Effects of Admixes on the Compressive Strength of Permeable Concrete

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Compression tests were performed on three samples of permeable concrete to evaluate the effects of admixes on a conventional permeable concrete. The first mix served as the control, representing a standard permeable concrete sample. The second mix replicated the control but added a small amount of fiberglass, accounting for 0.5% of the cement's weight. The third mix again mirrored the control and incorporated the manufacturer's recommended amount of a water reducing admix known as "Reducer 555". The objective of testing the two new mixes against the control mix was to evaluate the potential increase in ultimate compressive strength. Four 6” x 12” test cylinders were produced for each of the three mixes to allow destructive compression strength testing at 7, 14, 21, and 28 days from the date of initial pouring. The results of the tests revealed that there was a 168.1 psi increase in the ultimate compressive strength over the control mix with the addition of fiberglass, and that the addition of fiberglass did not greatly affect the permeability of the concrete. It also revealed that further testing would be necessary to accurately evaluate the effects of the water reducing agent, due to excess slump and the mix stratifying.

Key Words: Concrete, Testing, Permeable, Paving System, Fiberglass, Admix

Introduction

In recent years the use of permeable concrete as a paving system has gained significant attention due to the environmental benefits these systems have when compared to conventional paving and water management methods. Permeable paving systems alleviate strain on stormwater infrastructure. Permeable pavements also allow for the infiltration of water back into the ground, replenishing groundwater supplies. They also contribute to a reduction in the amount of waste that finds its way into waterways from paved surfaces. However, the strength of permeable paving systems isn’t that of conventional AC pavement or concrete. Therefore, its utilization has largely been kept to light use areas such as parking lots and walkways. For widespread adoption in our world’s more demanding roadways, permeable pavements must be made stronger to increase their feasibility.

This project presents an analysis of three permeable concrete samples: a conventional permeable concrete mix, a permeable concrete mix containing fiberglass, and a permeable concrete mix utilizing a water-reducing admixture. This laboratory testing was conducted using ASTM standards as part of a senior project at Cal Poly San Luis Obispo. The objective of this project is to evaluate the potential increase in permeable concrete compressive strength, through the use of admixes, to make permeable concrete a more viable option for future roadway construction.

Variables

The test samples for this research project consisted of three different mixes. One standard and two containing admixes. The admixes for the test samples were chosen based on research conducted on permeable concrete through review of current literature on the subject. The first sample was a simple permeable concrete mix. This mix served as the baseline of comparison for the other two mixes. To ensure the baseline sample met the specifications of an industry standard permeable concrete, this senior project used a mix ratio set forth in a study conducted by the National Center for Sustainable Transportation in a paper titled, “Sustainable mitigation of stormwater runoff through fully permeable pavement” (Ralla, A. & Saadeh, S., 2017). Their report outlined the uses and exact ratio, by weight, for a standard permeable concrete. The exact quantities of components used in this project’s mixes will be explored in greater detail in the methods section of this report. During research of ways to strengthen permeable concrete the article, “Pervious Concrete Pavement Gets Fiber Reinforcement” on Constructionpros.com was discovered (Constructionpros.com, 2013). In this article, it was discussed how glass fiber was utilized to strengthen a permeable concrete paving system. However, it did not detail the exact strength advantage provided by utilizing glass reinforcement or what quantity of glass they used in their mix. The use of glass reinforcement in conventional concrete is quite common. After researching the standard quantities of glass fiber used in glass fiber reinforced concrete, a document titled, “Carbon Fiber Reinforced Concrete” for the Strategic Highway Research Program was found (Chung, D. D., 1992). In this paper Chung revealed that a common quantity of glass fiber for a reinforced concrete would be the amount of 0.05% the weight of cement. This amount of fiberglass was selected for these tests. Finally, the use of an admix was explored for the third and final test sample. A water reducing admix named “Reducer 555” was used in the dosage recommended on the manufacturer’s website (Buddy Rhodes, 2023). This admix was selected due to the manufacturer's claim that it increases workability and performance of concrete. One of the increased performance parameters claimed was compressive strength.

Hypothesis

Due to the common utilization of glass fiber to reinforce conventional concrete systems, as well as the finding that glass fiber has been used for some permeable concrete systems, it’s reasonable to believe that we would see an increase in the overall compressive strength of the glass fiber reinforced concrete sample over the standard permeable concrete sample. In addition, given the claims and real-world utilization of “Reducer 555” in creating high performance concrete, it would also be reasonable to assume this admix would increase the overall compressive strength of the permeable concrete over the standard permeable concrete mix. By conducting laboratory tests using ASTM standard test procedures, the changes in compressive strength of the concrete due to these admixes can be accurately quantified. With these findings, this report can add new knowledge to the subject of permeable pavements, and set the foundation for further research in the area of strengthening paving systems to make them more feasible in heavy roadway use.

Methods

The concrete samples were formed in test cylinders measuring 6" in diameter by 12" tall. There was a total of 12 test cylinders produced, four for each mix. The samples were mixed in a cement mixer located at Cal Poly's concrete lab. The concrete was then poured from the mixer into wheel barrows and transported to the courtyard at the lab for placing the concrete, via scooper, into the test cylinders. Each cylinder was first filled up 1/3rd of the way, with their respective mixes, and doweled 25 times in a circular pattern. This sequence was repeated two more times until each cylinder was full. The excess concrete was scraped off the top of the cylinder to ensure it was flush. The 12 specimens then received a lid, were labeled with black permanent marker, and were placed in a tank to be submerged with water. All of these processes followed ASTM C31 standards for making and curing concrete test specimens (ASTM, 2018). During the pouring process, excess concrete was used to conduct slump tests for each of the three mixes. This process involved filling the standard slump test cone (4" diameter at the top and 8" at the bottom by 12" tall) with concrete. The cone was then lifted away. Using a straight edge, and tape measure, the slump of the concrete from the original height of the cone was measured and recorded. This process followed ASTM C143 standard test for slump of concrete (ASTM, 2015). The exact weights of materials used for each mix can be seen in the table below (see table 1), as well as the results of the slump tests.

Table 1

MIX	Course Aggregate (LBS)	Water (LBS)	Cement (LBS)	Admix	Unit for admix amount	Slump (In.)
Control (1)	151.8	12.2	41.4	N/A	N/A	1/2
Fiberglass (2)	152.0	12.2	41.4	0.21	LBS	0
Reducer 555 (3)	152.0	12.2	41.4	6.20	Ounces	8

The scale used for weighing bulk materials was accurate to the nearest 0.2 pounds. The scale used to weigh the glass fiber was accurate to 0.01 ounces. The measuring cup used for measuring the liquid "Reducer 555" was accurate to 0.1 of a fluid ounce. The cement used in all three samples is Cal Portland type II. The coarse aggregate used in all of the samples was naturally rounded 3/8's pea gravel, sourced from the Cal Portland quarry in San Luis Obispo. The amount of fiberglass used in Mix 2 accounts for 0.05% the weight of cement, and the 6.21 ounces of "Reducer 555" for Mix 3 is the manufacturers recommended amount for the amount of cement in Mix 3. Buddy Rhodes' website, the manufacturer of "Reducer 555", recommends 8 to 20 fluid oz per 100 lbs. of cement in a standard mix. Given that 41 pounds of cement was used in Mix 3, 6.20 ounces was within the manufacturers specs and fell at the mid-range of the allowable dosage.

Instrumentation and Testing

The breaking of the cylinders occurred at intervals of 7,14,21, and 28 days from the date of initial pouring. The hydraulic press used, the procedures practiced in the process of breaking of the specimens, and recording the strength data, conformed with standards outlined in ASTM C39 test method for compressive strength of cylindrical concrete specimens (ASTM, 2019). The procedure involved sandwiching each specimen between two padded steel plates, placing the sample in the hydraulic press and closing the door. The presses digital read out was tared (zeroed out) once the correct cylinder size was selected on the digital read out of the press. The advance dial of the press was set to 1.5 turns out and the lever to start the press was pulled. Once the load on the sample reached 1000 pounds of pressure the read out began to display the psi load on the sample in real time. There was a section of the readout that displayed the increase in psi/second and the dial was adjusted to keep this number between 30 psi/second and 60 psi/second during the test to avoid loading the sample too quickly. Once the press sensed the sample wasn't resisting any more of the load from the press it provided the peak compressive strength in psi for the sample.

Results and Data

Below is a visual representation of the end product of each of the three mix samples (see figure 1). Mix 1 and 2 came out as expected and had no noticeable deficiencies or issues with any of the 4 samples tested. Mix 3 did however show obvious signs of stratifying. The large 8" slump of Mix 3 could be to blame, as it did not cure in one cohesive mass like the other two did. While on the subject of slump, it is noteworthy that the fiberglass specimen (Mix 2) did not exhibit any slump. When forming the concrete test specimens, Mix 2 was noticeably harder to work with when compared to the standard (Mix 1) although it did not present any significant issues. Mix 1 and 2 maintained their ability for water to permeate through them, when tested with running water. Mix 3 did not retain its ability for water to permeate through it, as the bottom was a solid mass of impermeable concrete.

Figure 1. Examples of Concrete Samples

While conducting the destructive compression tests, it was noted that many pieces of coarse aggregate were ejected from the specimens at high velocity. PPE was required in the Cal Poly Lab prior to testing, and is recommended during any future tests of this kind. Below you will find pictures representing the concrete samples after failure in the press (see figure 2). Each mix group failed similarly across each of their respective breaks. Mix 1 crumbled and large sections fell off of the cohesive mass. Mix 2 did not crumble apart as much as Mix 1 and remained mostly intact, presumably from the glass fiber holding everything together. Mix 3 gave way the most, and crumbled significantly at the top due to the forces induced by the hydraulic press.

Figure 2. Examples of Concrete Samples prior to Compression Testing

The results of the compressive tests for the three mixes, at each of the 4 testing intervals, is displayed in the table below (see table 2). Mix 1 saw a steady increase in strength for the first three weeks then the strength dropped at the fourth week. Mix 1 displayed an ultimate compressive strength of 1584.9 psi. The strength of Mix 2 strangely went up and down over the 4 weeks and landed above the control (Mix 1) at a final strength of 1753.0 psi. Mix 3 acted similarly to Mix 1, gradually getting stronger, then losing some strength at the final week. The final compressive strength of Mix 3 was 925.9 PSI.

Table 2				
MIX	Strength Day 7 PSI	Strength Day 14 PSI	Strength Day 21 PSI	Strength Day 28 PSI
Control (1)	987.5	1269.7	1724.9	1584.9
Fiber Glass (2)	1275.4	1936.7	1469.9	1753.0
Reducer 555 (3)	802.8	841.8	1024.0	925.9

Looking at a table is often not as easy to follow when compared to examining a graph. Below is a graphical representation of the results of the destructive compression testing (see figure 3).

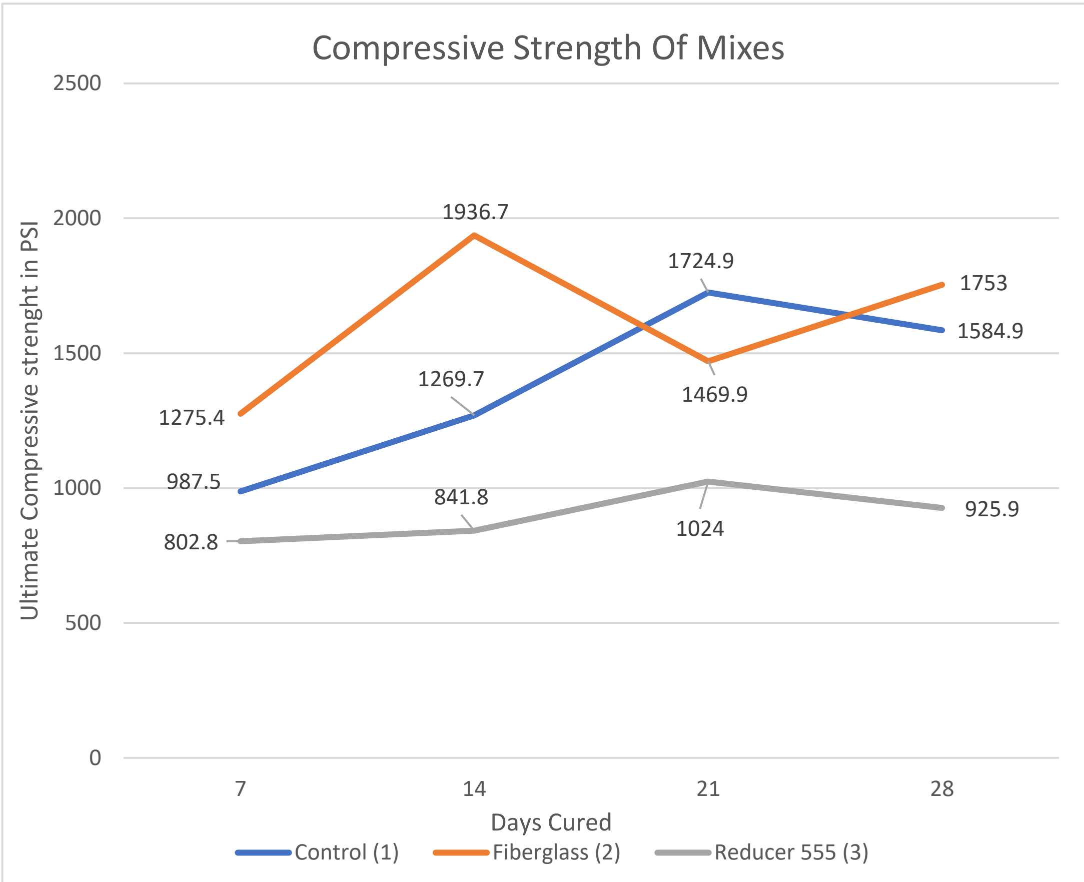

Figure 3. Graph of Compressive Tests Results

Conclusion

The standard permeable concrete sample seemed to perform in a satisfactory manner and was a worthy baseline for comparison across the other 2 mixes. After conducting research into the kinds of compressive strengths one could expect from a standard permeable concrete, a paper titled, "Evaluation of Mix Designs and Test Procedures for Pervious Concrete" by Medhani, R., & Han, W. was discovered. In this dissertation it was said that the expected compressive strength range for a standard permeable concrete is between 500 to 4000 psi. (Medhani R., & Han W., 2014). The concrete used as a baseline for comparison for this senior project performed at a peak strength of 1584.9 psi, landing its performance in the mid to lower range of the expected strength parameters. Although on the weaker side of the range, the standard mix is still well within this broad specification set out by Medhani and Han. The standard mix was also capable of water permeating through it, further demonstrating that the mix performed adequately and as expected. The second permeable concrete mix (Mix 2) containing fiberglass did meet the objective of increasing the ultimate compressive strength of permeable concrete. Mix 2 had an overall compressive strength of 1753.0 psi. When compared to the standard permeable concrete mix, the glass fiber mix was 168.1 psi stronger at day 28. This is a 10.61% increase over the standard mix. A 10.61% increase in compressive strength over the standard mix by just adding some fiberglass is a noteworthy performance gain without too much of a negative effect. The addition of fiberglass did not seem to greatly hinder the ability for water to permeate through the mix, which would have defeated the main benefit of the paving system. The exact effects of fiberglass on the rate at which water permeates would require further laboratory testing. In addition to the gain in compressive strength, the ability for the concrete containing glass fiber to stay as a cohesive mass after destructive testing may be an indicator that it has increased durability and even an increase in tensile strength. Substantiating these speculative durability claims would require further laboratory testing. One of the drawbacks of the glass fiber concrete seen from these tests, was that it has less slump and was subjectively examined to be harder to work with. While the workability did not hinder these tests in any meaningful or significant way, the workability of the fiberglass mix could be an issue during a large placement of this paving system. Again, further testing would be required to substantiate this speculative claim. The erratic peaks and valleys in the compressive strength of the glass fiber reinforced permeable pavement through its curing process was perplexing to the administrators of this research project. The presence of fiberglass could be the cause, but is not a decisive explanation for this phenomenon. The fiberglass concrete was not the only specimen exhibiting abnormal strength characteristics. In most concrete applications, the compressive strength is supposed to gradually increase over time while curing. Both the standard (Mix 1) and the "Reducer 555" (Mix 3) had drops in compressive strengths in their final week's compression testing. The cause for this can only be speculated and further testing would need to be conducted to diagnose why exactly these samples had abnormal compressive strength characteristics. The effects of "Reducer 555" on Mix 3 was drastic. Eight inches of slump is significant when compared to the baseline mixes slump of half an inch. The workability of this mix when poured into the 6"x12" molds and while conducting the slump tests made it extremely easy to work with. However, as can be seen by the photos, performance data, and inability of this system to allow water to permeate through it. This third mix is all but rendered a failure in the objectives of this senior project report. The compressive strength was weaker by a significant margin in all of the four compression tests conducted. Mix 3 was so runny that the coarse aggregate at the top appeared to be all but missing any cement binder after curing had completed. All of the water and cement slurry seemed to flow to the bottom and the mix was greatly stratified in the test cylinder. Further tests of Mix 3 in different mix ratios would be necessary to accurately decide if "Reducer 555" is a viable option for increasing the compressive strength of a permeable concrete system. Whether the future test would be a mix containing less water, or less "Reducer 555", would be at the discretion of a possible future researcher.

Overall, the results of this senior project were successful and provided some interesting results. Many new findings were presented and many new questions were formed from the performance of these tests. The objective of strengthening a standard permeable concrete mix, through the use of an admix, was met with the addition of fiberglass. Future research is needed to make a conclusive verdict on the extensive effects both of these admixes have on permeable concrete paving systems.

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