UMASS University of Massachusetts Lowell

Strength to Weight Ratio of Lightweight Concrete

CIVE.5050 Concrete Materials

Submitted by:
Victor Phou
Domenic Valeri
Geoffrey Scannell
Everlyn Galloway
Hla Wut Yee

Submitted to:
Dr.Tzuyang Yu, Ph.D.
Department of Civil & Environmental Engineering
University of Lowell Massachusetts

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I. Introduction

The experiment was designed to create a lightweight, high strength Portland cement concrete. Lightweight concretes are designed for non-structural uses such as insulation, decorative uses and sound reduction. A mixture of Portland cement, water, sand, and aggregate was formulated to produce a concrete cube with the highest ratio of compressive strength to density. Perlite, a volcanic glass containing mostly silicon dioxide and aluminum oxide that expands when heated, was used as the aggregate because of its low density. A final design specimen was chosen after samples using different ratios of cement, water, sand, and aggregate were made. The chosen specimen was cast in a cube. After casting, the sample was cured for 28 days. A compression test was performed, using an Instron testing machine as seen in figure 1, to determine the 28-day compressive strength of the concrete. Compression testing is done after 28 days because concrete strengthens with time and to provide comparisons between research standards. However, most of its final strength was developed within the first 28 days. The concrete specimens were cured in water for 14 days to prevent shrinkage caused by moisture loss that would compromise the compressive strength of the sample. The performance of the concrete, specific strength (p), is measured by the 28-day compressive strength (f_c') divided by the density of the concrete specimen (ρ).

$$p = f_c'/\rho$$

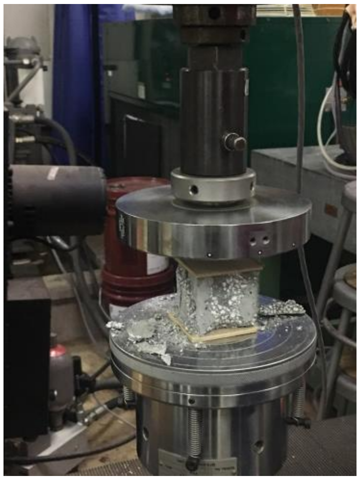

Figure 1: ASTM C109/C109M Testing

II. Experimental Approach

The items provided for the experiment were:

- Type II Portland cement
- Ottawa Sand
- Miracle Gro Perlite
- 2 in. x 2 in. x 2 in. casting mold as seen in Figure 2.

Figure 2: Casting mold

In order to find an optimal design, we casted four sets of specimens, using different combinations of water to cement ratios (w/c), sand to cement ratios (s/c) and aggregate to cement ratios (a/c). Originally, the second and third specimen sets were casted using 2.3 specific gravity of perlite, the mix proportions can be seen in Table 1. The first specimen tested used a w/c ratio of 0.9 to ensure there was enough water for the hydration process to take place. The second and third specimen tested both had a w/c ratio of 0.6 because we wanted to increase the compressive strength. However, the second specimen had a 1:1:1 ratio while the third specimen had a 1:0.5:1 ratio. Then an adjustment to the specific gravity of the perlite was made because it became obvious that the original value used was similar to coarse aggregate in typical concrete. The average density of the perlite is 105 kg/m^3, thus having a specific gravity of 0.105. Once the adjustment was made, a fourth specimen was casted with a 1:1:6 ratio and a w/c ratio of 0.4, as shown in Figure 3. This reduced the amount of perlite in the mix with intentions to increase the compressive strength. Table 2, shows the dates of casting the specimens as well as the day they were tested.

In determining the mix design, the w/c was chosen first then a volume ratio of cement, sand, and perlite. After calculating the volume of water, the volumes of each component were used to calculate a mix design by mass. An excess of 15% was made to account for loss while mixing or casting the concrete into the molds. As the concrete settled in the mold, constant hammering and shaking occurred to ensure small amounts of void within the specimen. The specimen was left in the mold for a day to harden. In Table 3, it can be seen that specimen two and three were cured in water for 14 days while specimen one and four were not cured in water. Curing in water provided strength to the specimen, as this method will help with the hydration process. All the concrete cubes were left exposed to the air in Falmouth 000 with varying temperatures due to the heat and cold air entering the lab. The specimen was then tested on the 28-day mark to obtain the 28-day compressive strength. Two out of the three cubes were tested, for each set of specimen via crushing, and the third cube was saved for observation.

Table 1: Mix Proportion

Specimen Set	Cement (lb)	Sand (lb)	Perlite (lb)	Water (lb)	w/c	Ratio	Specific Gravity of Perlite
1	0.39	0.07	0.55	0.35	0.9	5:1:20	0.105
2	0.56	0.47	0.41	0.34	0.6	1:1:1	2.3
3	0.62	0.26	0.45	0.38	0.6	1:0.5:1	2.3
4	0.34	0.28	0.07	0.14	0.4	1:1:6	0.105

Assumptions				
	Specific Gravity	Water Absorption		
Cement	3.15	-		
Sand	2.65	1%		
Perlite	0.105	0.00%		
Excess Total Volume for Waste = 15%				
Water Cement Ratio 0.4	**0.4**			
Volume Ratio (C:S:A = 1:2:3)				
Material	Volume (ft^3)	Weight (lb)	SSD (lb/ft^3)	wt/ft^3 (dry)
Cement	1	196.56	21.22678186	21.22678186
Sand	1	165.36	17.8574514	17.67887689
Perlite	6	39.312	4.245356371	4.245356371
Water	1.26	78.624	8.490712743	8.669287257
Total	9.26			
Total Specimen =	3			
Dimensions of specimen	W	H	T	
Volume of specimen (12"w* 12"h*4"t) =	2	2	2	
Total Volume of Specimen = (ft^3)	0.01388888889			
Total Volume with Excess (15%) = (ft^3)	0.01597222222			
Materials	Total Weight (lb)			
Cement	0.3390388769			
Sand	0.2823709503			
Perlite	0.06780777538			
Water	0.1384677826			
Total	0.8276853852			

Figure 3: Optimal Design Mix

III. Experimental Results and Analysis

As shown in Table 3, there was a wide range of compressive strengths for each specimen set. The optimal design, which was the fourth specimen, had the highest compressive strength of 2,686 psi compared to the previous specimen which had compressive strengths as low as 25 psi, seen in Figure 4. One of the reasons for the first three specimens to have such poor compressive strengths was because of the specific gravity of perlite that was originally used was incorrect. This resulted in an excessive amount of perlite in the design mixture, as seen in Table 1. Once the value was adjusted, the amount of perlite decreased making the specimen denser than the previous specimen as well as significantly stronger. This resulted in the optimal specific strength of 47,751 psi*in^3/lb. It seems that strength is the determining factor for a larger specific strength value. Specimen set one and three floated in water, specimen set two and four do not float in water.

Table 2: Specimens Prior to Casting

Specimen Name	Cast Date	Crush Date	Cast Time	Final Weight	Area (in^2)	Volume (in^3)	Density (lb/in^3)	Density (lb/ft^3)
1-1	10/23/2017	11/20/2017	5:30 PM	0.16	4	8	0.02	34.56
1-2	10/23/2017	11/20/2017	5:30 PM	0.16	4	8	0.02	34.56
2-1	10/19/2017	11/16/2017	3:30 PM	0.31	4	8	0.03875	66.96
2-2	10/19/2017	11/16/2017	3:30 PM	0.31	4	8	0.03875	66.96
3-1	10/19/2017	11/16/2017	4:30 PM	0.26	4	8	0.0325	56.16
3-2	10/19/2017	11/16/2017	4:30 PM	0.25	4	8	0.03125	54
4-1	10/30/2017	11/27/2017	4:30 PM	0.45	4	8	0.05625	97.2
4-2	10/30/2017	11/27/2017	4:30 PM	0.45	4	8	0.05625	97.2

Table 3: Test Results

Specimen Name	Force (lb)	Compressive Strength (psi)	P Ratio (fc'/ρ)	Comment	Cure Begin Date	Cure Time	Cure End Date
1-1	1,448	362	18,100	Did not cure in water, but used digital machine	N/A	N/A	N/A
1-2	1,071	268	13,400		N/A	N/A	N/A
2-1	1,500	375	9,677	Cure in water for 14 days, but used analog machine	10/19/2017	5:00pm	11/2/2018
2-2	1,000	250	6,452		10/19/2017	5:00pm	11/2/2018
3-1	200	50	1,538	Cure in water for 14 days, but used analog machine	10/19/2017	5:00pm	11/2/2018
3-2	100	25	800		10/19/2017	5:00pm	11/2/2018
4-1	10,745	2,686	47,751	Did not cure in water, but used digital machine	N/A	N/A	N/A
4-2	8,795	2,199	39,093		N/A	N/A	N/A

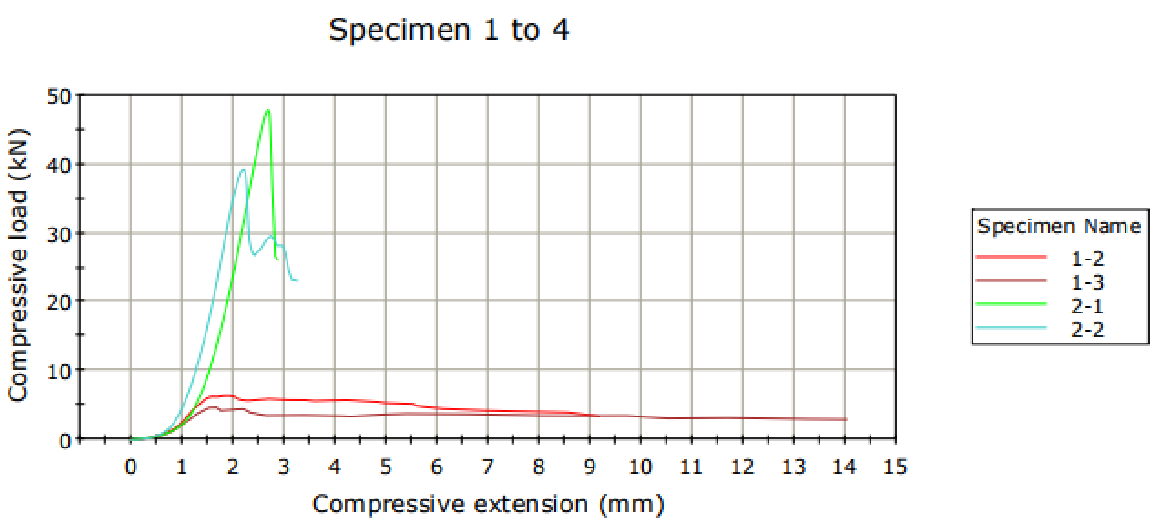

Figure 4: Load-Strain Graph (Specimen 1-2 & 1-3 refer to specimen 1-1 & 1-2 and specimen 2-1 & 2-2 refer to specimen 4-1 & 4-2)

IV. Discussion

The original specimen was designed using a specific gravity of Perlite of 2.3 which was much higher than the actual value. This resulted in a sample that contained too much perlite and too little cement. This specimen fell apart before it could be tested. Two more specimen were created using a different aggregate ratio but the compressive strength was still too low. The addition of perlite to the concrete design is not beneficial. As more perlite were added to the mix, the workability of the mix was less than mixing a normal concrete with a w/c of 0.35. Since perlite is a porous material, the porosity of the concrete specimen increased. This resulted in a lesser compressive strength in specimen set 1, 2, 3 than specimen set 4. The voids can also be seen in specimen set 1, 2, and 3. The uncertainty of the specific gravity of perlite affected our experimental result. There were a couple of switches due to the inconsistent value of expanded perlite from different sources. The specific value of 2.3 was also strange by having the same specific gravity as gravel.

Another problem occurred when two different testing machines were used. The analog compression machine was less accurate and less precise than the digital machine. The digital machine had a precision of five decimal places and made a load-strain graph. This reasoning shows why specimen set 1 has a higher or similar compressive strength to specimen set 2 and 3 even though specimen set 1 had more perlite in the mix proportion.

There are multiple decisions that would have eliminated any errors or given better results. An example would be when the cubes were taken out of the mold, some pieces of the cube specimen broke off. This proceeded in a lesser compressive strength and a lesser cross sectional area. The cubes cross sectional area were not truly $4in^2$, but the load was still divided by $4in^2$

which produced a lower compressive strength than it should have been. An improvement to that problem would have been to use a better quality mold that has the proper handles and screws. The mold used was missing some parts and a hammer was needed to demold the cubes. The excess energy from hammering the mold could have also weakened the concrete cubes. As stated earlier, the curing location of the specimen were not in the ideal spot. The temperatures had various ranges from hot air, to cold air entering the room from outside environment. Furthermore, the humidity and moisture content could not be controlled.

There still needs to be more testing on the performance of perlite to accurately evaluate the use of perlite in comparison to normal concrete. As a result, the data shows that the strength to weight ratio of normal concrete is greater than the strength to weight ratio of concrete containing perlite. An experiment was done at an earlier date where the average specific strength was 81,336 with a w/c of 0.40. The normal concrete only contained cement type II, Ottawa sand, and water. Furthermore, concrete cubes containing brick aggregates had a specific strength of 33,613. The mix proportion ratio was 1:2.21:2.92 with a w/c of 0.55. [**2].** Looking at another research where pumice was used instead of perlite or bricks as the coarse aggregate, the ratio of mix proportion was approximately 27,000. [**3].** Again, this is lower than using perlite, but the size of cubes matter. However, size and shape of specimen is not the main focus of the experiment.

There are various other parameters that can be study or perform experimentally and the following recommendations are provided. Perlite is falls under the category of low density concrete where its main purpose is insulation. **[4]**. Experiments to find the strength ratio of different lightweight aggregates can be performed such as using pumice, expanded slag, clay, fly ash, vermiculite, etc. Research in deterioration such as freeze thaw or carbonation of lightweight concrete with perlite. Another idea is to try different admixtures in concrete with perlite and obtain the 28-day compressive strength. The performance of the perlite concrete can be evaluated with various mix designs since only a small range of w/c, s/c, and a/c were tested earlier. Another recommendation is to find the internal properties such as thermal conductivity, porosity, dielectric properties, etc.

V. Conclusion

To conclude, we casted four specimens each set used different combinations of w/c ratios, s/c ratios and a/c ratios. The first three specimens were created with the larger specific gravity of perlite that we originally used and the fourth specimen was designed with the 0.105 specific gravity. The first and third specimen floated in water while the other specimens failed to float, however, the main focus of the experiment was to maximize the value of specific strength(p). Our fourth specimen had a density of 97.2 lb/ft^3. Typical concrete is 120 lb/ft^3, making our specimen about 20 lb/ft^3 less dense. The fourth specimen has highest specific strength (p) of 47,751 among all specimens. The recommendations mentioned earlier can also be studied to obtain further knowledge of perlite within concrete.

VI. References

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