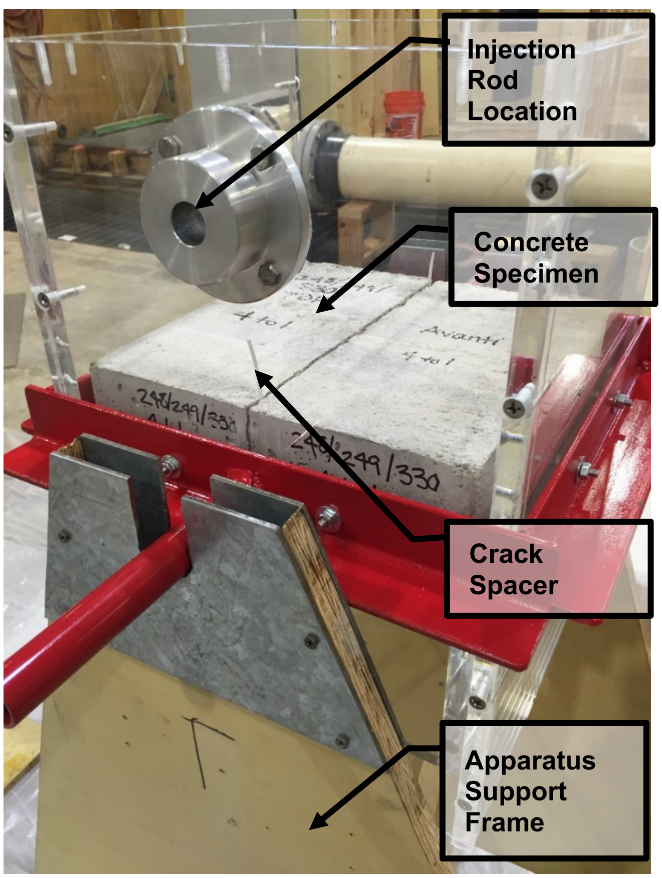

Figure 5. Concrete Specimen in Test Chamber

The pressure system was the same system that was used in the 2015 research. It is comprised of several components, starting with a 6 in. diameter × 14 ft. tall standpipe (E-1). A shutoff valve (V-1) is located on the standpipe so that the filling operations of the test chamber can be stopped at any time. The top of the chamber is equipped with a 3-way diverter valve (V-4). The purpose of the 3-way valve is to allow the top of the chamber to be drained from the top if the concrete crack were to be sealed with no leaks. A hose is hooked up to the 3-way valve that discharges to the water collection tank (P-4). The bleeder valve (V-2) at the top of the chamber allows air to be released from the system. The pressure gage (I-1) at the top of the system allows the team to determine when the system has reached the desired pressure. The test tank (E-2) is equipped with a shut-off valve (V-3) at the bottom of the tank so that flow can be shut off during the tank filling process. The valve is opened and adjusted during testing so that water going into the tank equals water going out. A complete procedure can be found in Appendix A.

E-1	Standpipe
V-1	Shut-off Valve at Standpipe
V-4	3-way Diverter Valve
I-1	Pressure Gage
V-2	Bleeder Valve
E-2	Test Tank
V-3	Shut-off Valve at bottom of Tank
P-4	Tank Bypass Drain Line
E-3	Water Collection Tank

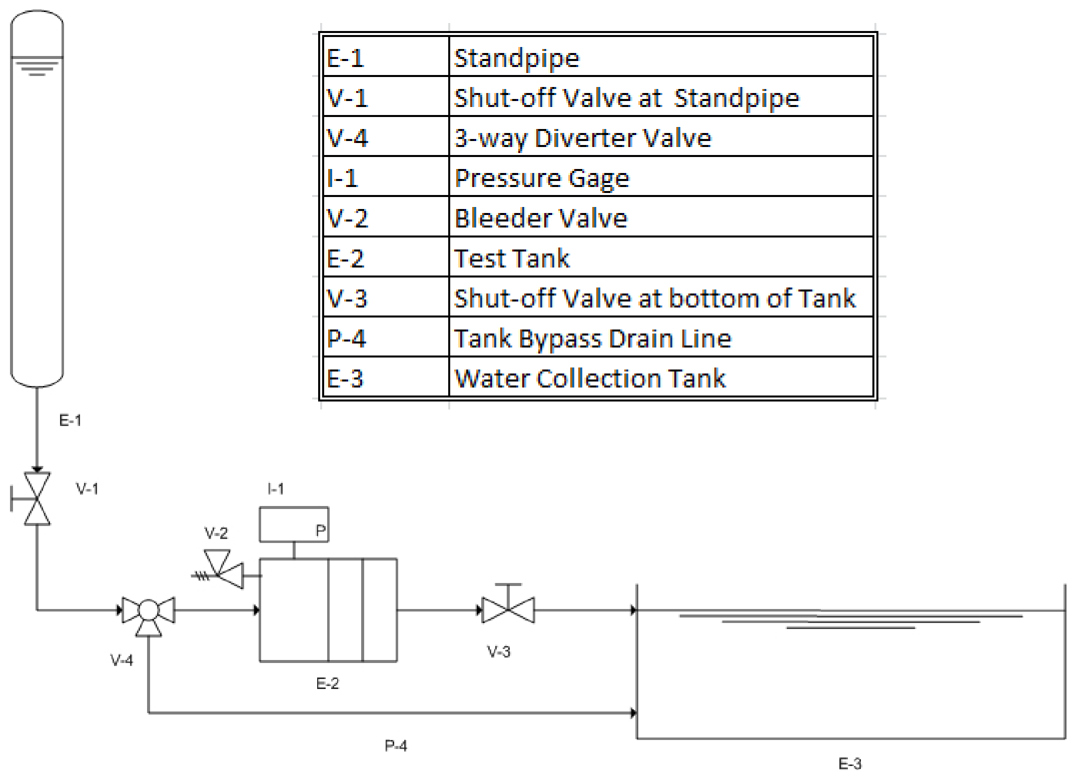

Figure 6. Test Setup Diagram from [1]

Procedure

Testing was initialized by opening the inlet valve and allowing water to fill the test chamber. The standpipe was simultaneously supplied with water so that the required pressure head was maintained. Once the tank was completely full and air had been released from the system using the bleeder valve, the injection process was ready to begin.

To simulate flow through the crack, as in a leaking canal, the valve at the bottom of the tank was opened. The standpipe water level was adjusted so that 1 psi was maintained during the duration of the testing. Once this steady state had been reached (maintaining 1 psi pressure with the shut-off valve at the bottom of the tank open and the standpipe continuously filling), grout was injected into the crack using the injection rod. Grout was slowly pumped into the crack by opening and closing the injection valve to give the grout some time to react with the water. The cup test set times were used to estimate when the grout had reacted with the water to start forming the seal before adding more. The injection rod delivering the grout was translated back and forth along the crack opening multiple times throughout the duration of the testing.

As the concrete crack was sealed, less water would flow through the crack, increasing the stand pipe pressure. The testing was considered complete when one of the following conditions took place:

- Pressure was maintained above 1 psi with the shut-off valve at the bottom of the tank fully open. Water drained out of the bottom but remained in the top, above the concrete specimen.
- The pressure was maintained above 1 psi with the shut-off valve at the bottom of the tank fully open. However, water drained out of both the bottom of the tank and above the concrete specimen. This would indicate that cured grout floated to the top of the chamber and sealed the water inlet.

Performance Evaluation

The same parameters used during the 2015 testing were used here. Cup test rating and post-testing evaluations were additions to this year's suite of evaluations. The performance of the polymeric grouts applied underwater were judged based on four parameters: cup test rating, sealing ability, water visibility, and workability.

1) **Cup Test Rating** – The cup test served two purposes: 1) to understand and adjust the set time and 2) to observe the cured product after a standard time. The cup test was evaluated after 24 hours for Avanti products and after 72 hours for Strata-Tech products. Both products were evaluated again after 1 week. The ideal product would be flexible with little to no shrinkage. A product was considered to have good flexibility if the product bounced back after being compressed. The product was also evaluated to see if the product had any shrinkage by pulling away from the container.
2) **Sealing Ability** – Sealing ability was determined to be suitable if the hybrid grout sealed the crack by maintaining 1 psi pressure for 30 min. If the pressure was not maintained, the grouts were evaluated based on penetration, gaps in the seal, adhesion, and shrinkage of the product after one month. If the grout filled or fully filled the crack with only minor gaps, the product would be recommended for further study.

3) **Visibility** –The sample was considered to have acceptable visibility if the injection nozzle could be clearly observed from the opposite side of the tank (about 12 inches) throughout testing. If the water was clear or mostly clear, the product received a “good” rating.
4) **Workability** – The workability of the grout was judged on ease by which the grout flowed thru the crack and adhered to the walls of the crack. If the cured resin floated, the product received a “Poor” rating.
5) **Post-Evaluation** –
    a. **Penetration -** Excess grout was removed from the top and bottom of the specimen to determine how much penetration was achieved by the grout. If the grout was continuous along the bottom of the specimen, the combination achieved a “good” rating, otherwise, the combination received a “poor” rating.
    b. **Gaps –** If there were numerous or large gaps in the seal, the product received a “poor” rating, otherwise, it received a “good” rating
    c. **Adhesion –** Adhesion was evaluated by pulling on the grout. If it was difficult to pull and remained attached to either the top of the concrete specimen or the crack walls, the combination received a “good” rating, otherwise, it received a “poor” rating
    d. **Shrinkage –** Shrinkage was judged on visual inspection of the crack. If the product appeared to have shrunk back significantly from the crack walls, the product received a “poor” rating, otherwise, it received a “good” rating.
    e. **Final Product –** As mentioned in cup testing, the final product is important to the successful performance of the grout as an underwater repair material. If the products were flexible, compressible foams, the product received a “good” rating. If it was a rigid product, it received a “poor” rating.

RESULTS AND DISCUSSION

Cup Test Rating

Besides sealing the crack, the physical properties of the final product is a very important characteristic. If the final product is brittle or too rigid, the seal will not perform well long term. Rigid or brittle seals may crack at the seal or crack the surrounding concrete if there is crack movement.

Shrinkage is also an important characteristic of the final product. Since canals are often dewatered during off season, the crack repair materials are subjected to drying conditions that could cause shrinkage. If there is substantial shrinkage in the repair that does not expand when water is added, the crack seal may leak. For this reason, it was important that the final product exhibit minimal shrinkage.

Cup tests were performed on Avanti products first. The first proportion that was tested was the three part Avanti AV-248 to two part Avanti AV-330. This proportion was selected because it was the same proportion used in a documented field application on a traditional grouting job [3]. The 4:1 ratio and the 1:1 ratio were selected to vary the proportions of the two components. Based on the performance of the cup tests, the 3:2 proportion and the 4:1 proportion were selected to be used in the underwater application testing.

The proportions selected for the testing of Strata-tech ST-530 and ST-504 were based on the proportions used in the Avanti testing. The team wanted to keep the proportions constant for comparison of the two manufacturers. However, based on the finding in this study, it may have been appropriate to use different proportions since the final products were so vastly different.

Table 6. Avanti Cup Test Visual Description

Product Ratios	72 Hour	1 Week
AV-248/330 1:1 ratio	● Shrunk back slightly but remained mostly expanded. ● Product felt more rigid than the other 2 proportions.	● Shrunk back slightly more than 72 hour inspection. ● Final product remained fairly rigid.
AV-248/330 3:2 ratio	● Shrunk back slightly but remained mostly expanded ● Product was very flexible and sprung back into its original form when compressed. ● Product was more rigid than 4:1 ratio product.	● No change in shrinkage. ● No change in flexibility of final product.
AV-248/330 4:1 ratio	● Slightly pulled away from cup edges. ● No major shrinkage observed. ● ~½ in. water remained at bottom. ● Product was a soft foam that sprung back into its original form when compressed.	● No change in shrinkage. ● No change in flexibility of final product.
AV-248 only	● Shrunk significantly. ● Product had a sticky rubber feel.	● No change in shrinkage. ● No change in flexibility of final product.
AV-330 only	● Remained touching all edges of cup. ●Shrunk slightly towards the middle. ● Product was a soft, flexible, compressible foam.	● No change in shrinkage. ● No change in flexibility of final product.

AV-248/330 1:1 ratio was eliminated from the underwater testing due to its poor performance in the cup tests (excessive shrinkage and rigid final product). The

3:2 and 4:1 ratios were selected for testing based on the minimal shrinkage that was observed and the flexible spongy foam that was generated.

Table 7. Strata-Tech Cup Test Visual Description

Product Ratios	24 Hour	1 Week
ST-530/504 3:2 ratio	● No shrinkage. ● Product was very flexible and sprung back into its original form when compressed. ● Some excess water remained in the cup.	● No change in shrinkage. ● No change in flexibility of final product.
ST-530/504 4:1 ratio	● No shrinkage. ● Product was very flexible and sprung back into its original form when compressed. ● Some excess water remained in the cup. ● Product was more rigid than 3:2 ratio product.	● No change in shrinkage. ● No change in flexibility of final product.
ST-530 only	● No shrinkage. ● Significant initial expansion. ● Product was a very rigid foam. ● Product felt like Styrofoam where compressing the product broke the cell structure.	● No change in shrinkage. ● No change in rigidity of final product.
ST-504 only	● Slight shrinkage all around from the edges of the cup, starting at the top 1" of the cup. ● Product was a soft, flexible, compressible foam.	● Approximately 1/4 to 1/2 in. shrinkage from the sides starting from the top of the product. ● No change in flexibility of final product.

Both Strata-Tech combinations of 3:2 and 4:1 ratios had similar performance. Both combinations would make good crack seal materials because of their minimal shrinkage and highly flexible characteristics. Profile and top view pictures of all the cup tests can be found in Appendix C.

Sealing Ability

The seal performance of the grout is the most important parameter in this study. Due to leaks from the test chamber itself, the pressure was reduced from 5 psi used in the 2015 study and expected to be used in this study to 1 psi. However, none of the products were able to maintain a 1 psi pressure for 30 min. See Appendix C for pictures of the injection process and final evaluation of the specimens.

Comparison to the chamber from the year before indicated that the test chamber this year had been smoothly finished along the top edges where the lid meets the sides. The top of the chamber last year was not finished leaving a slightly rougher finish that may have allowed the sealing grease to perform better. If future studies are conducted, the top and bottom of the chamber should be left unfinished or roughened if the same test chamber is used again. In addition, the team should consider making a small groove in the top of the chamber that could be infilled with a rubber gasket.

Although none of the products were able to maintain the 1 psi pressure, two of them (Strata-tech 530/504 4:1 and Avanti 248/249 3:2) performed well in the post evaluation which showed they either fully filled or filled the crack with minimal gaps, respectively. For this reason, these two hybrid products are recommended for further study.

Table 8. Crack Seal

Product Name	Seal	Sustained 1 psi Pressure	Recommend
Strata-Tech 530/504 4:1	Full Fill	NO	Further study
Avanti 248/330 3:2	Fill	NO	Further study
Avanti 248/330 4:1	Partial Fill	NO	NO
Strata-Tech 530/504 3:2	Partial Fill	NO	NO

Post-Evaluation

The post-evaluation was conducted approximately one month after the completion of the testing. Each specimen was evaluated for their performance in penetrating the crack, the presence of gaps in the grout seal, adhesion of the grout to the crack walls, shrinkage of the final grout product in the crack, and the consistency of the final grout product. Refer to Appendix C for photos of the top and bottom surface of each of the specimens during the post-evaluation.

Table 9 ranks the combinations from best to poorest based on how much penetration was achieved by the grout. Each specimen was closely examined at the top and the bottom.

Table 9. Penetration

Product Name	Penetration	Rank
Strata-Tech 530/504 4:1	GOOD	Best
Avanti 248/330 3:2	GOOD	↓
Avanti 248/330 4:1	GOOD	
Strata-Tech 530/504 3:2	POOR	Poorest

Table 10 shows the results of examining each specimen to see if there were gaps that could be viewed from the top of the specimen. For example, for the Avanti

248/330 4:1 ratio, the grout penetrated all the way through to the back side of the specimen, but it had a few large full depth gaps in the seal.

Table 10. Gaps in Seal

Product Name	Gaps	Score	Rank
Strata-Tech 530/504 4:1	No Visible Gaps	GOOD	Best
Avanti 248/330 3:2	Very Small Gap	GOOD	
Avanti 248/330 4:1	Some Gaps	POOR	
Strata-Tech 530/504 3:2	Large Gaps	POOR	Poorest

Table 11 shows the adhesion performance of the hybrid grouts. The Strata-Tech 530/504 3:2 combination received a very poor rating because the product crumbled when removed from the top and bottom of the specimen. It appeared that the product had little adhesion, even to itself.

Table 11. Adhesion Performance

Product Name	Adhesion	Rank
Avanti 248/330 3:2	GOOD	Best
Strata-Tech 530/504 4:1	GOOD	
Avanti 248/330 4:1	POOR	
Strata-Tech 530/504 3:2	VERY POOR	Poorest

Each specimen was also examined to see if any shrinkage of the grout had occurred when the specimen dried out. This parameter is important to take into consideration because if it remains shrunk back, it may become a leaking seal in the future. If the product will be injected into a crack that will remain underwater at all times, this parameter may not be as important. Table 12 shows the results of the shrinkage evaluation.

Table 12. Shrinkage

Product Name	Shrinkage	Score	Rank
Strata-Tech 530/504 4:1	None	GOOD	Best
Strata-Tech 530/504 3:2	Minor	GOOD	
Avanti 248/330 3:2	Minor	GOOD	
Avanti 248/330 4:1	Significant	POOR	Poorest

Besides sealing the crack, flexibility is the most important parameter when selecting a grout to use. If the crack is anticipating movement at the crack, a product should be selected that would allow movement and still prevent water from leaking. Table 13 presents ranking based on the grout flexibility.

Table 13. Flexibility

Product Name	Description	Score	Rank
Avanti 248/330 3:2	Flexible Foam	GOOD	Best
Avanti 248/330 4:1	Gelatinous Foam	GOOD	
Strata-Tech 530/504 4:1	Rigid Styrofoam	POOR	
Strata-Tech 530/504 3:2	Bread Crumbs	POOR	Worst

Visibility

The visibility performance of the grout was based on how cloudy the water became while performing the injection. The reduction in visibility is related to the suspension of grout particles as they are introduced to the water. In a field application, if the water completely clouded during the injection process, the diver may not be able to see the crack he is trying to seal. Table 14 ranks the grouts from clearest to cloudiest. The 2015 study found that the hydrophobic grouts tested kept the water clear and the hydrophilic grouts made the water cloudy [1]. This study was successful in that some of the grout combinations resulted in clear water.

Table 14. Visibility

Product Name	Water Appearance During Injection	Score	Rank
Strata-Tech 530/504 4:1	Clear	GOOD	Clearest
Strata-Tech 530/504 3:2	Mostly Clear	GOOD	
Avanti 248/330 4:1	Mostly Clear	GOOD	
Avanti 248/330 3:2	Cloudy	POOR	Cloudiest

Workability

The workability performance is important for determining which products are suitable for underwater applications. Table 15 summarizes the behavior of the grout during the injection process. All the products had a significant amount of reacted grout that did not adhere to the concrete or previously injected grout. The

2015 laboratory study found that hydrophobic grouts floated however, hydrophilic grouts flowed slowly through the crack [1].

Table 15. Workability

Product Name	Behavior	Score
Strata-Tech 530/504 4:1	Floated	POOR
Strata-Tech 530/504 3:2	Floated	POOR
Avanti 248/330 4:1	Floated	POOR
Avanti 248/330 3:2	Floated	POOR

Recommendations for Future Studies

Further study is recommended to see if the recommended products can seal the cracks.

- The issues with the grout pumps appeared to impact the results of the testing. Any future studies should include having backup pumps on hand and having plenty of premixed grout to eliminate gaps in time between passes of the grouting tube over the cracks. If using a similar test chamber, a minimum of four gallons total should be mixed and ready for testing.
- Future lab studies should include performing tests on the specimens to quantify the adhesion, penetration, amount of grout injected, and time to seal of the grouts.
- The field study conducted in February 2016 on the hydrophilic grouts found that adding premixed warm water to the resin immediately prior to injection with the use of an F-assembly decreased the set time and appeared to improve performance. Future lab studies should include testing different temperature premix water to see if this will improve sealing.
- Durability of the combined grouts should be tested.
- In future lab studies, the edges of the test chamber should be left rough to allow better sealing.

REFERENCES

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[2] S. Harrell, P.E. and M. Klein, P.E., Ph.D., "Cap Underwater Group Demonstration," Casa Grande, AZ, 2016.
[3] B. Poos and G. Day, "Chemical grouting of leaking cracks and joints in the upstream face of Gerber Dam," Klamath Falls, Oregon, 2014.
[4] Avanti, "AV-249 Flexseal Hydrophobic Polyurethane Foam [data sheet]," 2016. [Online]. Available: https://www.avantigrout.com/products/grout-products/item/av-248-flexseal.
[5] Avanti, "AV-330 Safeguard Hydrophilic Polyurethane Foam [data sheet]," 2014. [Online]. Available: https://www.avantigrout.com/products/grout-products/item/av-330-safeguard.
[6] Strata-Tech, "ST-530 Injection Resin [data sheet]," 1990.
[7] Strata-Tech, "ST-504 Vari-gel Injection Resin [data sheet]," 1990. [Online]. Available: http://www.strata-tech.com/tds/504.pdf. [Accessed 2016].

Appendix A:

Test Setup Procedures

1) Apply M-D Building Products EPDM- All Climate Rubber Weatherseal for gaps 1/8 in. to 7/32 in. to the top of the specimen support cleats.
2) Set the pre-cracked concrete specimen on the specimen support frame.

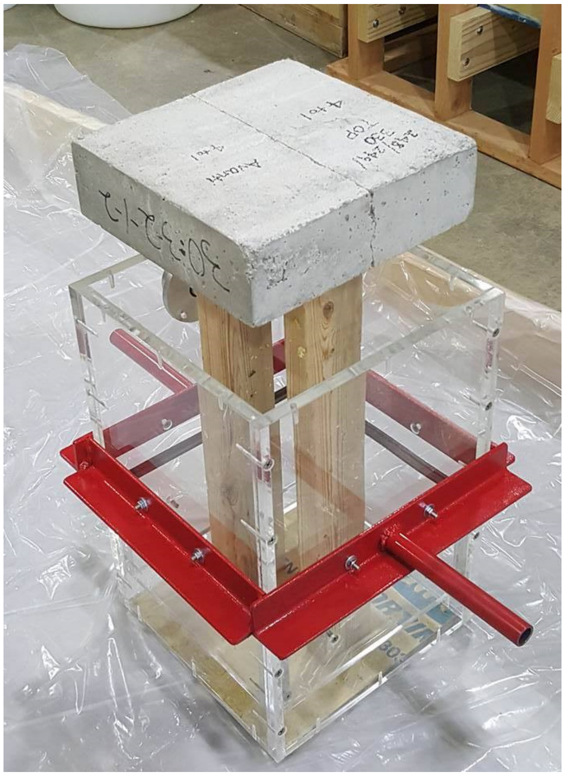

Figure 1. Specimen stacked on specimen support frame

3) Lift the test chamber up and around the support frame/concrete specimen until the chamber engages the specimen on the concrete support cleats

4) Lift the test chamber up onto the chamber support frame.

Figure 2. Concrete specimen and chamber in chamber support frame

5) Clean the bottom of the chamber with a damp rag to remove any debris collected from the ground.
6) Apply a thin coat of Dow Corning General Purpose Silicon Vacuum and Pressure System Grease or petroleum jelly to the perimeter of the tank prior to bolting the bottom lid to the bottom of the chamber. Fully tighten all bolts.
7) Cut off approximately a 5 in. long × 3/8 in. strip of M-D Building Products white vinyl garage weather stripping. This serves as a spacer to keep the crack open while sealing the perimeter of the specimen and seals the vertical face of the crack during testing.
8) Use approximately a 4 ft. long strip of oakum to seal around the entire perimeter of the specimen. Use a flathead screw driver and a rubber mallet to tap the oakum into the gaps between the plexiglass tank and the concrete specimen. Be sure to fully seal the gap between the specimen and the tank so that water and resin do not escape along the sides of the specimen.

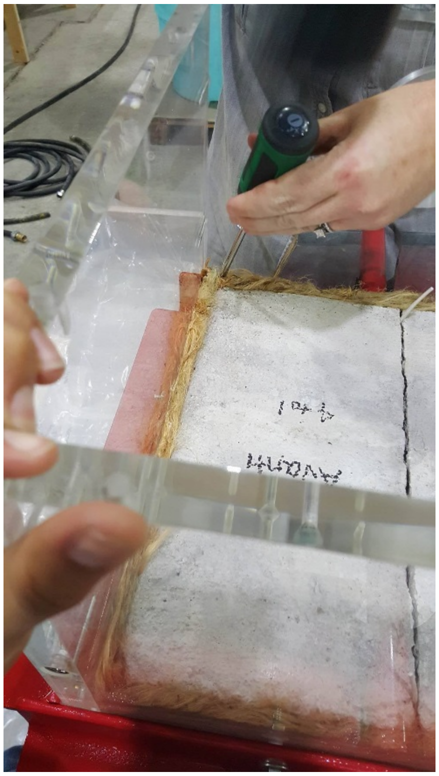

Figure 3. Oakum installation

9) Install the injection rod thru the injection rod collar on the side of the chamber.
10) Install the four in. long polyethylene adhesive injection nozzle with 1/8 in. opening to the injection rod.

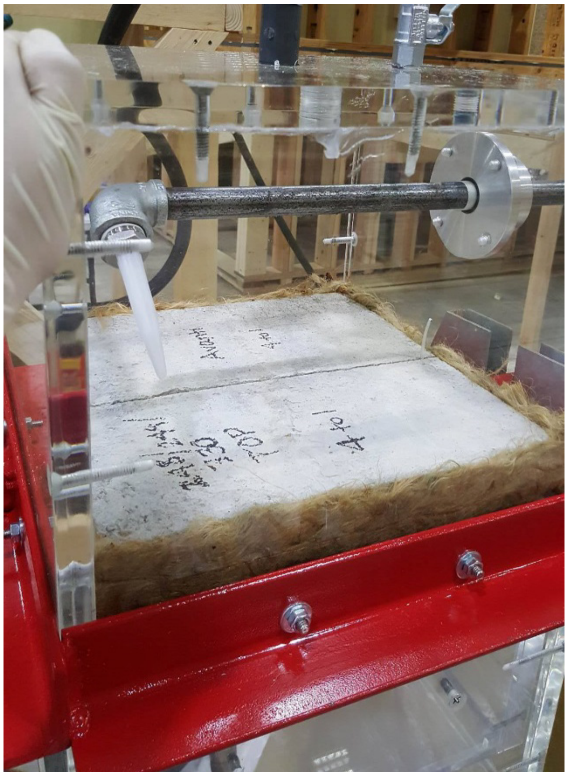

Figure 4. Injection rod and grout nozzle installed

11) Lubricate the injection rod with a thin coat of Dow Corning General Purpose Silicon Vacuum and Pressure System Grease
12) Clean the top perimeter of the apparatus tank to remove any debris prior to attaching the top plexiglass lid.
13) Apply a thin coat of Dow Corning General Purpose Silicon Vacuum and Pressure System Grease to the top of the chamber and attach the top lid. Fully tighten all bolts on the lid.
14) Attach a drain hose to the shut-off valve at bottom of the chamber. Position the hose to discharge into a water collection tank to collect any water with un-adhered reacted grout.

Figure 5. Hose attached to shut-off valve at bottom of tank.

15) Attach a short hose from the bottom of the standpipe to the 3-way diverter valve at the top of the tank. The three positions are shut-off, inlet to the test chamber and bypass to the water collection tank.
16) Connect a second drain hose at the 3-way diverter valve at the top of the tank to direct water to the water collection tank.
17) Fill the standpipe with water.
18) Close the shut-off valve at the bottom of the tank and position the 3-way diverter valve to direct water into the test chamber. Open the shut-off valve at standpipe to fill the chamber.
19) Open the bleeder valve at the top of the chamber to allow air to escape.
20) Once the tank is full and all the air is out, close the bleeder valve and add water to the standpipe until the pressure gage reaches 1 psi indicating the standpipe has reached its desired hydraulic head.
21) Open the shut-off valve at the bottom of tank and adjust the hose connection to the standpipe so that the flow coming out of the tank matches the flow coming in at the top of the standpipe at 1 psi.
22) Starting at the far end of the specimen from the injection rod collar, slowly inject polyurethane resin into the crack. Slide the injection nozzle slowly over the crack towards the collar while maintaining a continuous flow of grout.
23) Slowly inject resin along the crack by sliding the nozzle over the crack with as many passes required to seal the crack, or until it is determined that the grout does not have the desired properties to seal the crack.

24) Hose pressure must be adjusted frequently to maintain 1 psi due to partial sealing of the crack

25) The crack is considered sealed when 1 psi or more pressure is held for 30 minutes with the shut-off valve at bottom of tank is open.

Appendix B:

Technical Data Sheets

Stop leaks. Stabilize soil.
Control groundwater. Permanently.

TECHNICAL DATA SHEET

AV-248 FLEXSEAL

HYDROPHOBIC POLYURETHANE FOAM

DESCRIPTION

Injected as a single component, catalyzed **AV-248** Flexseal is a moisture activated MDI-based polyurethane resin. The chemical reaction is catalyzed by using **AV-249** Flexseal AC and uses moisture as an initiator. Like other hydrophobics, **AV-248** Flexseal withstands wet/dry cycles and reacts with moisture; but unlike other hydrophobics, it forms a resilient, impermeable *flexible* foam. This high quality resin is designed for sealing active and potential water leaks in various cracks, and annular spaces where flexibility is needed but is susceptible to wet/dry cycles. Avanti's **AV-248** is one of the most versatile products on the market.

APPLICATION

- For use above or below grade in humid or arid atmospheres
- Fills various cracks and pipe penetrations
- Stops leaks in concrete structures
- Designed for tunnels, mines, dams, reservoirs, block walls and structures that may shift

FEATURES AND BENEFITS

- Expands 400% – 600%
- Solvent-free system
- Controllable reaction time by adjusting **AV-249** Flexseal AC volume
- Withstands wet/dry cycles
- Unique hydrophobic that cures into a flexible, closed-cell foam

GROUTING TECHNIQUES

- Expanded Gasket Placement Technique (EGP)
- Variable Pressure Application Technique (V-PAT) – Crack Injection

HOW IT WORKS

AV-248 is a moisture-activated reaction. When injected into a concrete structure, the low viscosity resin will react with moisture and begin to expand. The final product is a very dense, closed cell foam impermeable to water yet flexible in nature.

ADDITIVES

- **AV-249** Flexseal AC – catalyst, 16 oz. (0.5 L) container

PACKAGING

Product packaged by weight based on specific gravity.

- Drum = Net Wt. 435 lbs. / Volume 48 – 49.36 gal.
- Pail = Net Wt. 44 lbs. / Volume 4.85 – 5 gal.
- Gallon = Net Wt. 8 lbs. / Volume ~1 gal.

SHIPPING

- Motor Class 55
- Non-Hazardous
- Air freight available

CLEANING PRODUCTS

- **AV-208** Acetone, Technical Grade (CAS# 67-64-1) – removes moisture from equipment
- **AV-284** Pump Wash (Proprietary Blend) – removes uncured resin from pump and hose
- **AV-222** Cleaner (Proprietary Blend) – removes cured resin from equipment

STORAGE

Store in temperatures within or near 60°F – 100°F (16°C – 38°C) in a dry atmosphere.

PROPERTIES*

AV-248 – UNCURED

Appearance:	Milky white to clear liquid
Viscosity:	550 – 830 cP @ 72°F (22°C)
Flash Point:	>200°F (>93°C)
Specific Gravity:	1.056 @ 72°F (22°C) ±3%
Weight:	8.8 lbs./gal ± 3% (1.054 kg/L ± 3%)

AV-248 – CURED

Appearance:	Milky white flexible foam
Tensile Strength:	TBD
Toxicity:	Non-toxic

AV-249 Flexseal AC

Appearance:	Light yellow to white, clear liquid
Viscosity:	5 cP @ 72°F (22°C)
Flash Point:	>200°F (>93°C)
Specific Gravity:	1.02 @ 72°F (22°C) ±3%
Weight:	8.5 lbs./gal ± 3% (1.018 kg/L ± 3%)

*Laboratory Results

MIX PROCEDURE

Typically, one container of **AV-249** Flexseal AC is used per 5-gallon container of **AV-248** Flexseal. Depending on the desired reaction time, **AV-249** may be doubled. Mix thoroughly, but slowly, to avoid creating bubbles in the solution. Perform the standard cup test with site water to determine the desired reaction time.

PERFORMANCE

Flush equipment with **AV-208** before and after use to remove moisture and clean equipment. Performance will be influenced by site conditions. If site temperatures are low, heat the product to recommended operating temperatures of 60°F – 90°F (16°C – 32°C) and/or increase catalyst amount by 1% – 2%. Do not exceed more than 32 oz. (1 L) of **AV-249** Flexseal AC per 5-gallon container of the **AV-248** Flexseal resin. Do not use open flame as a heat source. Excess amounts of **AV-249** may adversely affect performance. Because catalyzed resin will react to moisture from the air, use product soon after mixing for best results.

SAFETY

Always use OSHA-approved personal protective equipment (PPE). Refer to the SDS for complete safety precautions. The SDS is available by request or via download at www.AvantiGrout.com.

NOTICE

Gel (Cure) Times for AV-248 Flexseal (Min:Sec)

Temperature (°F)	Half Catalyst	Full Catalyst	Double Catalyst
40°F	14:30	9:15	6:43
50°F	12:10	7:15	5:34
60°F	10:54	6:15	3:12
70°F	9:04	4:40	2:30

TECHNICAL DATA SHEET

AV-330 SAFEGUARD

HYDROPHILIC POLYURETHANE FOAM

DESCRIPTION

AV-330 Safeguard is a 100% MDI-based, single component, mid-range viscosity, moisture activated polyurethane injection resin. This high quality water-activated resin is designed for sealing active leaks in below grade structures. It is a mid-range viscosity grout that permeates well in various cracks and joints, but offers added safety in confined spaces or where there is poor ventilation. It cures to become a resilient and flexible, yet tough, closed-cell foam. Certified for use in potable water.

APPLICATION

- Areas with poor ventilation or confined spaces (utility vaults, sub-grade pump houses, lift stations, mines, tunnels, and basements)
- Medium cracks or joints in concrete structures
- Great for manholes and pipe penetrations

FEATURES AND BENEFITS

- ANSI/NSF 61 Potable Water Systems UL Certified
- 100% MDI-based
- Mid-range viscosity penetrates well
- Expands 400% – 600%
- Solvent-free system and non-corrosive
- Forms a resilient, flexible foam with superb adhesive properties

GROUTING TECHNIQUES

- Expanded Gasket Placement Technique (EGP)
- Variable Pressure Application Technique (V-PAT) – Crack Injection

HOW IT WORKS

AV-330 Safeguard can be applied via two techniques: EGP or V-PAT. The resin reacts to moisture to form a resilient, flexible seal accomplished by three mechanisms: the resin seeks out water in the space and *adheres* to the surface, then begins to expand forming a tight *compressive* seal while the network of compressed grout material within all the cracks forms a *mechanical* lock.

RATIOS

Preferred ratio is 1:1 (water to resin), however no pre-mixing is required. Pumped as a single component.

PACKAGING

Product packaged by weight based on specific gravity.

- Drum = Net Wt. 465 lbs. / Volume 48.5 – 49.8 gal.
- Pail = Net Wt. 44 lbs. / Volume 4.58 – 4.7 gal.
- Gallon = Net Wt. 8 lbs. / Volume ~1 gal.

SHIPPING

- Motor Class 55
- Non-Hazardous
- Air freight available

PROPERTIES*

UNCURED

Appearance:	Pale yellow liquid
Viscosity:	350 – 750 cP @ 72°F (22°C)
Flash Point:	>200°F (>93°C)
Specific Gravity:	1.12 @ 72°F (22°C) ± 3%
Weight:	9.32 lb/gal ± 3% (1.117 kg/L ± 3%)

CURED

Appearance:	Milky colored flexible foam
Tensile Strength:	TBD
Elongation:	TBD

*Laboratory Results

PERFORMANCE

Flush equipment with AV-208 before and after use to remove moisture and clean equipment. For best results, use between 60°F – 90°F (16°C – 32°C). Performance will be influenced by site conditions. If site temperatures are low, use a heat source to warm to ~72°F (22°C) and apply. Do not use open flame as a heat source.

CLEANING PRODUCTS

- AV-208 Acetone, Technical Grade (CAS# 67-64-1) – removes moisture from equipment (see Performance section).
- AV-284 Pump Wash (Proprietary Blend) – removes uncured resin from pump and hose, leave in pump for storage.
- AV-222 Cleaner (Proprietary Blend) – removes cured resin from equipment.

STORAGE

Store in temperatures within or near 60°F – 90°F (16°C – 32°C) in a dry atmosphere.

SAFETY

Always use OSHA-approved personal protective equipment (PPE). Refer to the MSDS for complete safety precautions. The MSDS is available by request or via download at www.AvantiGrout.com.

NOTICE

The data, information and statements contained herein are believed to be reliable, but are not construed as a warranty or representation for which Avanti International assumes any legal responsibility. Since field conditions vary widely, users must undertake sufficient verification and testing to determine the suitability of any product or process mentioned in this or any other written material from Avanti for their own particular use. NO WARRANTY OF SUITABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE. In no case shall Avanti International be liable for consequential, special, or indirect damages resulting from the use or handling of this product.

CLASSIFIED UL WATER QUALITY

DRINKING WATER SYSTEM COMPONENT
ANSI/NSF 61
88NN

ST-504

VARI-GEL INJECTION RESIN

INTRODUCTION

Stratathane ST-504 Vari-Gel Injection Resin is a solvent-fee, MDI-based water control and soil stabilization system. ST-504 is hydrophilic and reacts with water to form either a flexible gel or an elastomeric foam depending on the amount of reaction water added to the mix.

Stratathane ST-504 contains no measurable amount of TDI as performed by the Modified Analysis for Diisocyanates. ST-504 is non-flammable, non-carcinogenic, and non-corrosive as defined by 40 DFR and as described in the NIOSH Pocket Guide for Hazardous Materials.

ST-504 has NSF 61 approval for potable water contact and carries the Underwriters Laboratories UL seal.

Stratathane ST-504 is mixed with water at the work site to form a single injection material. The inert end product forms a water barrier which is essentially unaffected by acids, gasses, and organisms usual found in soil. A minimum amount of water (around 5% by volume) is needed for a reaction to occur, but large amounts can be accommodated through reaction or displacement.

Stratathane ST-504 is useful for a wide range of water control and soil stabilization applications, including grout curtains, stabilizing water bearing soils, and sealing cracks or joints in concrete walls, buildings, dams and utility vaults.

Stratathane ST-504 may be placed by hand pumps or multi-ratio power pumps. Stainless steel fittings are recommended but not strictly required because ST-504 is no more corrosive than water. Cleanup of solidified material in the system, however, is often accomplished with caustic cleaning compounds, making stainless steel advisable.

The low viscosity of ST-504 makes it easy to inject. Once cured, its impermeability makes it an effective water shut-off system. The permeability of soil grouted with ST-504 depends on how well its voids are filled with grout. Values in the 10-7cm/sec range should be obtained using ASTM Constant Head Permeability Test Method D-2434.

A three stage reaction takes place when ST-504 mixes with an equal volume of water and foams. The mixture first thickens and becomes creamy. Then, carbon dioxide gas evolves rapidly and the mixture expands as it cures. The expanded ST-504 volume then sets into a strong impermeable water barrier. Unrestrained St-504 foam may expand up to 10 times its starting volume depending upon the degree of confinement applied to the expanding mass.

When St-504 mixes with a large volume of water (i.e. 10:1 or greater), the three stages of the foam reaction cycle are not visible in the reacting mass, Instead, a marked viscosity increase will be seen just before the mass solidifies.

The reaction sequence with water takes place continuously during injection as product exits the packer. Initial penetration of the St-504 grout mixture is facilitated by its low viscosity. After setting (in the case of the foam sequence), the expansive mixture pressure induces further filling of the grout zone. An St-504 seal will tolerate freeze-thaw, wet-dry cycling, extrusion, and compression to the a substantial degree.

DESCRIPTION

Uncured ST-504 is a dark brown liquid with a viscosity of about 700 cps at 25C (77F). This low viscosity is reduced even further after water is added. ST-504 contains non-volatile materials making up almost 100% of its total weight. Cured St-504 is very firm and flexible. Its solid is a three dimensional cross-linked molecular structure which is insoluble in water.

PHYSICAL PROPERTIES

Color	Dark Brown	
Viscosity	700 cps at 25C	ASTM D1838
Specific Gravity	1.1g/cc	9.25 lbs/gal
Flash Point	>220 F	ASTM D-93
Solids Content	> 85%	ASTM D2832
Tensile Strength	>250 psi	ASTM 3574
Elongation	>400%	ASTM 3574
Shrinkage	<11%	ASTM D-1042
Vapor Pressure	0.0000002 psi	
Vapor Density	8.5 (Air=1.0)	
Solubility	Insoluble; Reacts with water	

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Set time is the period from first contact of ST-504 with water to the point where the mix becomes too thick for gravity flow. The set time (sometimes called foam time) is influenced primarily by the mix temperature and the ratio of ST-504 to water. Set times are longest at low temperatures and ST-504 ratios, and vary a little with the age of the resin and mineral content of the water. The viscosity of mixed ST-504 is lowest for the first 40% to 50% of the set time and increases rapidly as the mix approaches set.

SET TIME

Seconds at 20ºC

Water: Resin	GEL	TACK RISE	FREE
9:1	150	-	-
4:1	95	-	110
2:1	85	95	100
1:1	95	110	160
1:2	100	120	170
1:3	100	120	180

CLEAN UP

ST-504 should not stand in equipment more than 12 hours without precautions because the possibility of moisture contamination is high. Flush equipment with ST-590 purging fluid and ST-522 Cleaner soon after use. The most common solvent for removal of liquid ST-504 is Methylene chloride. Check solvents for water content prior to use.

HANDLING AND STORAGE

Use reasonable care in handling and storing ST-504. The material is moderately sensitive to high storage temperatures. Under optimum storage of 40-60ºF in dry conditions, the material should have a useful shelf life of one year. Storage temperature should not exceed 80º F. Once a container has been opened, the life of the material is reduced. Let the container stand and adjust to ambient temperature before opening to prevent contamination by condensation. Test a resealed container to assure that moisture contamination has not occurred. Before handling this product, read and understand the Material Safety Data Sheet (MSDS). Instruction in sound safety practices is beyond the scope of this publication.

Direct contact of ST-504 liquid may cause skin and eye irritation. If ST-504 comes in contact with skin, wash with soap and water. For eye contact, flush immediately with water and consult a physician. St-504 must not be ingested. Before eating, smoking or drinking, remove protective clothing, was with soap and water, and stand away from the immediate work site. Do not smoke while working with ST-504. If respiratory difficulties occur, seek medical attention. Avoid exposure to vapors created from this product when it is heated. Gloves, goggles, respirator and protective clothing are recommended. Ventilate the work area as a matter of good practice, although hazardous levels of toxic vapors are not generally given off of the bulk product below 90º F. Small amounts of MDI may be present and some users may be sensitive to MDI.

Summary of Handling Precautions:

1. Wear goggles and rubber gloves.
2. Wash any body contact area thoroughly with water.
3. In case of eye contact, wash immediately with water and seek medical attention.
4. Keep material away from heat and flame.
5. Ventilate and use respirator in hot or closed spaces.

STATEMENT

Strata Tech believes that the information herein is an accurate description of the general properties and characteristics of the product(s), but the user is responsible for obtaining current information because the body of knowledge on these subjects is constantly enlarged. Information herein is subject to change with out notice. Field conditions also vary widely, so users must undertake sufficient verification and testing of the product or process herein to determine performance, safety, usefulness, and suitability for their own particular use.

Strata Tech warrants only that the product will meet Strata Tech's then current specification. NO WARRANTY OF SUITABILITY OR FITNESS FOR A PARTICULAR PURPOSE IS MADE. Users should not assume that all safety requirements for their particular application(s) have been indicated herein and that other or additional actions and precautions are not necessary. Users are responsible for always reading and understanding the Material Safety Data Sheet, the product technical literature, and the product label before using any product or process mentioned herein and for following the instructions contained therein.

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STRATA-TECH, INC.

ST-530

INJECTION RESIN

INTRODUCTION

STRATATHANE ST-530 is an expanding urethane prepolymer grout with reacts with water and sets into a rigid, closed cell foam. ST-530 is mixed with ST-531 at the work site to form a single injection material whose reaction time with water is governed by the concentration to ST-531 in the blend.

The ST-530/531 blend is hydrophilic before reaction with water and hydrophobic when the reaction is complete. The inter end-product forms a water barrier which is essentially unaffected by acids, gasses, and micro-organisms usually found in soil.

A minimum of water is needed for reaction, but large amounts can be accommodated through reaction or displacement.

ST-530 is useful for a wide range of water control and soil stabilization applications. ST-530 has been effective in forming grout curtains, in stabilizing water-bearing soils, and as a locking agent for rock anchors. ST-530 has also been in concrete, buildings, dams, and utility vaults.

ST-530 may be placed by hand pumps or multi ratio power pumps. Stainless steel fittings are recommended but not strictly required because of ST-530 is not caustic. Clean up of solidified material in the system, however, is often accomplished with caustic cleaning compounds, making stainless steel advisable.

The low viscosity of ST-530 mixture is easily injected. Once, cured, its impermeability makes it an effective water shut-off system. The permeability of soil grouted with ST-530 depends on how well its voids are filled with grout. Values in the 10^7 cm/sec range should be obtained using ASTM Constant Head Permeability Test Method D-2434.

A two stage reaction takes place when ST-530 comes in contact with water.

The mixture first expands and quickly thickens. Then, as it cures, ST-530 solidifies into a strong impermeable water barrier in just minutes. Unrestrained ST-530 foam expands up to twenty-times its starting volume, with a final foam density of about 27 kg\m^3·F However, a dense material is preferred for most applications, Greater density is obtained by controlling the amount placed relative to void space and static head pressure.

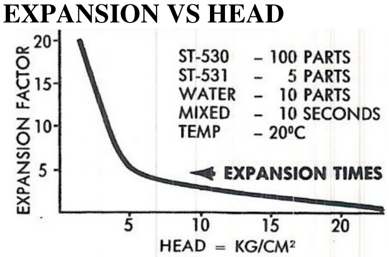
The two stage reaction takes place continuously during injection as product exits the packer. Initial penetration is facilitate by the low viscosity of the mixture. After reaction begins, the expansive mixture pressure induces further penetration of the grout zone depending on the amount of static head pressure. Figure 1 shows the typical relationship of foam expansion as a function of static head.

ST-530 creates a seal which is impervious to water yet is able to tolerate freeze-thaw, wet-dry cycling, extrusion, and compression.

DESCRIPTION

Uncured ST-530 is a dark brown liquid with a viscosity of about 140 cps at 77°F. This low viscosity is further reduced after addition of ST-531. ST-530 contains non-volatile materials making up almost 100% of its total weight. Cured ST-530 is firm and semi-rigid. Its foam is a three dimensional cross-linked molecular structure which is insoluble in water.

ST-530
EXPANSION VS HEAD



ST—530
PHYSICAL PROPERTIES

State Liquid
Color Dark Brown
Odor Sharp
Viscosity 110 to 170 cps at 25°C
Density 1.11 to 1.15 at 20°C
Solidification Pt -15°C
Flash Point 188 C per ASTM D-93 PMCC
Solubility, water Insoluble in water

ST-531
PHYSICAL PROPERTIES

State Liquid
Color Homogenous Red
Odor Characteristic Amine
Viscosity 10 to 18 cps at 25°C
Density 0.90 to 0.93 at 20°
Solidification Pt 7°C
Flash Point 119°C per ASTM D-93 PMCC
Solubility Insoluble in water

ST-530 AND ST-531
"FREE-FOAMED" PROPERTIES

Density 27.5 kg\m3 per DIN 53420
Compression 27kPa at 10% compression
Hardness DIN 53421
Friability 20.2% (Wt after 2') – 62.7%(Wt after 10') ASTM C241
Tensile Strength Shell Method
Tension 204 kPa
E-Modulus 5925 kPa
Elongation 6%

Set time is the period from first contact of ST-530 with water to the point where the mix becomes too thick for gravity flow. Set time is influenced primarily by the mix temperature and the ration of ST-531 to ST-530. Set times are longest at low temperatures and ST-531 ratios and also vary a little with age of the resin and mineral content of the water.

The viscosity of mixed ST-530 is lowest for the first 20 to 30 % of the set time and then increase rapidly as the mix approaches set.

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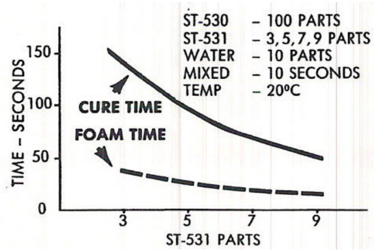
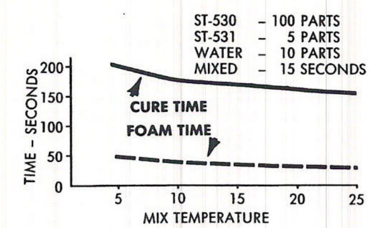
SET TIME AND ST-531 CONCENTRATION



ST -530
SET TIME vs TEMPERATURE



ESTIMATING

As a rule of thumb, on ounce of ST-530 will be needed per 2 cubic inches of void, but considerable variance is possible. Application techniques can minimize quantity while maintaining seal quantity. The advice of an experienced contractor is most helpful. The primary factors which affect quantity are:

1. Application method used
2. Void size to be filled
3. Penetrability of the grout zone
4. Water flow volume of velocity
5. Type of equipment used.

CLEANUP

ST-530 should not stand in equipment for more than 12 hours because the possibility of moisture contamination is high. Flush equipment with solvent and cleaner soon after use.

When using solvents during cleanup, extinguish all ignition sources and observe proper precautions for handling such materials. For cleanup of cured ST-530, soak in a 100% solution of ST-522 cleaner using a covered polyethylene container. Grout spills on clothing are permanent, so disposable coveralls are recommended. See “Safety Procedures" for safety and first aid information. See “Injection” for additional product use information. See equipment manuals for equipment cleaning instructions.

HANDLING AND STORAGE

Use care in handling and storing ST-530. The material is sensitive to high storage temperatures. Under optimum storage of 40-60°F in dry conditions, the material should have a useful shelf life of more than one year. Storage temperature should not exceed 80°F. Once a container has been opened, the life of the material is reduced. Let container stand and adjust to ambient temperature before opening to present contamination by condensation. Reseal opened containers as quickly as possible. Prior to use, carefully test resealed containers to assure that moisture contamination has not occurred. Do not seal any container of the ST-530 to which ST-531 has been added because condensation o moisture in the air may cause a reaction leading to rupture of the container.

SAFETY

Before handling or using this product, read and understand the Material Safety Data Sheet (MSDS). Instruction in sound safety practices is beyond the scope of this publication. Any user who does not have a Safety Professional available to him for this instruction is strongly advised to obtain such service before handling or using this product. Direct contact of ST-530 liquid my cause skin and eye irritation. If ST-530 comes in contact with skin, wash with soap and water. For eye contact, flush immediately with water and consult a physician, ST-530 must not be ingested. Before eating, smoking, or drinking remove protective clothing, wash with soap and water, stand away form the immediate work site. Do not smoke while working with ST-530. If respiratory difficulties occur, seed medical attention.

Avoid exposure to vapors from this product. Gloves, goggles, respirator and protective clothing are recommended. Ventilate the work area as a matter of good practice, although hazardous levels of toxic vapors are not generally given off the bulk product below 90° F. Avoid exceeding the MDI Threshold Limit Value (LTV). Small amounts of MDI may be present and some users may be sensitive to MDI . An organic vapor respirator should always be available and normal ventilation augmented by blowers or fans as appropriate.

Summary of Handling Precautions

Wear Goggles and rubber gloves.

Wash any body contact area thoroughly with water.

In case of eye contact, wash immediately with water and boric acid solution and seek medical attention.

Keep material away from heath and flame.

Ventilate, and use a respirator on hot or closed spaces.

STATEMENT

Strata Tech believes that the information herein is an accurate description of the general properties and characteristics of the product(s), but the user is responsible for obtaining current information because the body of knowledge on these subjects is constantly enlarged. Information herein is subject to change with out notice. Field conditions also vary widely, so users must undertake sufficient verification and testing of the product or process herein to determine performance, safety, usefulness, and suitability for their own particular use.

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Appendix C:

Pictures

Cup Testing Pictures
Testing Pictures
Final Evaluation Pictures

Cup Testing Pictures

Avanti 248/330

Figure 1. AV-248/330 1:1 ratio 72 hours after cup test (a) side view (b) top view

Figure 2. AV-248/330 3:2 ratio 72 hours after cup test (a) side view (b) top view

Figure 3. AV-248/330 4:1 ratio 72 hours after cup test (a) side view (b) top view

Figure 4. AV-248 72 hours after cup test (a) side view (b) top view

Figure 5. AV-330 72 hours after cup test (a) side view (b) top view

Figure 6. AV-248/330 1:1 ratio 1 week after cup test (a) side view (b) top view

Figure 7. AV-248/330 3:2 ratio 1 week after cup test (a) side view (b) top view

Figure 8. AV-248/330 4:1 1 week after cup test (a) side view (b) top view

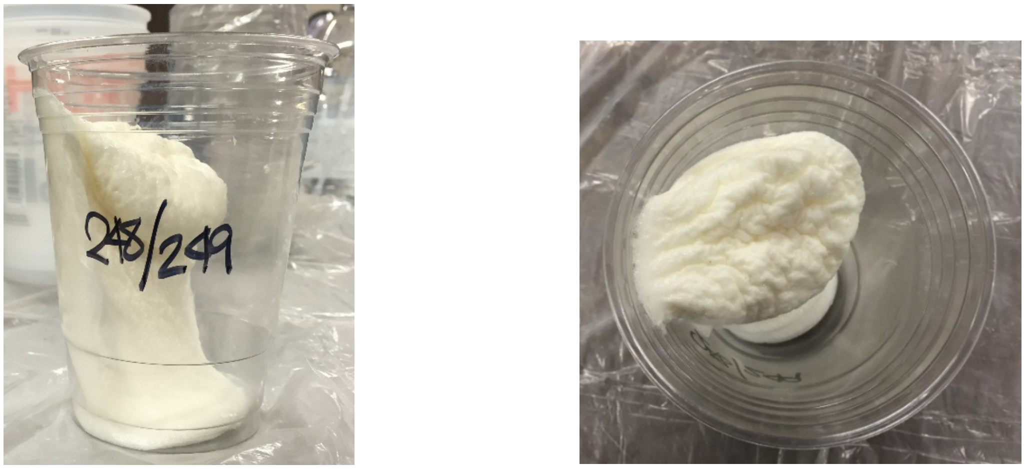

Figure 9. AV-248 1 week after cup test (a) side view (b) top view

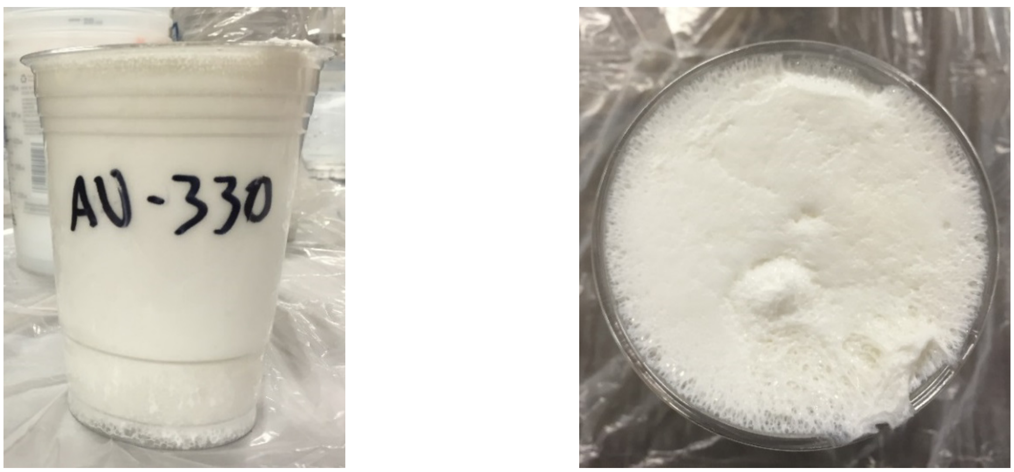

Figure 10. AV-330 1 week after cup test (a) side view (b) top view

Strata-Tech 530/504

Figure 11. ST-530/504 3:2 ratio 24 hours after cup test (a) side view (b) top view

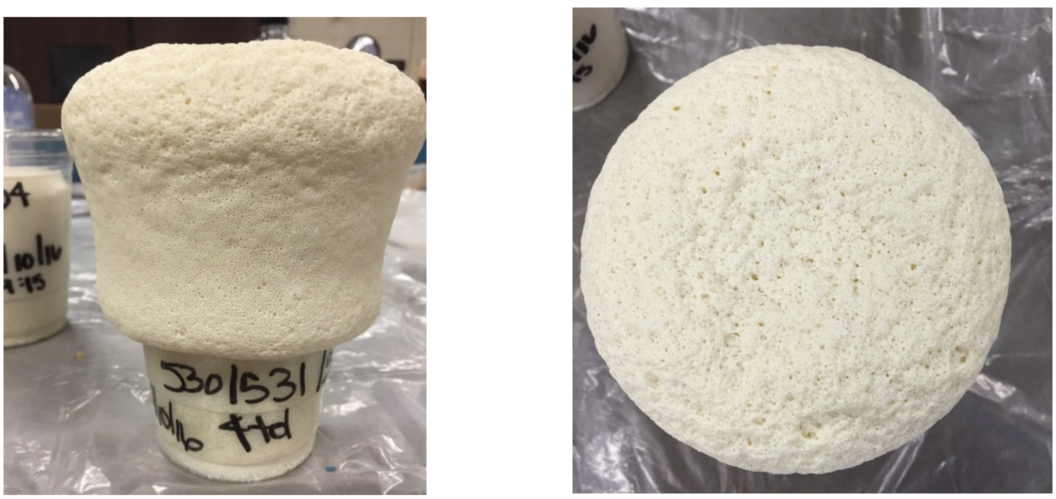

Figure 12. ST-530/504 4:1 ratio 24 hours after cup test (a) side view (b) top view

Figure 13. ST-530 24 hours after cup test (a) side view (b) top view

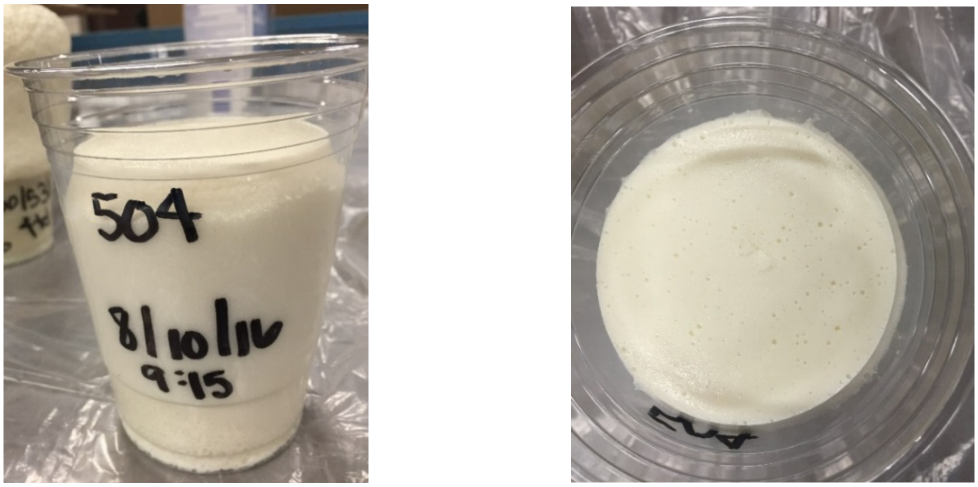

Figure 14. ST-504 24 hours after cup test (a) side view (b) top view

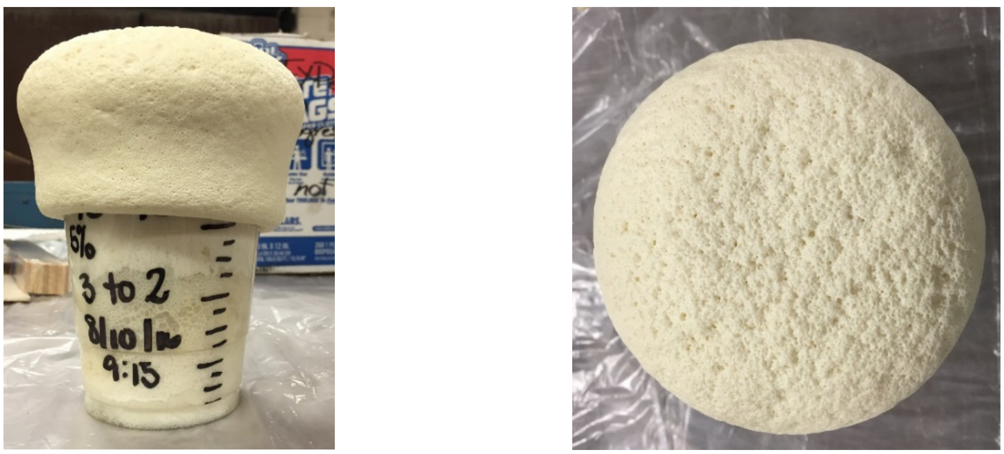

Figure 15. ST-530/504 3:2 ratio 1 week after cup test (a) side view (b) top view

Figure 16. ST-530/504 4:1 1 week after cup test (a) side view (b) top view

Figure 17. ST-530 1 week after cup test (a) side view (b) top view

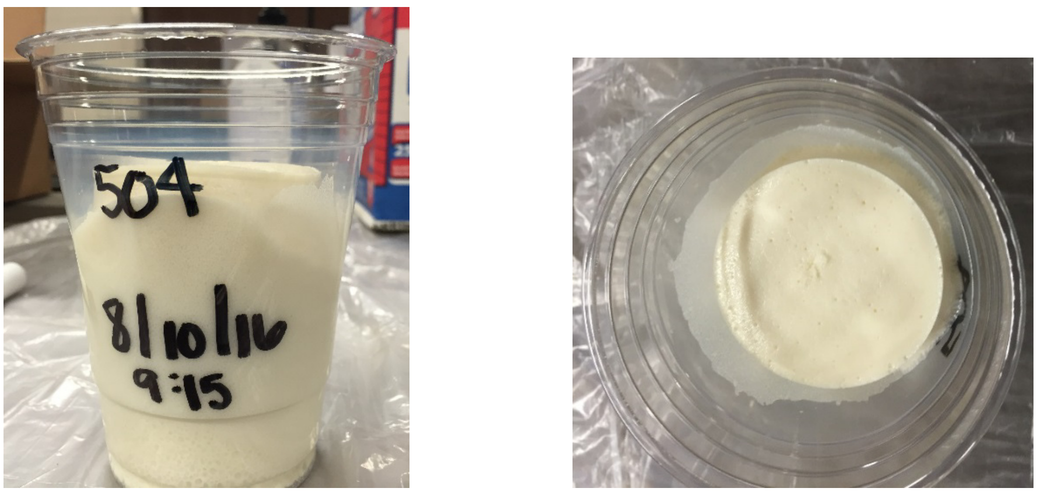

Figure 18. ST-504 1 week after cup test (a) side view (b) top view

Testing Pictures

Avanti 4:1 248/330

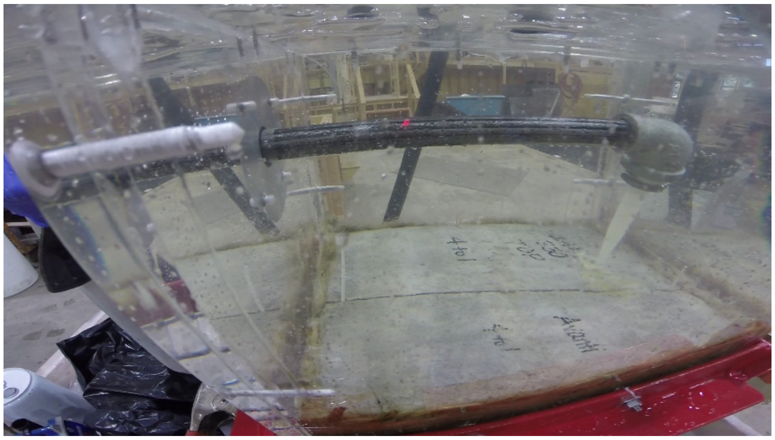

Figure 19- Initial injection

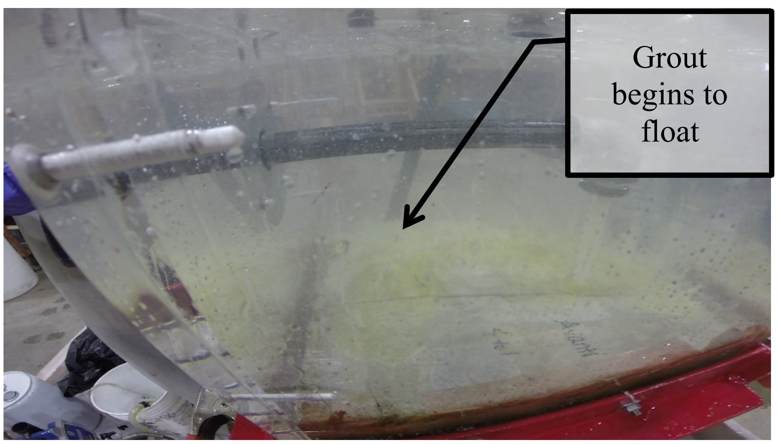

Figure 20- Curing resin

Figure 21- Post-testing: cured grout floats but water is fairly clear

Figure 22- Top of specimen immediately after testing

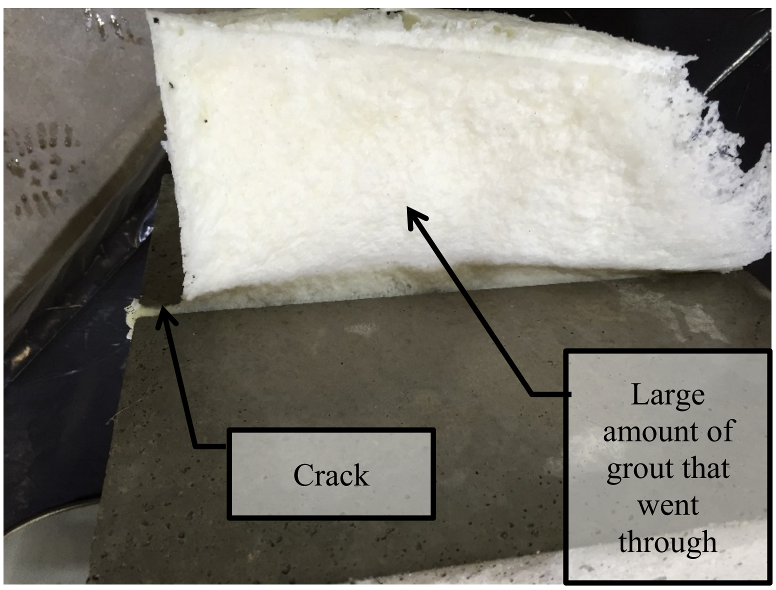

Figure 23- Bottom of specimen immediately after testing

Avanti 3:2 248/330

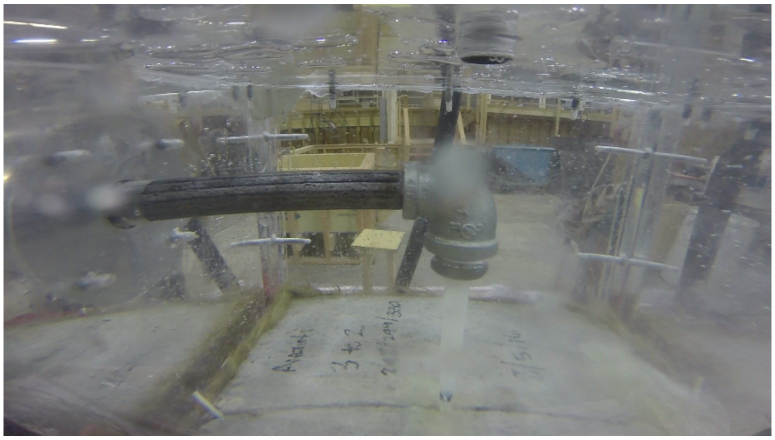

Figure 24- Initial injection

Figure 25- Water clouds as resin cures

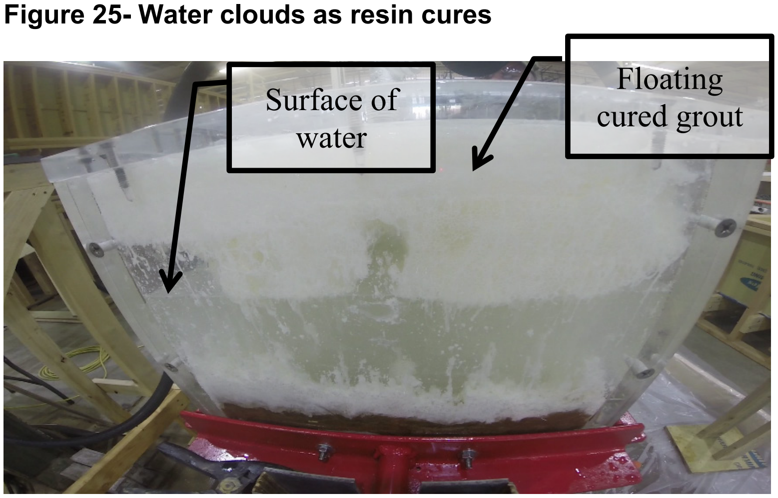

Figure 26- Post-testing: significant floating product and chamber begins to drain

Figure 27- Top of specimen after testing

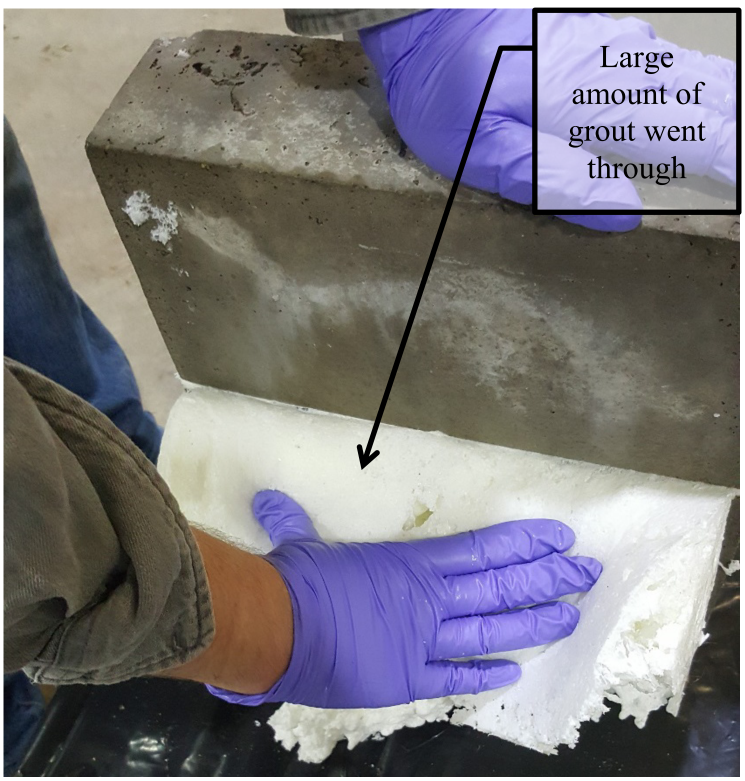

Figure 28- Bottom of specimen after testing

Strata-Tech 3:2 530/504

Figure 29- Initial injection

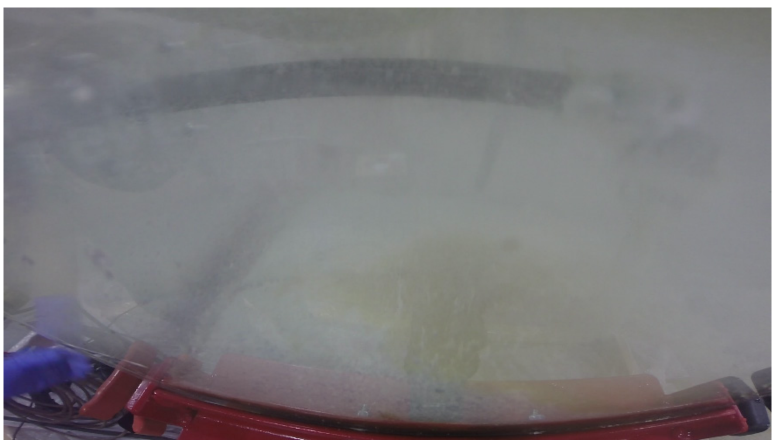

Figure 30- Water clouds as resin begins to cure

Figure 31- Post-testing: Water clears as resin floats

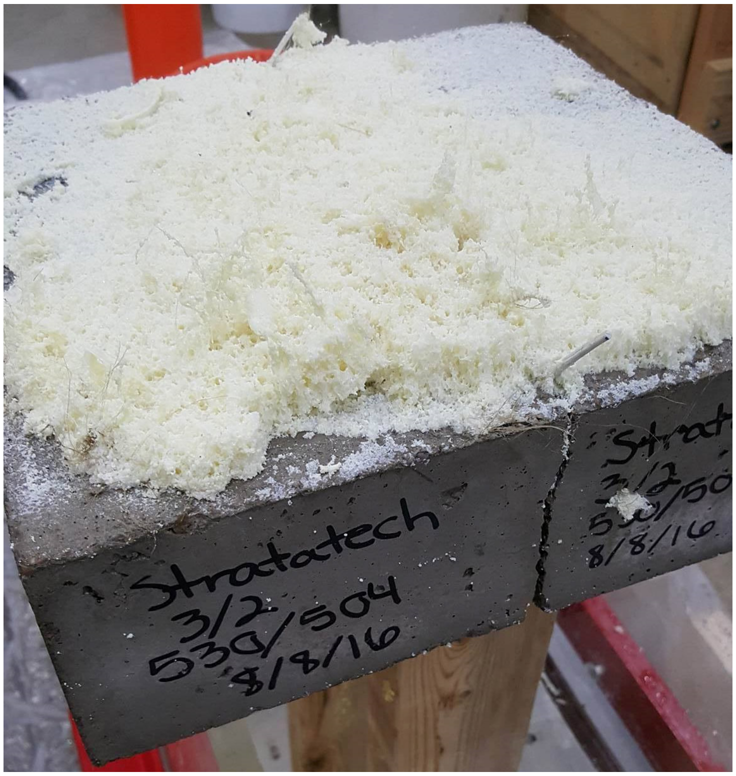

Figure 32- Top of specimen immediately after testing

Figure 33- Bottom of specimen immediately after testing

Strata-Tech 4:1 530/504

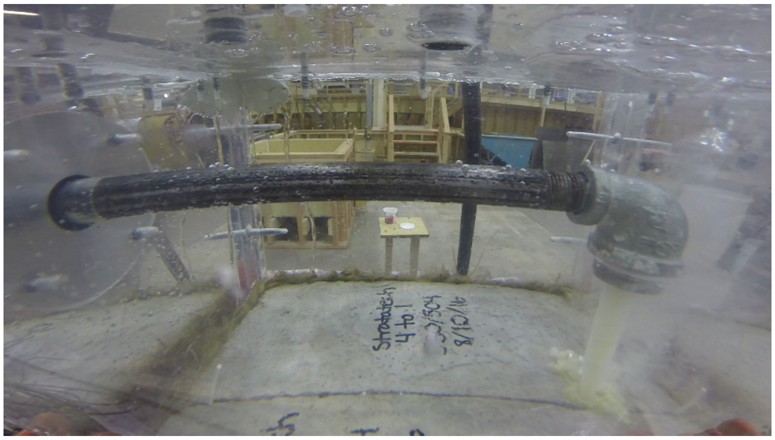

Figure 34- Initial injection

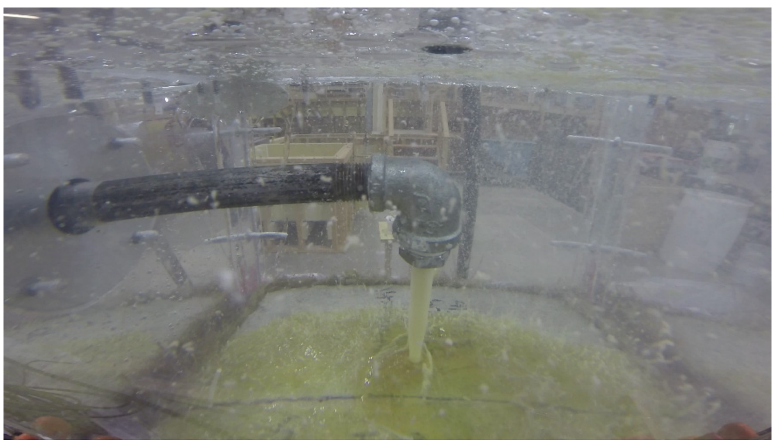

Figure 35- Resin begins to float

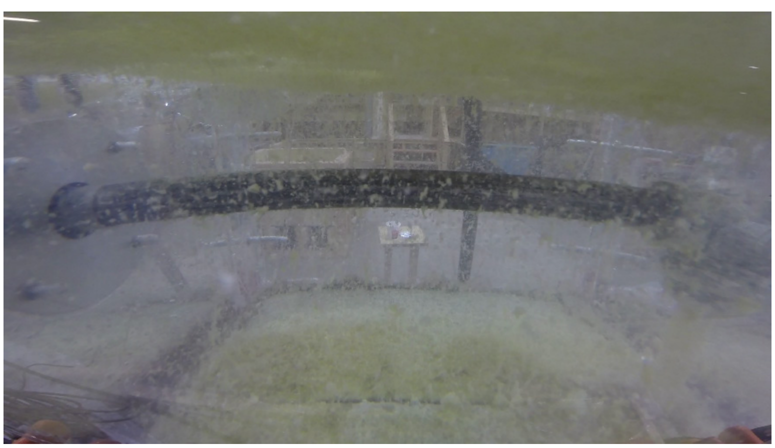

Figure 36- Post-testing: grout floats but water is clear

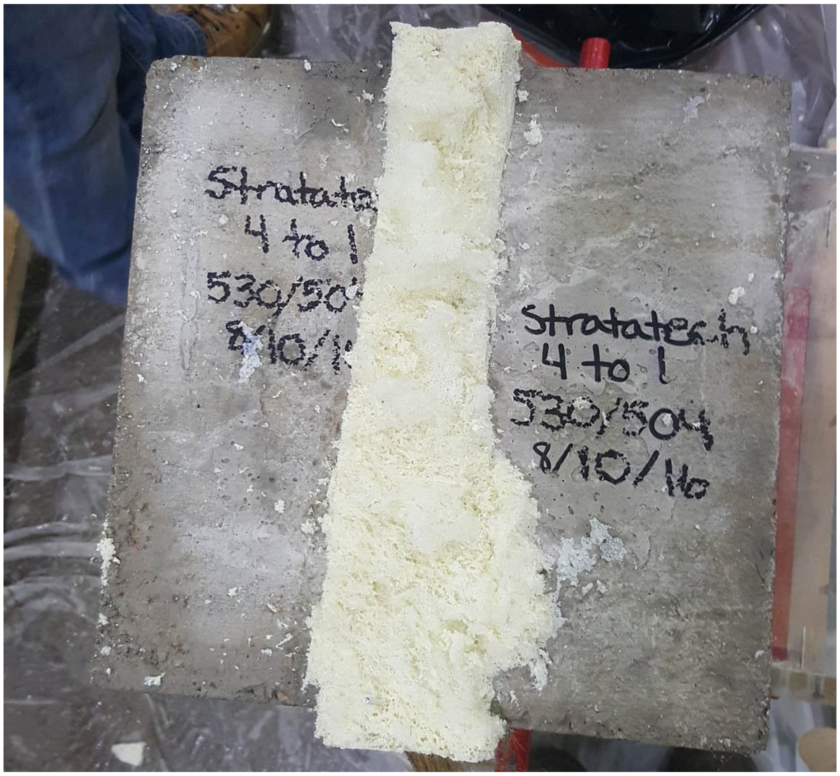

Figure 37- Top of specimen after partial removal of excess grout

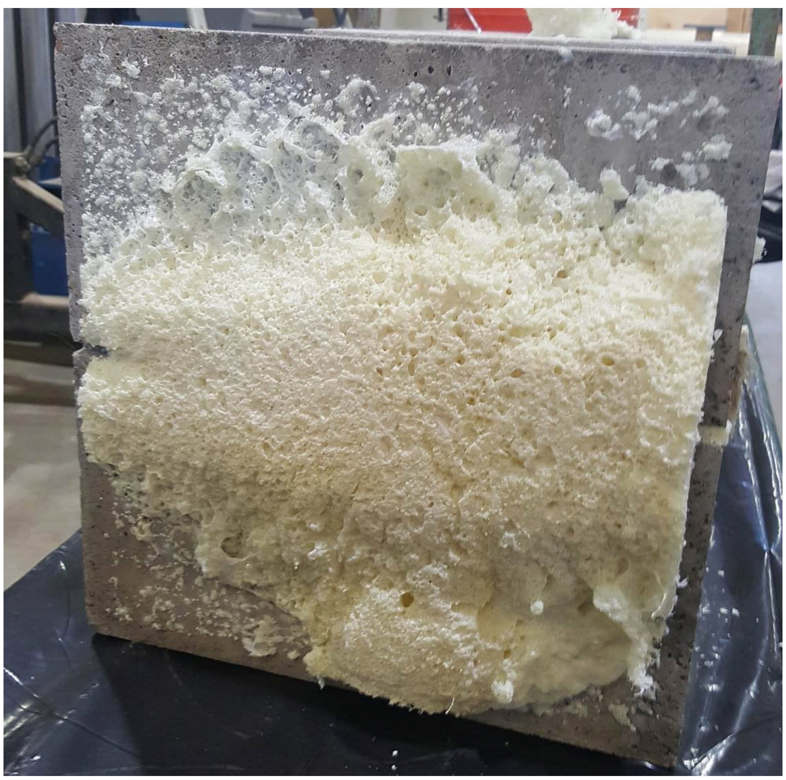

Figure 38- Bottom of specimen immediately after testing

Final Evaluation Photos

Avanti 4:1 248/330

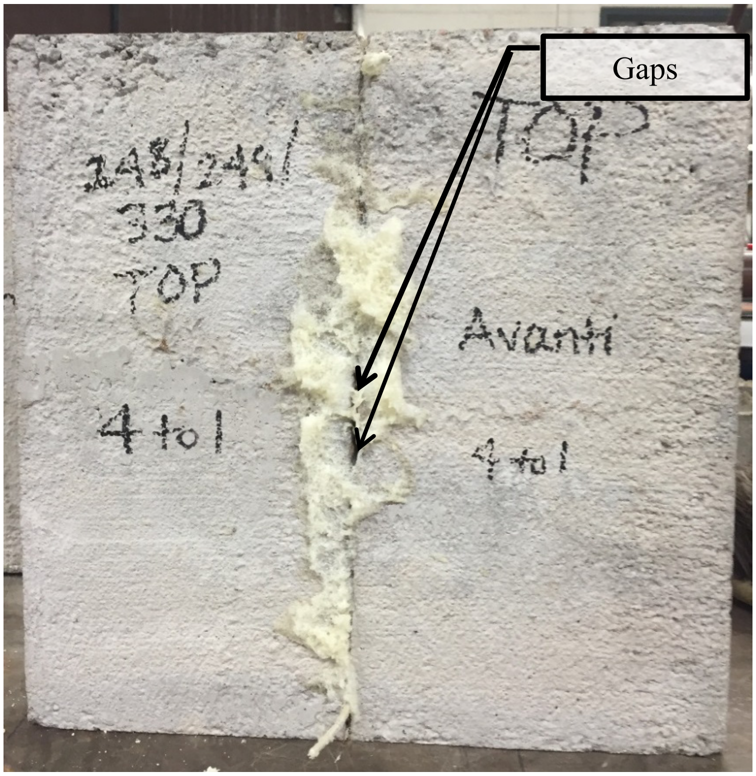

Figure 39- Top of specimen

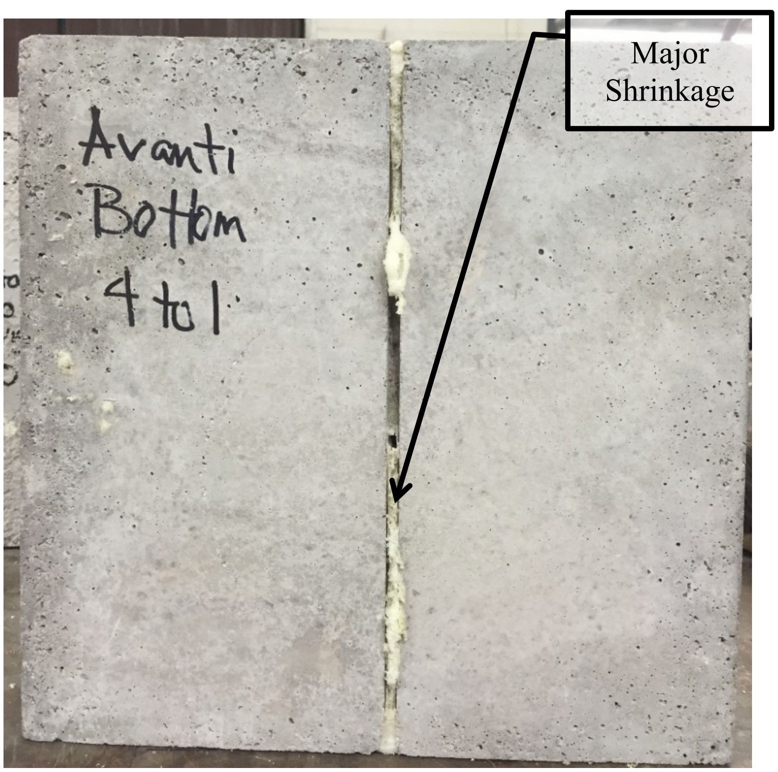

Figure 40- Bottom of specimen

Avanti 3:2 248/330

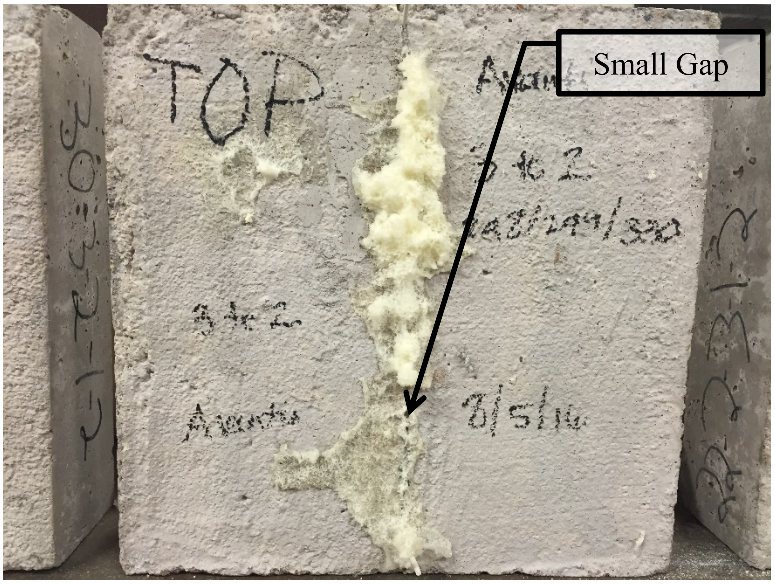

Figure 41- Top of specimen

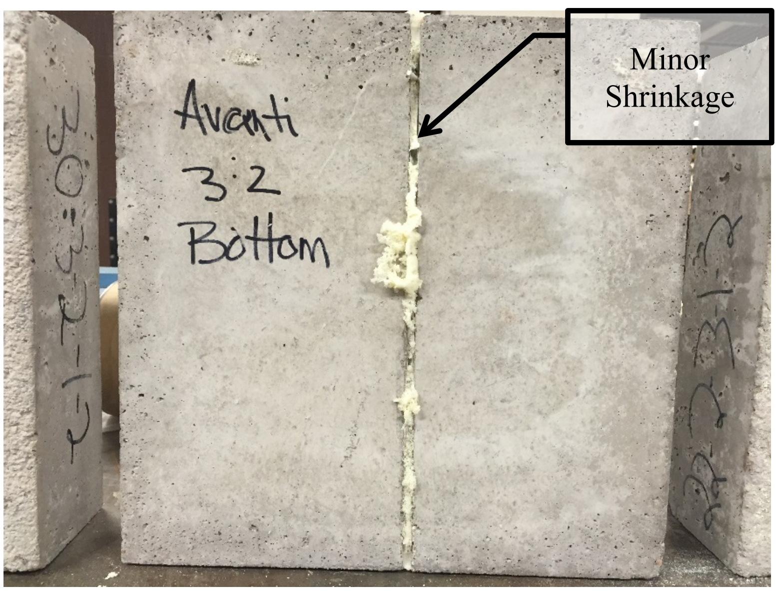

Figure 42- Bottom of specimen

Strata-Tech 3:2 530/504

Figure 43- Top of specimen

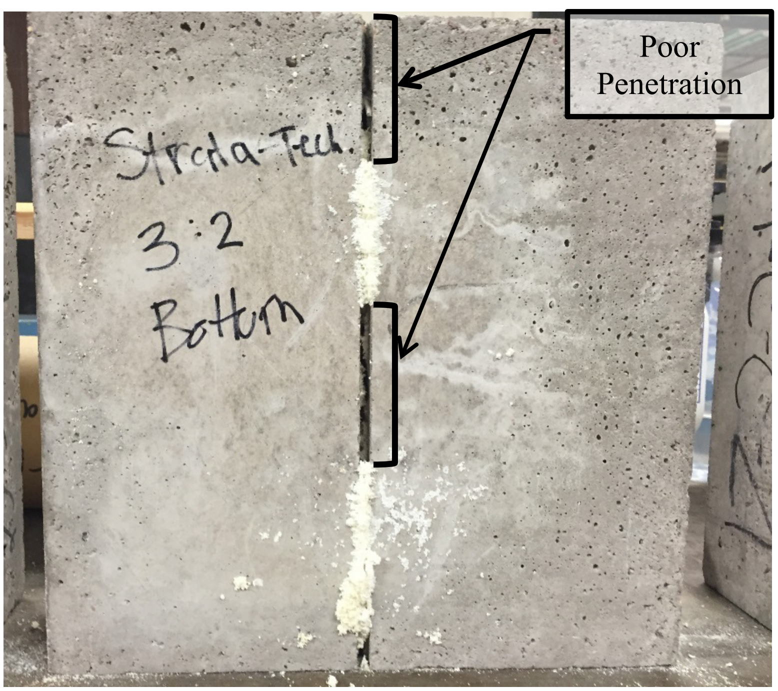

Figure 44- Bottom of specimen

Strata-Tech 4:1 530/504

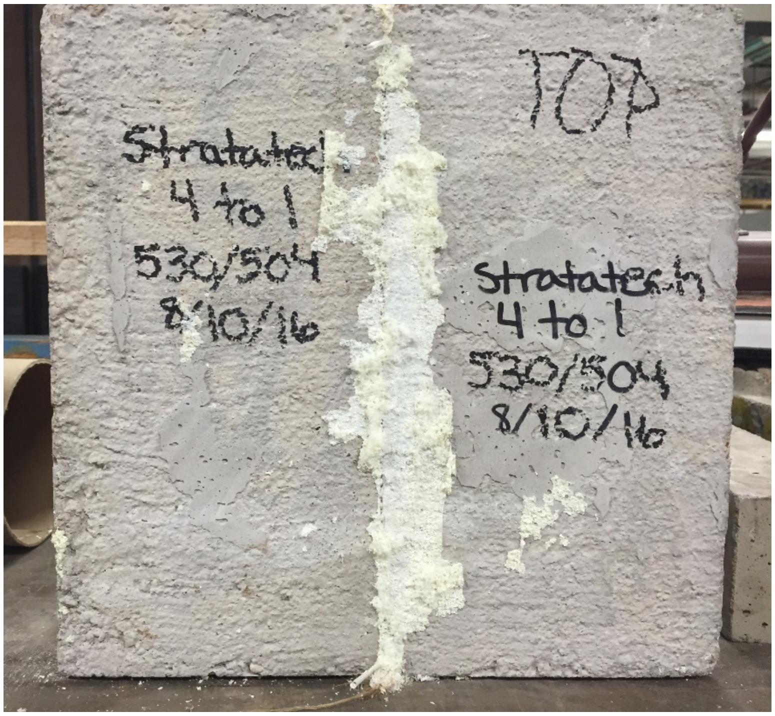

Figure 45- Top of specimen

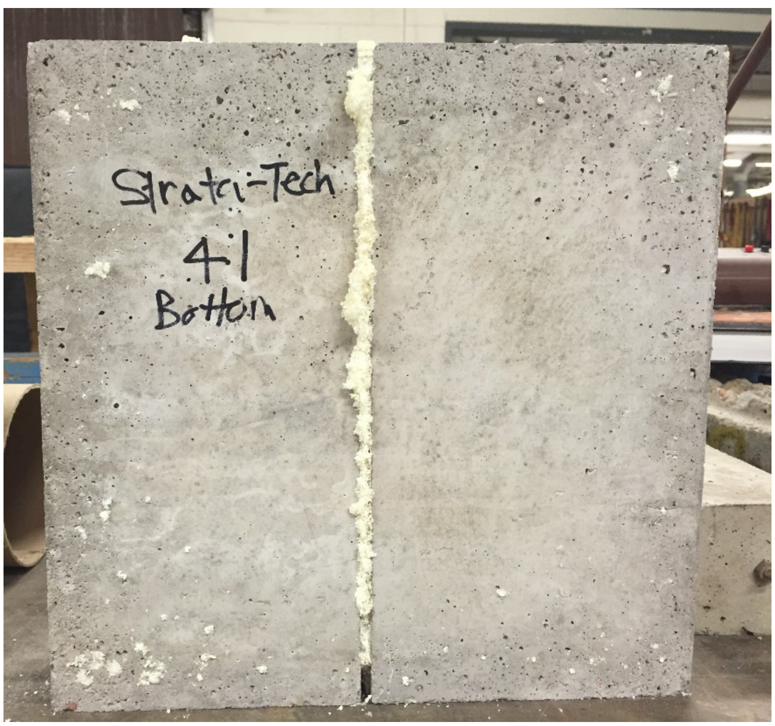

Figure 46- Bottom of specimen