**Module 7: Portfolio Milestone: Final Research Paper**

Carley Rizzo

Colorado State University Global

MIS581: Capstone – Business Intelligence and Data Analytics

Dr. Lisa Bryan

November 27, 2022

**Module 7: Portfolio Milestone: Final Research Paper**

**Abstract**

Concrete is relied upon every minute of the day to protect society, and such a versatile and essential material needs to be tested for consistency to ensure poor concrete is not being used. American Society for Testing and Materials (ASTM International) produces concrete material standards that concrete testing laboratories must follow when testing materials for infrastructure use. One concrete standard allows laboratories to select up to five different end preparation methods to test the concrete for its strength. The five methods described include: unbonded capping, sulfur capping, gypsum capping, a cement paste, or grinding the cylinder ends. This research questions the validity that all five methods produce similar compressive strength results, and gathered data from concrete laboratories across the United States in 2018, which includes the end preparation method the laboratory used and their concrete compressive strength results. This research performed multiple paired t-test and ANOVA testing evaluations on the gathered data, and given the results, concluded that the methods do return statistically similar compressive strength values. However, the descriptive statistics of the dataset suggest there is bias in the results due to uneven sample sizes, thus continued exploration of this research question is recommended.

*Keywords:* Concrete, ASTM, end preparation, compressive strength, standard

**Table of Contents**

**Abstract 2**

**How the End Preparations of Concrete Cylinders Affect its Measured Strength 4**

**Objectives 4**

**Overview of Study 5**

**Research Question and Hypotheses 6**

**Literature Review 8**

**Concrete Mix Designs 8**

**Concrete Cylinder Sizes 9**

**Unbonded Caps in Detail 9**

**Compressive Strength on a Large Scale 10**

**Research Design 10**

**Methodology 10**

**Methods 11**

**Limitations 12**

**Ethical Considerations 13**

**Findings 13**

**Paired T-Tests 13**

**ANOVA Testing 15**

**Conclusion 19**

**Recommendations 19**

**References 21**

**How the End Preparations of Concrete Cylinders Affect its Measured Strength**

The modern world could not function without the production of concrete. Society lives on top of it as the foundation for most housing, drives on it as they travel to and from work every day, and uses it to protect them from flooding with dams. In order for concrete to continually keep performing its duties, it needs to be continually tested. One concrete standard making company, American Society for Testing and Materials (ASTM International) has globally recognized concrete standards that concrete testing laboratories in the United States need to follow in order to legally test concrete materials. While most standards only provide one correct way to perform the procedure, one particular concrete standard includes five different methods for preparing the ends of a concrete cylinder to test its compressive strength; claiming that they all yield the same results, despite their differences in procedural approach (ASTM International, 2021). Recently, there has been chatter among the laboratories that they are partial to certain methods, and have their own reasons why they believe the method they chose is superior. This chatter sparked the interest to gather data from the laboratories themselves, to see what the most popular method is, and if the different methods produce different concrete compressive strengths. Therefore, this research will provide current results, in an attempt to shed additional light upon this issue to understand the different approaches, and discuss their validity in determining concrete’s compressive strength.

**Objectives**

While this subject is not new to the concrete community, within the past five years there is minimal published research that evaluates all five methods in a uniform context, which makes this research proposal groundbreaking. The ultimate goal with this research project is to contribute to the end preparation discussion, and provide ASTM International with trusted results regarding the validity of their published standards. These results shall either provide ASTM International with the confirmation that their standards are still up-to-date, or start the conversation to revise the concrete compressive strength standard, which would affect the way concrete is tested across the United States.

**Overview of Study**

ASTM International’s concrete division ships regulated concrete materials to participating US laboratories, where they can run the desired number of ASTM concrete standards, and submit their results to see how they compare to laboratories across the US. In 2018, two concrete material samples were shipped to the participating laboratories, in the spring and fall, where laboratories also received a survey question of what end preparation method they used for completing the compressive strength standard. The survey question had six options: unbonded caps, sulfur caps, gypsum caps, cylinder grinding, cement paste, and an “other” write-in option. Out of the 2,751 observations between both the spring and fall datasets obtained, not a single laboratory chose to use the cement paste method, thus this method is not explored within this research project.

The four end preparation methods considered for this research can be broken down into two categories: unbonded and bonded. The unbonded caps fall under the unbonded category due to the cylinder being seated within steel rings with reusable neoprene pads. Grinding the cylinder ends is also considered an unbonded method since it utilizes a diamond-impregnated wheel which makes the cylinder ends plane to 0.0001 inches (Graybeal, 2015). The sulfur capping and gypsum capping fall under the bonded category since both materials, either a hot sulfur or gooey gypsum, is introduced to the cylinder ends in a liquid state and bonds to the cylinder for testing (ASTM International, 2015). Using unbonded caps tends to be the most popular method due to it being cost effective and time efficient, while grinding is fairly rare with the proper equipment costing hundreds of thousands of dollars. Even with the burn risk, using sulfur is preferred over gypsum bonded caps since the mix for gypsum can be easily used incorrectly. Each of these four methods are drastically unique, yet it is curious they all claim to yield similar strength results. The following pages will declare the formal research question the collected datasets will evaluate through hypotheses and various statistical testing, followed by a comprehensive literature review, and discussion of the research design followed by illustrations of the findings.

**Research Question and Hypotheses**

The single most important aspect of a research project is to have a properly written research question. Articulating a quantitative research question consists of being mindful of the affected population, considering the exposure variable in question, and determining the impact of the research outcome (Mitchell et al., 2020). A research question must be clear, concise, realistic, and have an actionable impact on its area of study. For this research project, the following research question is proposed: Does the end preparation of a concrete cylinder have an effect on its reported compressive strength? Given the nature of the variables within the datasets, this question will be partitioned by the following two concrete cylinder sizes: 4-inch diameter by 8-inch height (4x8) and 6-inch diameter by 12-inch height (6x12). This research question will also be applied to both the spring and fall datasets, as well as both datasets combined, given the datasets are found to be statistically similar.

Based off of the research question posed above, there are a number of hypothesis statements that can be made. Figure 1 below contains the list of hypothesis statements to be tested, to determine if there is statistical significance between the spring and fall sample datasets. The statements are broken down into the four different end preparation methods that were used on the concrete samples. The results of these hypotheses will be used in determining if the spring and fall sample datasets can be combined to assist in the evaluation of the research question.

Given the results of the hypotheses in Figure 1, the research question can be properly evaluated through the hypotheses in Figure 2.

**Figure 1**

*Hypotheses for Paired T-Test*

The Null Hypothesis Ho : There is no statistically significant difference between spring and fall samples using unbonded caps.

The Alternative Hypothesis HA: There is a statistically significant difference between spring and fall samples using unbonded caps.

The Null Hypothesis Ho : There is no statistically significant difference between spring and fall samples using sulfur capping.

The Alternative Hypothesis HA: There is a statistically significant difference between spring and fall samples using sulfur capping.

The Null Hypothesis Ho : There is no statistically significant difference between spring and fall samples using gypsum capping

The Alternative Hypothesis HA: There is a statistically significant difference between spring and fall samples using gypsum capping.

The Null Hypothesis Ho : There is no statistically significant difference between spring and fall samples using ground cylinder ends.

The Alternative Hypothesis HA: There is a statistically significant difference between spring and fall samples using ground cylinder ends.

The Null Hypothesis Ho : There is no statistically significant difference between spring and fall samples.

The Alternative Hypothesis HA: There is a statistically significant difference between spring and fall samples.

Note. Located above are the five sets of hypotheses between the spring and fall sample datasets in relation to the four end preparation methods in the datasets.

**Figure 2**

*Hypotheses for ANOVA Testing*

The Null Hypothesis Ho : There is no statistically significant difference in 4x8 concrete cylinder’s compressive strength using unbonded caps, sulfur capping, gypsum capping, or grinding cylinder ends.

The Alternative Hypothesis HA: There is a statistically significant difference in 4x8 concrete cylinder’s compressive strength when using unbonded caps, sulfur capping, gypsum capping, or grinding cylinder ends.

The Null Hypothesis Ho : There is no statistically significant difference in 6x12 concrete cylinder’s compressive strength using unbonded caps, sulfur capping, gypsum capping, or grinding cylinder ends.

The Alternative Hypothesis HA: There is a statistically significant difference in 6x12 concrete cylinder’s compressive strength when using unbonded caps, sulfur capping, gypsum capping, or grinding cylinder ends.

Note. Located above are the two sets of hypotheses in relation to answering the research question regarding if the end preparation has an effect on the concrete cylinder’s compressive strength.

Each of the two sets of hypothesis statements in Figure 2 will be tested within the spring dataset, the fall dataset, and given the results of the hypotheses in Figure 1, the spring and fall datasets combined. The null hypothesis represents the outcome there is no statistical significance between the mean compressive strength values of each end preparation method. The alternative hypothesis represents the outcome where at least one of the end preparation methods produced a statistically significant different compressive strength mean that the other methods.

**Literature Review**

**Concrete Mix Designs**

While concrete in its most simplistic form consists of cement, aggregate, and water, there are hundreds of variations of material proportions and admixtures that can be applied to affect the concrete’s overall compressive strength. Gesoǧlu et al. (2002) compared end preparation methods on cylinders and divided the concrete mix into three groups based on their water-to-cement ratio being 0.22, 0.26, or 0.31, where each concrete mix design estimated a high compressive strength between 10,000 psi and 15,000 psi. The different cylinder mix designs were evaluated for compressive strength using cement paste, sulfur capping, and unbonded caps, and the study found through an ANOVA test that there was no significant difference between the three end preparation methods (Gesoǧlu et al., 2002). To avoid research confusion, all concrete cylinders for the current project were produced using the same type, amount and ratios of materials. This maximizes the amount of observations available for analysis and ensures the materials variable remains a constant variable for analysis.

**Concrete Cylinder Sizes**

Another variation that can be evaluated in the world of concrete is the size of cylinder tested. The two most common cylinder sizes have a 4-inch diameter by 8-inch height (4x8) or 6-inch diameter by 12-inch diameter height (6x12). Yazıcı and İnan Sezer (2007) tested this exact variation through a regression analysis and found that 4x8 cylinders tend to produce higher compressive strength values. Their study used four different end preparation methods: uncapped, cement paste, gypsum capping, and sulfur capping and aggregated the results in their findings (Yazıcı & İnan Sezer, 2007). This study illustrates the importance in separating the compressive strength results of the cylinder by size, and the current research project will follow this separation as well. The 4x8 cylinders use less concrete material, yet produce higher compressive strength values, and this should not be overlooked.

**Unbonded Caps in Detail**

Unbonded caps consist of reusable and disposable neoprene pads placed inside a set of steel retaining rings that surround the ends of the concrete cylinder. Different types of neoprene pads can be inserted into the retaining rings to account for the design strength of the concrete. Trejo et al. (2003) took a deeper dive into this specification, and tested low-strength concrete for the five different neoprene pad options as well as gypsum and sulfur for comparison. Their results confirmed the type of pad used matters, and that sulfur provided higher compressive strength results to both gypsum and the unbonded caps (Trejo et al., 2003). This study also used over eight different concrete mix designs, and is another example of having too many dependent variables.

**Compressive Strength on a Large Scale**

The fourth study chosen for review uses data gathered over multiple years, to build a model to determine the strength of bridge structures throughout the state of California (Unanwa & Mahan, 2014). The dataset for this research project used over 3,000 observations, and while the study did include multiple concrete mix designs, Unanwa & Mahan (2014) gathered consistent data of only 6x12 cylinders, that were used and tested in a uniform manner. California has their own state accepted concrete test methods, which mirror the ASTM International test methods, but have slight differences such that their 2012 compressive strength standard, Caltrans 521, specifies to only use the sulfur capping end preparation method (State of California-Business and Transportation Agency, 2012). This was the most consistent study found, on such a large scale, that shared the most similarities with the dataset prepared for answering the current research question, comparing the end preparation method and a cylinder’s reported compressive strength.

**Research Design**

**Methodology**

The data gathered and selected for this research project is particularly unique in that the same concrete sample was distributed to all participating US laboratories twice, once in the spring and once in the fall of 2018. This primary data was also obtained through the requirement of answering the survey question to understand what type of end preparation the laboratory used in the testing of their concrete cylinders. According to O’Leary (2021), survey data gathers strong quantifiable data, but if not designed correctly, can be a challenge to clean and get healthy participation numbers. There were a small number of laboratories that did not answer the survey question, and those observations were disregarded for this research. A number of laboratories wrote in the “other” section, meaning significant data cleaning was needed; however, this was completed in a timely manner.

The two datasets are each made up of ten variables, including the response to the end preparation question, and each variable is either a character type, meaning the variable contains text, or a numerical type, meaning the variable is a numerical value. The variables that will be used in the analysis are either quantitative, a numerical compressive strength value, or categorical, the distinct end preparation used. Therefore, the data follows a quantitative framework and will be tested from a quantitative perspective.

The two datasets will be further partitioned by the size of concrete cylinder tested. The company distributing the concrete sample, gave the laboratories enough material so they could have the option for what size of concrete cylinders to make, 4x8 or 6x12, to test the concrete’s compressive strength. This ensures that in the data evaluated, everything will be a constant variable except for the end preparation, which is the variable in question. Therefore, the two datasets will be evaluated in the following six formats: spring 4x8 sample, spring 6x12 sample, fall 4x8 sample, fall 6x12 sample, 4x8 total sample, and 6x12 total sample.

**Methods**

The first step in the analyzation process of the two datasets, is to see if they are statistically similar through the SAS software. If the datasets are found to be statistically similar, meaning a failure to reject the null hypothesis, they can be combined into a single set for additional analysis purposes. To determine this conclusion, a paired t-test will be conducted on each set of hypotheses in Figure 1 above. A paired t-test compares the means of two similar datasets, commonly over a span of time, to determine if they are statistically similar (Yusop et al., 2015). Thus, each of the end preparations will have their own mean compressive strength value, and these means will be tested for significance, as well as the overall means.

The heart of answering the research question will be accomplished through running multiple analysis of variance (ANOVA) tests within the SAS software. ANOVA testing is used to compare the mean values between independent events through a single related variable (Erdogdu et al., 2020). Each of the four end preparation methods have a mean compressive strength value, for both the 4x8 and 6x12 cylinder sizes. These four means will be compared within the ANOVA testing to determine if they are statistically similar. The ANOVA test will be applied to the spring and fall dataset separately, and given the results of the paired t-test, potentially together as well. If the result of the analyses is to fail to reject the null hypothesis, then the end preparation method does not have an effect on the concrete’s compressive strength. If the result of the analyses is to reject the null hypothesis, then one or more end preparation methods produces statistically significant results, and further testing will be required.

**Limitations**

The data gathered for this research project is unique to other similar studies in that all of the data collected was from the exact same materials, amounts used, and standards followed; every single observation was treated the same so the only dependent variable would be the end preparation survey question. However, to get such a large pool of responses across the United States, the company gathering the data could not control who tested the concrete and the equipment they used. Every laboratory should be following the ASTM standards, meaning the technician should have the proper training and current certifications, and the equipment calibrated and maintained within the ASTM tolerances, but there was no way this could be verified. It is a possibility this could have created an interval of error within the compressive strength results.

**Ethical Considerations**

When working with any kind of dataset, the researcher has a moral obligation to practice good ethics throughout their project. Ethics such as ensuring the participants gave consent, are not harmed in any way, and keeping the data confidential and anonymous is essential (O’Leary, 2021). In the gathering of the two datasets used for this research project, all participants volunteered for their data to be aggregated. In the forming of the dataset, confidential information was gathered such as the laboratory name and location; however, for the purpose of this project this type of data has been filtered out of the analysis process. If particular data values need to be traced back to a laboratory, each laboratory has a unique laboratory ID that acts as a primary key for the company-secured database. This ID was also filtered out for the analysis purpose; thus, anonymity is guaranteed.

**Findings**

**Paired T-Tests**

To determine if the two datasets were statistically similar, five paired t-tests were performed to evaluate the five hypothesis statements that are located in Figure 1 above. Within SAS Studio, the first variable was set to the spring compressive strength results, and the second variable was set to the fall compressive strength results. This was intentional since the spring sample data was collected prior to the fall sample data collection. The paired t-test statistical results are located in Figure 3 below:

**Figure 3**

*Paired T-Test Statistical Results*

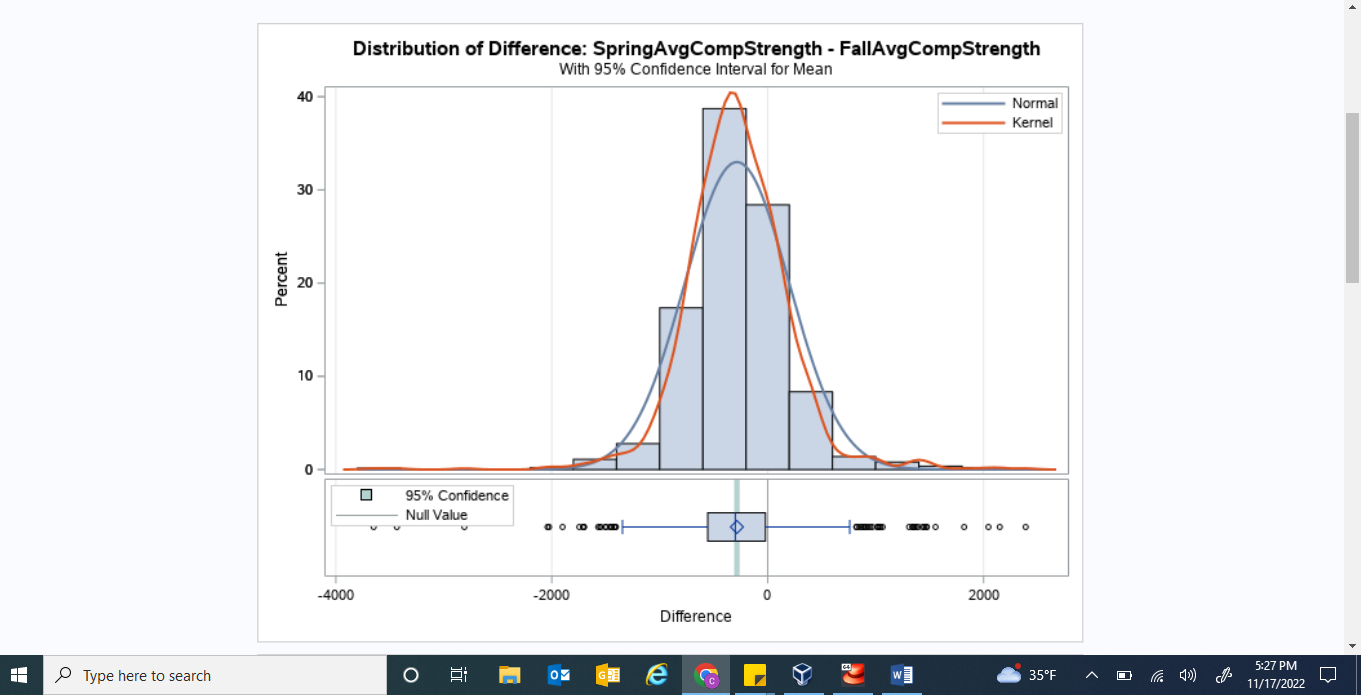
|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| End Preparation | N | Mean Difference | Standard Deviation | P-Value | Hypothesis Conclusion |
| Unbonded Caps | 1348 | 286.6 | 478.8 | < 0.0001 | Reject H0 |
| Sulfur Caps | 185 | 251.9 | 494.2 | < 0.0001 | Reject H0 |
| Gypsum Caps | 5 | 469.0 | 331.6 | 0.0341 | Reject H0 |
| Grinding | 58 | 208.6 | 508.8 | 0.0028 | Reject H0 |
| Spring/Fall Total | 1366 | 284.8 | 483.6 | < 0.0001 | Reject H0 |

Note. Located above are the five paired t-test outputs that correspond to the five hypothesis statements in Figure 1 above. The rightmost column displays the hypothesis statement outcome based off of the returned P-value result also contained in the above table.

Interpreting the results in Figure 3 above, surprisingly, all five paired t-tests returned a statistically significant P-value less than the threshold value of 0.05. This means that with each hypothesis statement in Figure 1 above, the null hypothesis can be rejected and the conclusion can be made that there is a statistically significant difference between the spring and fall samples. To ensure the validity of the hypothesis statement outcomes, the distribution of the samples was verified to have a normal distribution, as illustrated in Figure 4 below:

**Figure 4**

*Spring/Fall Total Graphical Display*



Note. Located above is the graphical output from performing the paired t-test on the spring and fall datasets, including all four end preparation methods. The histogram and boxplot follow a fairly normal distribution, with several outliers on both sides.

While the histogram and boxplot in Figure 4 above both show a significant number of outliers on either end of the distribution, the distribution follows a normal curve. Given the normal distribution, the paired t-test results were validated, and the conclusion was to not combine the spring and fall datasets for additional analysis purposes under ANOVA testing.

**ANOVA Testing**

Since all five conclusions from the paired t-tests above found a statistically significant difference between the spring and fall datasets, these two datasets were not combined for further ANOVA testing. Therefore, only four ANOVA tests were conducted, where the spring and fall datasets were evaluated separately, but still partitioned to account for the different cylinder sizes. In Figure 5, below are each of the four ANOVA tests completed, along with their descriptive statistics of each end preparation method.

**Figure 5**

*ANOVA Test Results*

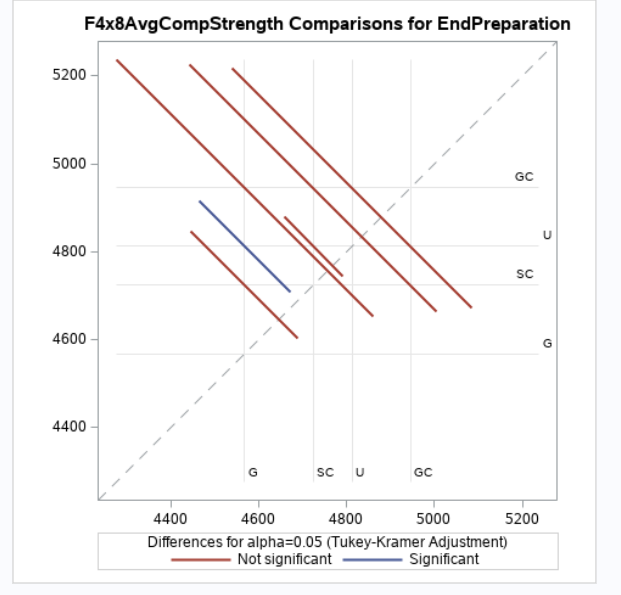
|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample | End Preparation Method | N | Mean | Standard Deviation | P-Value | Hypothesis Conclusion |
| Spring 4x8 | Grinding | 30 | 4470.83 | 259.7 | 0.7561 | Fail to Reject H0 |
| Gypsum | 1 | 4675.0 | - |
| Sulfur | 60 | 4479.6 | 330.9 |
| Unbonded | 1051 | 4512.6 | 340.3 |
| Spring 6x12 | Grinding | 3 | 4253.3 | 201.8 | 0.6065 | Fail to Reject H0 |
| Gypsum | 1 | 4095.0 | - |
| Sulfur | 44 | 4205.9 | 274.0 |
| Unbonded | 193 | 4148.5 | 286.6 |
| Fall 4x8 | Grinding | 21 | 4568.3 | 699.6 | 0.0072 | Reject H0 |
| Gypsum | 3 | 4945.0 | 295.1 |
| Sulfur | 53 | 4723.96 | 324.5 |
| Unbonded | 1043 | 4812.31 | 360.7 |
| Fall 6x12 | Grinding | 4 | 4417.5 | 137.5 | 0.9468 | Fail to Reject H0 |
| Gypsum | 1 | 4280.0 | - |
| Sulfur | 42 | 4452.4 | 301.4 |
| Unbonded | 199 | 4437.9 | 310.9 |

Note. Located above are the results for both the spring and fall datasets which were partitioned by cylinder size, 4x8 and 6x12. The ANOVA output also displays the number of observations per end preparation method, and their corresponding means and standard deviations. Finally, the returned results are within the P-value column and the rightmost column displays the hypothesis statement outcome.

In reference to Figure 5 above, three of the four ANOVA tests returned significantly high P-values. With the threshold p-value of 0.05, three of the four results resulted in a failure to reject the null hypothesis. This means that for the spring 4x8, spring 6x12, and fall 6x12 samples, there is no statistically significant difference in a concrete cylinder’s compressive strength using unbonded caps, sulfur capping, gypsum capping, or grinding cylinder ends. However, the fall 4x8 sample returned a statistically significant p-value of 0.0072, which results in a rejection of the null hypothesis, meaning there is a statistically significant difference in a concrete cylinder’s compressive strength in using at least one of the end preparation methods. The graphical output in Figure 6 below displays the findings specific to the fall 4x8 sample.

**Figure 6**

*Fall 4x8 End Preparation Comparison Graph*



Note. Located above is an output from the ANOVA testing on the fall 4x8 sample. The graph compares each of the four end preparation methods to each other, and the dotted diagonal line represents a 95% confidence interval for the difference between the two method’s means. The red lines crossing the dotted line mean the relationship is not significant, while the blue line not crossing the dotted line signifies a statistically significant relationship.

Interpreting the graphical results in Figure 6 above, there is a statistically significant relationship between the “G”, grinding, and “U”, unbonded, end preparation methods. It is important to note the vastly different sample sizes of the two end preparation methods; grinding had just 21 observations while unbonded capping was the most popular method with 1,043 observations. As the difference in sample sizes increases, the margin for error greatly increases as well (Fitts, 2010). With such a large difference in sample sizes, the statistically significant result that the unbonded caps produce a higher average compressive strength value compared to grinding the cylinder ends is cautiously noted. Therefore, even though the returned P-value of the fall 4x8 sample was statistically significant at 0.0072, the results are reported as a failure to reject the null hypothesis given the difference in sample sizes.

**Conclusion**

To recapitulate, this research project questioned the ASTM International concrete compressive strength standard that claims five cylinder end preparation methods all yield similar strength values (ASTM International, 2021). Two sets of data were gathered from concrete laboratories across the United States containing the end preparation method used and the compressive strength on a standardized concrete material. These datasets were evaluated through multiple paired t-tests and ANOVA tests. The findings conclude that each of the four end preparation methods considered in this project all yield statistically similar compressive strength values. Therefore, according to the research findings, the ASTM International concrete compressive strength standard is still a current and accurate standard for testing concrete in today’s society.

**Recommendations**

Next steps for future research include the possibility to send the standardized concrete materials to a smaller set of laboratories, based off of their historic results and reported end preparation method. Asking a smaller set of laboratories for their permission in the use of their data, a similar study could be conducted as the one above; however, the sample sizes would be equal to reduce bias in interpreting the results. The result may still be similar to the one discovered from this research project, but the additional research and equal sample sizes would increase the confidence that the ASTM International standard is still relevant.

At this time, it is recommended for ASTM International to continue the publication of their concrete compressive strength standard, with all five cylinder end preparation methods listed as viable options; however, further statistical testing is still advised. One of the four ANOVA tests reported a statistically significant strength difference between grinding the cylinder ends and using unbonded caps. Even if this is explored further and validated, cylinder end grinders are hundreds of thousands of dollars and not a piece of equipment every laboratory can afford. Using unbonded caps is by far the most popular method due to it being cost-effective, time efficient, and safer than the other four methods. The research outcome recommends that laboratories continue using whatever end preparation method works best for their laboratory situation, given that the compressive strength results were found to be statistically similar.

**References**

ASTM International. (2015). Standard Practice for Capping Cylindrical Concrete Specimens. *ASTM International.*

ASTM International. (2021). Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. *ASTM International.*

Erdogdu, Ş., Nayir, S., Kandil, U., Kurbetci, Ş., & Nas, M. (2020). Evaluation of the dependency of the compressive strength of concrete on the core drilling direction through Anova test. *Sigma: Journal of Engineering & Natural Sciences / Mühendislik ve Fen Bilimleri Dergisi*, *38*(4), 1879–1895.

Fitts, D. A. (2010). The variable-criteria sequential stopping rule: generality to unequal sample sizes, unequal variances, or to large ANOVAs. *Behavior Research Methods*, *42*(4), 918– 929. <https://doi.org/10.3758/BRM.42.4.918>.

Gesoǧlu, M., Güneyisi, E., & Özturan, T. (2002). Effects of end conditions on compressive strength and static elastic modulus of very high strength concrete. *Cement and Concrete Research*, *32*(10), 1545–1550. <https://doi.org/10.1016/S0008-8846(02)00826-8>.

Graybeal, B. (2015). Compression testing of ultra-high-performance concrete. *Advances in Civil Engineering Materials, 4*(2), 102–112. doi:10.1520/ACEM20140027.

Mitchell, R. D., O’Reilly, G. M., Phillips, G. A., Sale, T., & Roy, N. (2020). Developing a research question: A research primer for low- and middle-income countries. *African Journal of Emergency Medicine*, *10*(Supplement 2), S109–S114. <https://doi.org/10.1016/j.afjem.2020.05.004>.

O’Leary, Z. (2021). *The Essential Guide to Doing Your Research Project* (4th ed.). Sage.

State of California-Business and Transportation Agency. (2012). Method of Test for Compressive Strength of Molded Concrete Cylinders. *Department of Transportation – Division of Engineering Services.* [https://dot.ca.gov/-/media/dot- media/programs/engineering/documents/californiatestmethods-ctm/ctm-521-a11y.pdf](https://dot.ca.gov/-/media/dot-%09media/programs/engineering/documents/californiatestmethods-ctm/ctm-521-a11y.pdf).

Trejo, D., Folliard, K., & Du, L. (2003). Alternative cap materials for evaluating the compressive strength of controlled low-strength materials. *Journal of Materials in Civil Engineering*, *15*(5), 484–490. [https://doi.org/10.1061/(ASCE)0899- 1561(2003)15:5(484)](https://doi.org/10.1061/(ASCE)0899-%091561(2003)15:5(484)).

Unanwa, C., & Mahan, M. (2014). Statistical analysis of concrete compressive strengths for California highway bridges. *Journal of Performance of Constructed Facilities*, *28*(1), 157–167. <https://doi.org/10.1061/(ASCE)CF.1943-5509.0000404>.

Yazıcı, Ş., & İnan Sezer, G. (2007). The effect of cylindrical specimen size on the compressive strength of concrete. *Building and Environment*, *42*(6), 2417–2420. <https://doi.org/10.1016/j.buildenv.2006.06.014>.

Yusop, H., Yeng, F. F., Jumadi, A., Mahadi, S., Ali, M. N., & Johari, N. (2015). The effectiveness of excellence camp: a study on paired sample. *Procedia Economics and Finance*, *31*, 453–461. <https://doi.org/10.1016/S2212-5671(15)01174-0>.