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# LIGHTWEIGHT GROUT MIX DESIGN

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## ABSTRACT

The research presented herein intends to streamline the use of lightweight aggregate in masonry grout by developing a design standard for lightweight masonry grout. Lightweight concrete has been in use for decades—including in concrete masonry units—but lightweight aggregate has yet to be widely utilized in masonry grout. For example, the US masonry code does not include lightweight masonry grout in its provisions. The parameters explored in the experimental program include minimum grout compressive strength requirements, slump requirements, and aggregate proportions comparable to those of current normal weight grout standards. Relationships between these variables were analyzed to develop acceptable ranges for a tentative lightweight grout mix design standard. Preliminary findings showed that the aggregate proportion range for normal weight grout, when applied to lightweight grout, provided well over the required minimum grout compressive strength. Therefore, the range of aggregate proportion was increased, which resulted in compressive strengths closer to the minimum grout strength requirement. In addition, the slump range was slightly widened from that of the normal weight grout standard due to the absorptive nature of the lightweight aggregate. One of the main challenges of using lightweight aggregate is to achieve and maintain a saturated surface dry condition for the aggregate. Thus, carefully measuring, controlling and adjusting for moisture in the lightweight aggregates is critical and the most challenging part of the mix design process.

**KEYWORDS:** *grout, lightweight aggregate, lightweight grout, lightweight masonry, masonry*

## INTRODUCTION

Lightweight aggregate, including expanded shale and expanded clay, has been in standardized use since 1953, when ASTM C330 [1] was first approved, specifying a standard for Lightweight Aggregates for Structural Concrete. Lightweight aggregate has many benefits that have been

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proven extensively through its use in lightweight concrete especially in regards to lightweight concrete masonry units (CMUs) [2], but researchers have yet to explore uses for this technology in other fields, such as lightweight grout, for which there is no standard. It is hypothesized that the benefits of lightweight concrete can be applied to lightweight grout as well, but until a procedure is developed, this theory cannot be tested.

The objective of this research was to determine a repeatable procedure enabling industrial use of lightweight grout while keeping the required minimum grout compressive strength and allowing for adjustments or variance within a specified range of aggregate proportion, slump, and soaking time with predictable results. By establishing a lightweight grout mix design framework, this research laid groundwork for future research into the field of lightweight grout.

### *Background*

The most common type of lightweight aggregate is probably expanded clay, shale, or slate. These aggregates are manufactured by crushing raw material and heating the material to 1000 to 1200°C in a kiln. Small quantities of organic matter combust and rapidly form gas within the crushed materials, causing the pieces to bloat. The expansion is allowed through partial melting of the material and the resulting material is a low density, highly absorptive aggregate [3]. Lightweight aggregate can be approximately 20% lighter than normal weight aggregate, effectively reducing the overall weight of an entire structure [4].

Lightweight concrete has been used in structures and pavements for decades, becoming even more widely used in recent years. While the use of lightweight aggregate is common in CMUs, it is rarely used in masonry grout. This is likely due to research that shows lightweight aggregate to have a lower compressive strength and increased cost relative to normal weight aggregate [2,4]. There has been extensive research in the field of lightweight concrete, but research specifically targeting lightweight grout is sparse.

## LITERATURE REVIEW

The benefits of using lightweight aggregate could prove to be useful in a field like masonry. Lightweight aggregates are already being utilized in concrete masonry units, but grout can account for large volume of a structure, affecting the entire design. For example, since the thermal conductivity of air is significantly lower to that of concrete or grout, research has shown that lightweight aggregate can introduce air voids to reduce the thermal conductivity and increase fire resistance of the material [2,5,6]. There has also been investigation into the possibility of internal curing due to the high absorptiveness of lightweight aggregate. It has been proven that lightweight aggregate prewetting can increase the strength of concrete either through shrinkage cracking prevention or strengthening at the interfacial zone, somewhat compensating for the generally lower strength of lightweight aggregates relative to normal weight aggregates [7,8].

Lightweight aggregate can be more expensive to manufacture [9] but since it is a lighter option, cost of transport as well as cost of construction could decrease, especially if there is a manufacturing plant in the vicinity [2]. The overall cost of construction can also decrease since lighter structures will decrease the seismic weight, which will decrease reinforcement and element size. In addition, footings and foundations will be smaller, also cutting costs. These types of benefits have been proven many times over in lightweight concrete, and they could be easily applied to masonry.

## RESEARCH PROCEDURE

To investigate the effects of different variables on grout mix, a matrix of experiments was developed as a framework for the factorial statistical analysis to be performed. The main results include average maximum compressive strength and mode of failure.

### *Variables*

The grout mix design was simplified to lightweight aggregate, portland cement type I/II, and water, excluding any admixtures or pozzolans. The variables used in the experiment include aggregate-to-cement ratio, slump, and aggregate soaking time. Each variable range was determined by beginning with the normal weight grout standard [10] as a baseline and adjusting after preliminary tests were performed.

The lightweight aggregate used in this research was expanded shale—Utelite Crushed Fines—which is compliant with the fine aggregate gradation requirements of ASTM C330 [1], the standard used for lightweight concrete applications. The aggregate used had an absorption of 19% as determined by the absorption test as specified in ASTM C128 [10]. Not all types of lightweight aggregates have the same mechanical properties and this research may not be applicable to all types of lightweight aggregates.

The standard aggregate proportion for fine normal weight grout is from 2.25-3 times the volume of cement [11]. These values are extremely conservative—reaching normal weight grout compressive strengths with safety factors of approximately 3 using proportions at the top of the recommended range [4]. To analyze the region of grout strengths closer to the minimum grout strength of 2000 psi (13.8 MPa), the range used in this experiment was shifted.

Research shows that the use of lightweight aggregate results in weaker concrete [2,12], and therefore weaker grout as well, than the use of normal weight aggregate. However, preliminary tests performed to determine design ranges for this experiment showed that even the maximum recommended standard aggregate proportion, 3 parts aggregate to 1 part cement by volume, resulted in grout compressive strengths well above the minimum. To have a range of samples that approached the minimum required compressive strength of 2000 psi (13.8 MPa) [11], the range of aggregate proportions tested was adjusted from 2.25-3.00 to 3.00-4.75. The final aggregate proportion values used in this experiment were 3.00, 3.875, and 4.75 times the volume of cement. In the analyses, these proportions are referred to as, respectively, low, medium, and high aggregate proportions.

The range of slump required for normal weight grout is 8 to 11 in. (20 to 28 cm), high enough for the material to be poured into the concrete masonry unit cells [11]. Since grout slump is difficult to target, a margin of error of 0.5 inches was implemented. To span the normal weight grout slump requirements, the following three values were chosen: 8.25 in. (21 cm), 9.5 in. (24 cm) and 10.75 in. (27 cm). In the analyses, these slumps are referred to as, respectively, low, medium, and high slumps.

There has been research conducted on internal curing for lightweight aggregates [8,13,14], but this ideally requires the aggregate to be fully soaked. This process often including submersion, which is not feasible on an industrial scale, so a different soaking system was examined to be compared to samples with unsoaked aggregate. In lightweight concretes—especially in pavement applications—it has been proven that presoaking the lightweight aggregates can induce internal curing, which reduces concrete shrinkage cracking [8,13,14]. Shrinkage is a common problem with any cement-based mixture, such as grout, which is the basis for the hypothesis that some form of presoaking can benefit lightweight grout by preventing separation between masonry walls and grout caused by grout shrinkage which results from the high water absorption of concrete masonry units.

Shrinkage was not analyzed in this research, but aggregate prewetting was considered. Instead of soaking, an alternative procedure was designed to bring the aggregate to an approximately saturated surface dry (SSD) condition: a predetermined amount of water was added to the weighed aggregate and two cycles were applied to the aggregate. Each of the two cycles consisted of three minutes of mixing the water and aggregate followed by three minutes of stationary soaking in a concrete mixer, both cycles were included to enable the aggregate to evenly absorb enough water to approximate SSD condition. To examine the effects of soaking the lightweight aggregate, an alternate set of mixes were made with no soaking. In the analyses, these procedures are referred to as high and low soaking.

***Specimen Mixing***

During preliminary tests, it was determined that water was not absorbed fast enough by the aggregate during the mixing time allotted if the exact amount of water for 100% saturation was added into the mixer. Thus, for this experiment the amount of water in the mix design was calculated by doubling the amount of water required for full saturation.

The order in which the specimens were mixed was randomized to account for varying environmental conditions. For record-keeping purposes, they were each labeled with three letters signifying first aggregate proportion, then slump, then soaking method. For example, the sample with high aggregate proportion, medium slump, and no (low) soaking would be labeled “HML.”

For the actual mixing, tools were prewetted. The aggregate was added first to the concrete mixer and then the water—twice the water required to achieve 100% saturation—was added second. If the design specified soaking then the aforementioned soaking protocol was followed and if not, the concrete mixer was turned for a few seconds to distribute the water. The portland cement was then added incrementally and additional water was added as needed to achieve the target slump. A slump test was performed according to ASTM C143 [15] and the value was recorded.

Following the mixing, the grout was poured into a mold as specified by ASTM C1019 [16]. The specimens were removed after 24-48 hours, labelled, and placed in a fog room until the day of testing.

### *Specimen Testing*

The specimens were measured according to ASTM C1019 [16] and capped with gypsum according to ASTM C1552 [17]. Compressive strength tests were performed at 14 and 28 days and the strength results and the break types were recorded.

No compressive strength prediction equations have been established for grout, lightweight or otherwise, so a comparable equation for concrete was used. ACI Committee 209 [18] recommends the following relationship for moist-cured concrete made with type I portland cement:

$$f_{cmt} = \left[\frac{t}{a+bt}\right] f_{cm28} \quad (1)$$

where $t$ is the sample age in days, $a$ is 4.0 for Type I portland cement and moist-cured concrete, $b$ is 0.85 for Type 1 portland cement and moist-cured concrete, $f_{cm28}$ is the compressive strength of the sample at 28 days, and $f_{cmt}$ is the compressive strength of the sample at age $t$. At a sample age of 14 days, the ratio between $f_{cmt}$ and $f_{cm28}$ is 0.88 [18]. To compensate for the significantly higher water content of grout compared to concrete, this ratio was lowered to a back-calculated value of 0.85 as a prediction estimate for the grout compressive strength.

## RESULTS

The results compare the maximum compressive strengths and mode of failure to deduce if there are significant trends in any of the variables tested. The data was analyzed using JMP Pro 13 [19].

For this paper, six samples for each of the 18 mix designs were analyzed, resulting in a total of 108 specimens. The variables—aggregate proportion, slump, and soaking—were all used as categorical variables in the statistical analysis due to the nature of the testing matrix. The best model was accomplished by log transforming the compressive strength response variable and considering a three-way interaction between the three categorical explanatory variables.

### *Compressive Strengths*

All compressive strength results were above the required 2000 psi (13.8 MPa) minimum. The lowest average compressive strength in this experiment was 2475 psi (17.1 MPa) for the HHL mixture. Table 1 presents the average compressive strength results.

**Table 1: Average Grout Compressive Strengths, psi***

| Aggregate | High Soak | | | Low Soak | | |
|---|---|---|---|---|---|---|
| | Slump | | | | | |
| | High | Medium | Low | High | Medium | Low |
| High | 2978 (20.5) | 3012 (20.8) | 3475 (24.0) | 2475 (17.1) | 2743 (18.9) | 3308 (22.8) |
| Medium | 4301 (29.7) | 5182 (35.7) | 5701 (39.3) | 3871 (26.7) | 4707 (32.5) | 5252 (36.2) |
| Low | 6014 (41.5) | 6435 (44.4) | 7110 (49.0) | 6547 (45.1) | 6469 (44.6) | 6554 (45.2) |

*MPa values are given in parentheses.

The lowest average compressive strength from the lowest considered aggregate proportion, which is the higher aggregate proportion recommended by ASTM 476 [11], is 6014 psi (41.5 MPa). This compressive strength achieves the required minimum compressive strength for normal weight grout with a safety factor of 3.0.

***Inferences***

The order of testing was randomized, which allows for cause and effect inferences. Results from this study can be applied to all grout using portland cement Type I/II, Utelite Structural Fine (Crushed Fines) lightweight aggregate, and potable water.

***Model Development***

All explanatory variables were made categorical because the testing matrix was set up with three levels of aggregate proportion, three slump targets, and two methods of soaking. There is not enough continuity between the levels of each variable for them to be considered continuous.

The three-way interaction limits the number of quantifiable or graphical results, but this rich model was required to accommodate the interactions between all three variables. The residual plot of the resulting model showed that the response variable should be logarithmically transformed. Also, one sample had poor compaction and proved to be an outlier, so it was excluded.

***Trends***

Various models that included main effects, two-way interactions, and a three-way interaction were considered. The calculated p-values for most of the terms were less than or equal to 0.05 (or a significance level of 5%), which is the arbitrary threshold used herein to indicate the statistical significance of the results. The terms that were statistically significant were included in the final model as shown in Table 2. Although the two-way interaction between soaking and slump was not statistically significant—the p-value was 0.5831—it was included in the statistical analysis since the three-way interaction including these two variables was statistically significant.

**Table 2: Effect Test**

| Variable/Interaction | *p*-Value |
|---|---|
| Soaking Cycles | <0.0001 |
| Aggregate Proportion | <0.0001 |
| Slump Target | <0.0001 |
| Soaking Cycles*Aggregate Proportion | <0.0001 |
| Soaking Cycles*Slump Target | 0.5831 |
| Aggregate Proportion*Slump Target | <0.0001 |
| Aggregate Proportion*Slump Target*Soaking Cycles | <0.0001 |

The two-way interaction profiles are shown in Figure 1. In these plots, the log(strength) is in psi; the values 0, 2 for the soaking cycles indicate low and high soak, respectively; the values 3, 3.875, and 4.75 are the aggregate proportions in the mixtures; and the values 8.25, 9.5, and 10.75 are the slump targets for the mixtures.

Analyzing the two-way interactions can also be used to discern patterns. It was hypothesized that a lower aggregate proportion and a lower slump would both increase the compressive strength of the grout samples. The results indicate that the hypotheses are correct, but a much richer model—three-way interaction—is required to fully describe the interaction among the explanatory variables.

As shown in Figure 1, aggregate proportion had the largest while soaking had the smallest effect on the compressive strength. For example, the compressive strength difference between aggregate proportion levels is more than that between the three levels of slump and even more substantial than that of the two levels of soaking.

Figure 1 also shows that, as the aggregate proportion decreases, the compressive strength difference between slump levels decreases and the compressive strength values begin to converge. The observed tendency indicates that, with a lower aggregate proportion, the slump of a lightweight grout mixture has less of an effect on the compressive strength of the mixture. Similarly, as the aggregate proportion decreases, the effect of soaking on the compressive strength of the mixture decreases as well, with the two levels of soaking converging at the low aggregate proportion.

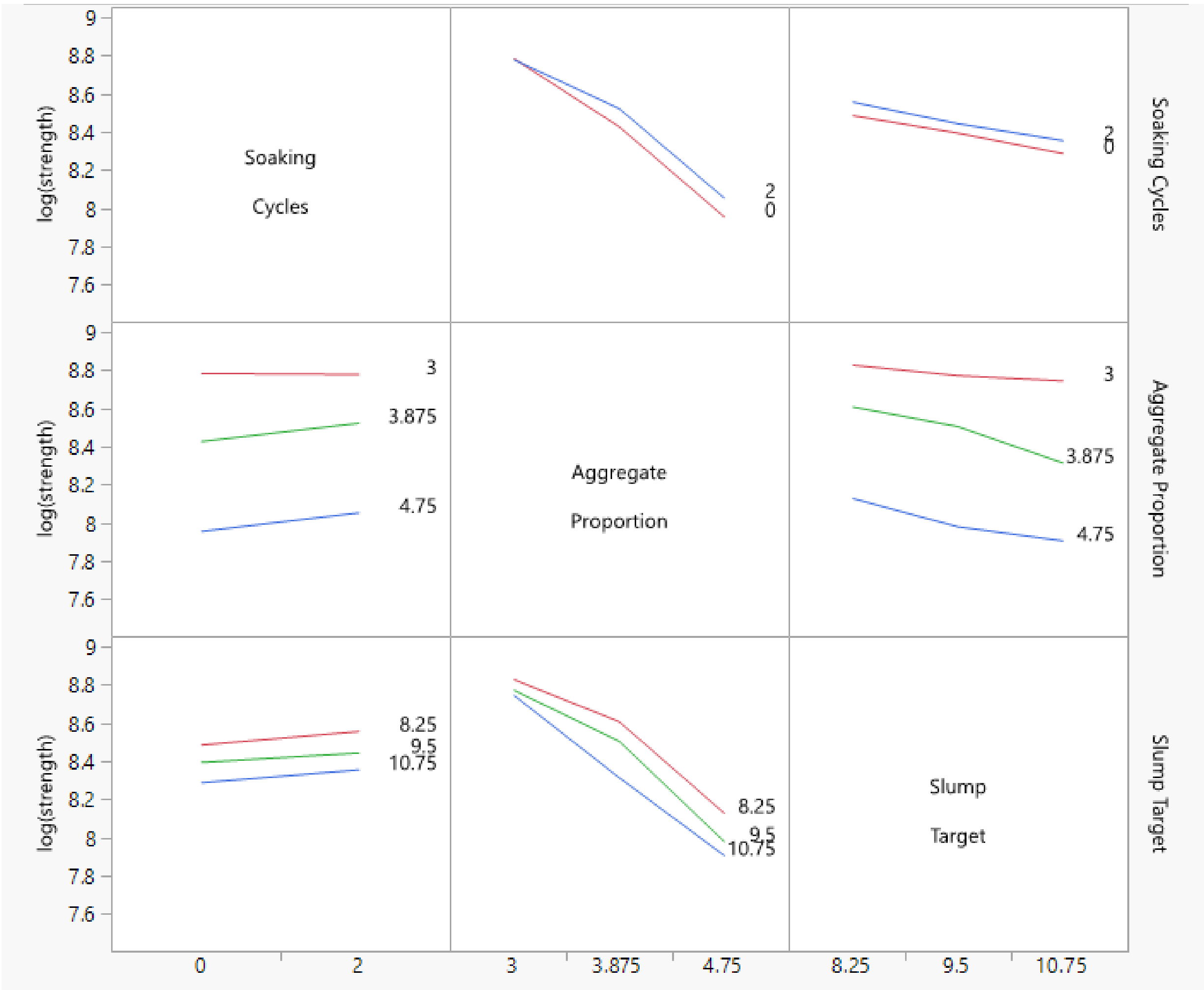


**Figure 1: Two-Way Interaction Profiles**

***Tukey-Kramer Results***

A Tukey-Kramer test was performed on the three-way interaction and the results are shown in Table 3. A Tukey–Kramer test is a single-step multiple comparison procedure and statistical test; it compares all possible pairs of means and the results indicate where there are significant differences between sample means. When two mixtures share a "letter," they are not statistically significantly different from each other. For example, mixtures LLH, LLL, LHL, and LMH share the letter A; thus, these mixtures are not significantly different from each other. According to the results, there is no evidence to show that there is a statistically significant difference in compressive strengths among the three slump levels at the lowest aggregate proportion. There are also very few instances where evidence shows there is a statistically significant difference between mean compressive strengths of an unsoaked sample and its soaked counterpart. The only instances soaking makes a significant difference are for the highest slump and the medium and high aggregate proportions. In regards to aggregate proportion, there is almost always a statistically significant difference between mean compressive strengths of samples with different aggregate proportions.

**Table 3: Tukey-Kramer Test**

| Mixture | | | | | | | | | | | | Log(Strength), psi (MPa) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| LLH | A | | | | | | | | | | | 8.866 (3.889) |
| LLL | A | B | | | | | | | | | | 8.787 (3.810) |
| LHL | A | B | | | | | | | | | | 8.786 (3.809) |
| LML | A | B | | | | | | | | | | 8.774 (3.797) |
| LMH | | B | | | | | | | | | | 8.767 (3.790) |
| LHH | | B | C | | | | | | | | | 8.700 (3.723) |
| MLH | | | C | D | | | | | | | | 8.648 (3.671) |
| MLL | | | | D | | | | | | | | 8.565 (3.588) |
| MMH | | | | D | E | | | | | | | 8.552 (3.575) |
| MML | | | | | E | F | | | | | | 8.456 (3.479) |
| MHH | | | | | | F | | | | | | 8.366 (3.389) |
| MHL | | | | | | | G | | | | | 8.261 (3.284) |
| HLH | | | | | | | | H | | | | 8.153 (3.176) |
| HLL | | | | | | | | H | I | | | 8.103 (3.126) |
| HMH | | | | | | | | | I | J | | 8.009 (3.032) |
| HHH | | | | | | | | | | J | | 7.998 (3.021) |
| HML | | | | | | | | | | J | | 7.950 (2.973) |
| HHL | | | | | | | | | | | K | 7.814 (2.837) |

## INTERPRETATION OF RESULTS

First and foremost, every compressive strength result from this experiment program was above the required 2000 psi (13.8 MPa). This demonstrates that lightweight grout indeed has a compressive strength comparable to that of normal weight grout.

All variables in question have a statistically significant effect on the compressive strength of a sample. However, statistical significance is not the same as practical significance. Two-way and three-way interaction analyses show that soaking has less of an effect on compressive strength when the aggregate proportion is lower. Since the lowest aggregate proportion of this experiment (3:1 ratio) is the highest proportion in the ASTM 476 suggested range [11], it is unlikely that the addition of soaking cycles will be of any use in regards to compressive strength improvement when using aggregate proportions within the advised range. There are other soaking options that could still be industrially feasible, but they were not explored in this experiment. Future research should investigate other soaking options.

The results of this analysis show that slump and aggregate proportion make a statistically significant—and likely practically important—difference in the grout compressive strength of the sample, which corroborates the fact that aggregate proportion and water content influence the compressive strength of a sample.

The results obtained herein are intended to provide a starting point for future research such as determining the tensile strength of lightweight grout, determining the development length of reinforcement embedded in lightweight grout, and standardizing a lightweight grout mixture design procedure. Future research intending to establish a lightweight grout mixture design as an ASTM standard would require a more thorough analysis of lightweight grout mixtures with aggregate proportions and slumps within ASTM recommended ranges, potentially even developing a predictive model.

## CONCLUSION

The purpose of this research was to determine a repeatable mixture design enabling the use of lightweight grout while obtaining the required minimum grout compressive strength. The results indicate that the standard for mixing normal-weight grout according to ASTM C476 is also adequate for mixing lightweight grout.

The most important conclusion of this research is that the compressive strength of lightweight aggregate more than reaches the minimum required strength of 2000 psi [13.8 MPa] when analyzing samples within the suggested aggregate proportion and slump ranges.

In this experiment, soaking the aggregate before mixing had a statistically significant effect on the compressive strength of a sample, but that effect was small and decreased as the aggregate proportion decreased. When used within the aggregate proportion and slump ranges suggested by ASTM, there is insufficient evidence to show that soaking will have a perceivable effect on the compressive strength of a sample. Further research is needed to confirm or refute the results obtained herein.

A model was developed using a three-way interaction between the following three categorical explanatory variables: aggregate proportion, slump, and soaking. The response variable was the logarithmically transformed compressive strength. The model was used to show that the main effects and interactions of all three variables have a statistically significant effect on the compressive strength of a lightweight grout mixture.

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