The Post–application Determination of Cement:Aggregate Ratios in Swimming Pool and Spa Plaster

J. Que Hales
Pool Chlor

The ratio of cement to aggregate in swimming pool and spa plaster plays an important role in its subsequent strength, durability, texture and appearance. When attempting quality control of the finished product, however, it has been difficult to ascertain that ratio once the swimming pool or spa is already plastered. In an attempt to develop a method for post–application determination of the ratio, two common methods were examined. After applying various methods to known samples of various ratios, the Archimedes (density) method was found to be the most reliable and appropriate. Results of further "blind" testing of experimental samples were in good agreement with the baseline developed by the initial tests.

Because of its constant contact with water, swimming pool and spa plaster is mixed with cement:aggregate ratios which are *richer* (with greater proportionate amounts of cement) than cementitious products such as plaster/cement on buildings, driveways, statues, etc. Where ratios in other applications may range from 1:4 to 1:6, swimming pools are generally plastered with mix ratios of 1:1½ to 1:2. Previously published material (Technical Manual 1994, Cardall 1981a, Cardall 1981b) has shown that an improper (i.e.: *lean*) cement:aggregate mix ratio can contribute to a rough finish, spalling, increased susceptibility to chemical aggression and premature erosion from water solvency.

In order to develop a quality control method for determining actual mix ratios after the plaster has already been applied to the pool or spa shell, two methods have been evaluated, both of which are commonly used in the cement and ceramic industries. The tests were the "point–count" method and the "Archimedes" method. Eight samples of various cement:aggregate ratios were formed for evaluation. The samples were prepared on a weight basis, with cement to aggregate ratios of 1:1, 1:1¼ 1:1½, 1:1¾, 1:2, 1:2½, 1:3 and 1:4. The materials used were Pool Mix Swimming Pool Aggregate from Georgia Marble Company and Riverside White Cement from Riverside Cement Company. Five cores from each sample type were tested using the Archimedes method, and one of each sample type was mounted for photomicrography.

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The "Point–count" Method

The "point count" technique involves direct visual examination of cross sections for each cement:aggregate ratio. One sample of each ratio was examined. The samples were mounted in plastic and polished, using standard metallographic techniques. Scanning electron microscopy (SEM) was used to view the cross sections. Two photomicrographs were taken for each ratio (see Figures 1 for an example). The photomicrographs were then overlaid with a grid, and each grid section was visually inspected and "counted" as cement, aggregate, or a combination of each (see Figure 2). It was determined that a baseline could be developed using this method, but that the method has several drawbacks. The cost for SEM work is expensive, the method has a large potential for operator error, and the time for sample preparation is long. Most importantly, the method is not quantitative and is volume based rather than weight based.

The "Archimedes" Method

Archimedes was a Greek mathematician and inventor who lived 200 BCE. Many of his discoveries are of great practical value, and are still used by scientists in the present day. He is credited with the discovery of specific gravity as a result of the request, by King Hiero of Syracuse, Sicily to ascertain whether the royal crown was comprised of pure gold. While sitting in the bathtub

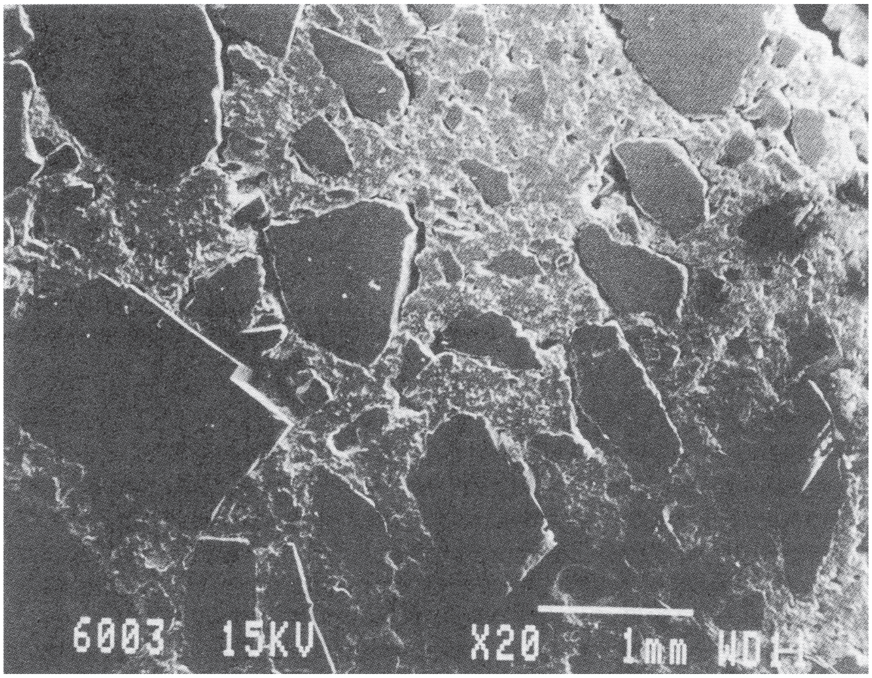

Figure 1 – 1:1½ Ratio Plaster at X20
The dark areas are the aggregate and the light areas are the cement

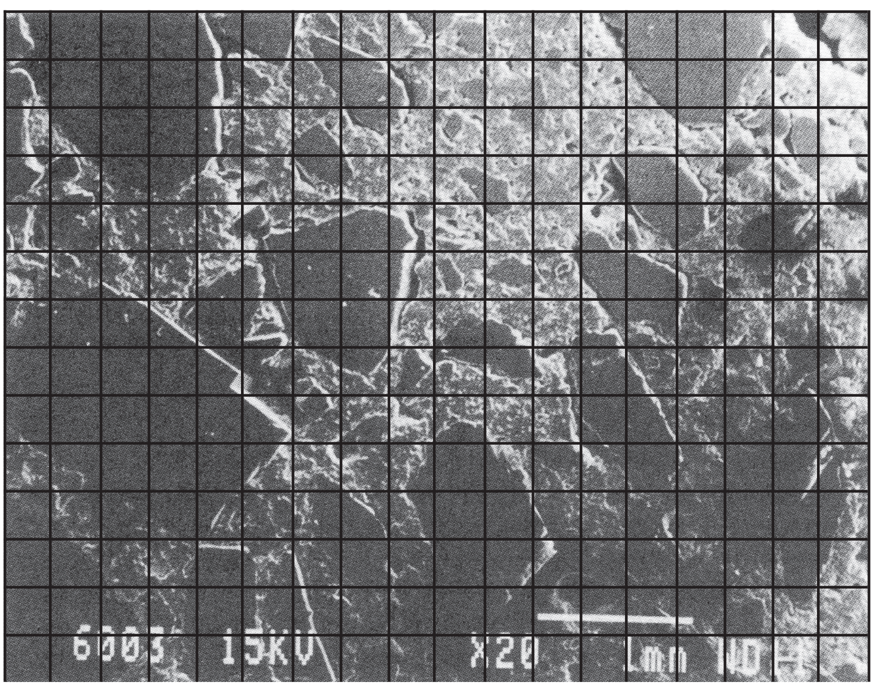

Figure 2 – 1:1½ Ratio Plaster at X20
The superimposed grid allows for visual counting of cement, aggregate, and combination grids

CONCRETE: AGGREGATEDENSITY (g/cc)	AVERAGE DEVIATION (g/cc)	STANDARD VARIATION (%)	COEFFICIENT OF
1:1	1.9419	0.0087	0.448
1:1.25	1.9536	0.0057	0.292
1:1.5	1.9669	0.0083	0.422
1:1.75	1.9936	0.0056	0.281
1:2	2.0057	0.0111	2.23
1:2.5	2.0263	0.0161	0.795
1:3	2.0723	0.0058	0.280
1:4	2.0699	0.0322	1.556

Table 1: Summary of the Density Data

one day Archimedes noted that his body displaced a certain amount of water. His musing while bathing led him to theorize that a crown of gold at a specific volume (water displacement) would weigh more than a crown of lead with an equivalent volume. A crown composed of an iron/gold alloy with an identical volume would have yet a different weight. He subsequently used the method to test the crown and found that it was not made of pure gold.

This method, which has come to be known as the Archimedes method, has been adapted to the measurement of porous cement and ceramics. It involves the determination of the density of each sample, and then the correlation of the measured density to the cement:aggregate ratio. The assumption is that the density of the components is not affected by the curing technique and therefore that samples follow the rule of mixtures. Four ASTM (American Society of Testing Materials) methods referencing the Archimedes method were reviewed, and one was adapted to the current project. These methods are C373–88 (Standard Test Method for Water Absorption, Bulk Density, Apparent Porosity, and Apparent Specific Gravity of Fired Whiteware Products), C905–85 (Standard Test Methods for Apparent Density of Chemical Resistant Mortars, Grouts, and Monolithic Surfacings), C948–81 (Standard Test Method for Dry and Wet Bulk Density, Water Absorption, and Apparent Porosity of Thin Sections of Glass–Fiber Reinforced Concrete), and D3800–79 (Standard Test Method for Density of High–Modulus Fibers). Method D3800–79 is of interest because it includes drawings of equipment used in the procedure. Method C373–88 was selected as the most appropriate and adaptable test protocol for the swimming pool and spa plaster tests.

In order to compensate for the porosity of the material, a three step process is used. First, the sample of the material is boiled in water for a period of five hours. This allows all accessible pores of the sample to be filled with water, and for loose pieces of the core sample to be separated from the main body prior to measurement. After cooling in the water, the sample is weighed in suspension. This weight is referred to as the *suspended mass* (S). Next, the sample is "patted" dry, and again weighed – this time without being suspended in water. This weight is referred to as the *saturated mass* (M). Finally, the sample is baked in an oven at 150ºC (302ºF) until all moisture is removed, and then it is allowed to cool in a desiccator. This last weight after cooling is referred to as the *dry mass* (D). Once these three weights are known, they are inserted into the following formula:

$$\text{Density} = \frac{D}{M - S}$$

The resultant value is referred to as the density in grams per cubic centimeter of the material.

Table 1 is a summary of the density data from the first sets of samples. The higher coefficients of variation for the 1:2 and 1:4 ratios are most likely due to entrapped air in the sample. The air was entrapped during the manufacturing of the sample.

Figure 3 is a graph of the density as a function of the cement:aggregate ratio. The raw data is listed in Table 2. Regression analysis was used to evaluate the data. The correlation coefficient (r^2) is 0.92. The equation for the regression line is:

$$Y = 0.0478X + 1.9021$$

where Y equals density and X equals the ratio of cement to aggregate. The deviation from linearity at the higher ratios was, as previously mentioned, likely due to porosity of the samples.

After the original testing was completed, a second set of tests were undertaken. Samples were prepared using the same materials, at ratios of 1:3 and 1:4. The samples were then sent to the lab without divulging the cement:aggregate ratios of the samples. The results from this blind check were comparable to the findings of the first set of tests, giving credence to the density method

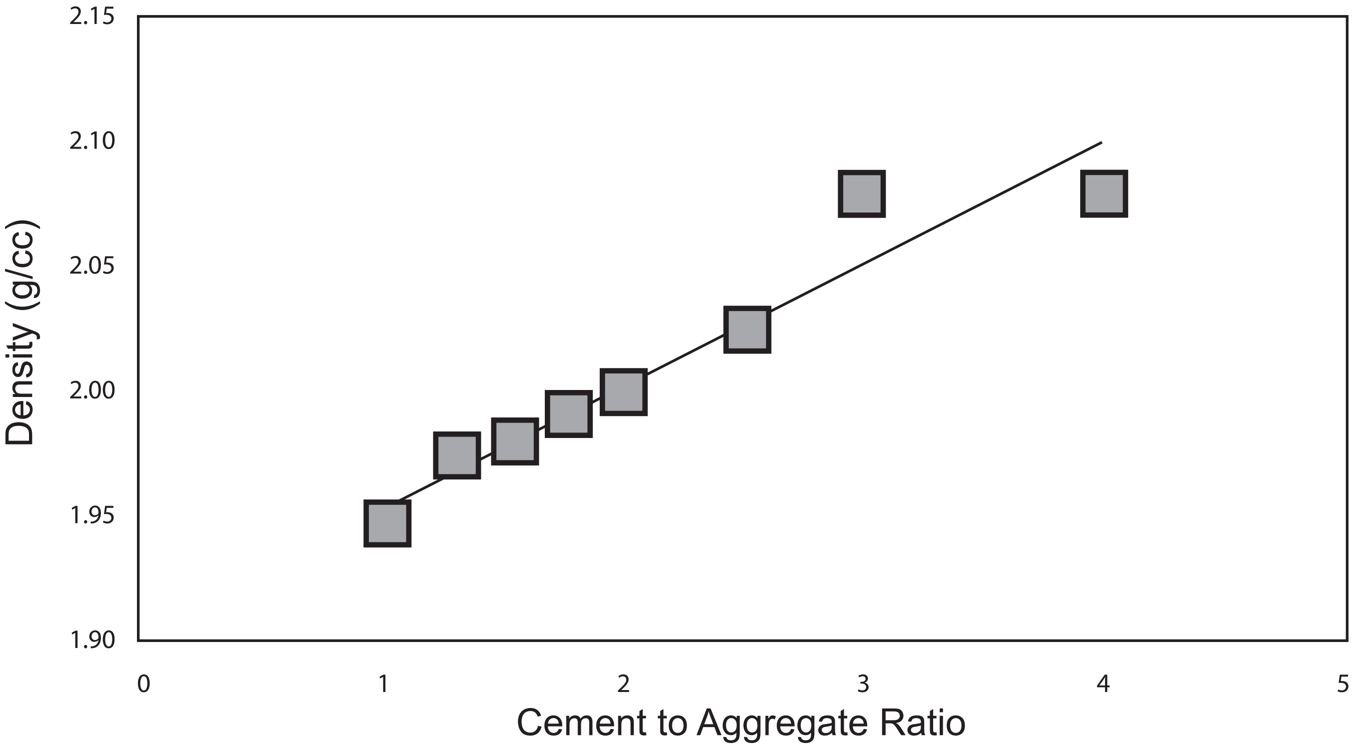

Figure 3 – Cement Density

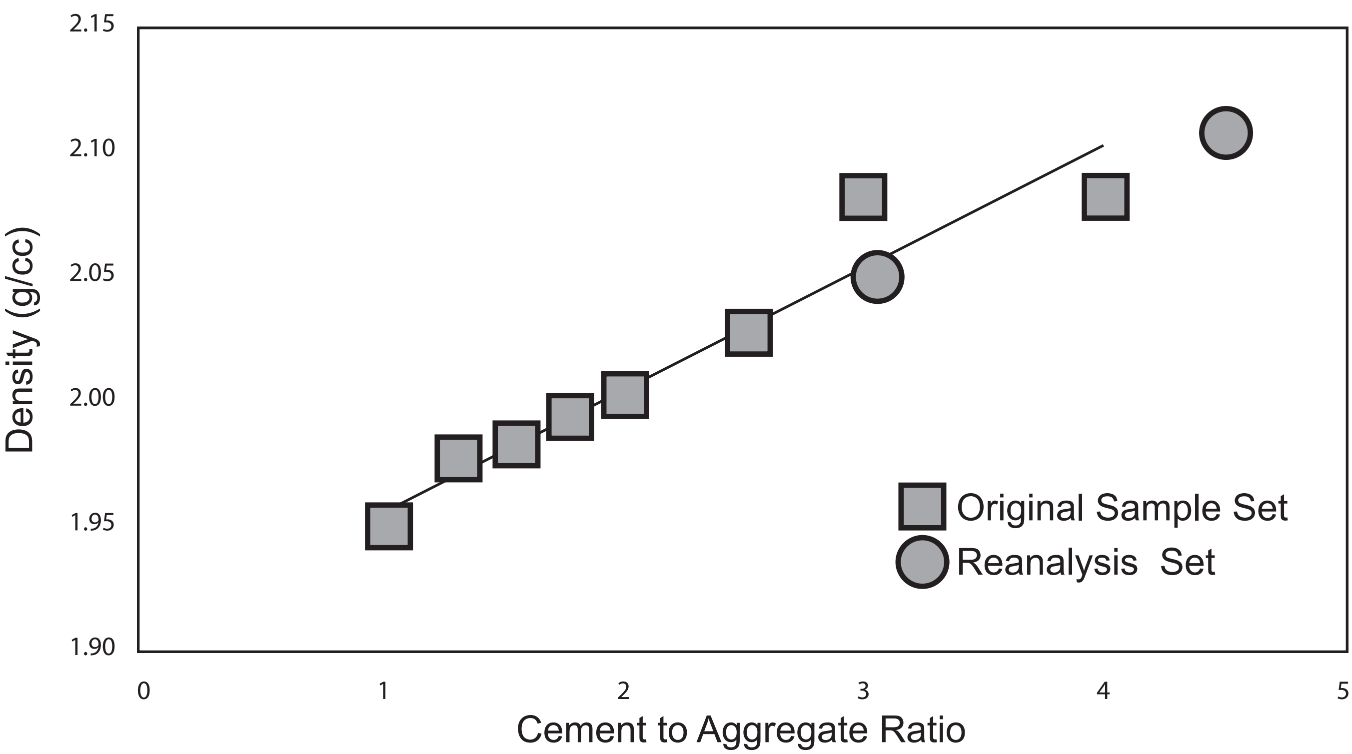

Figure 4 – Cement Density with additional samples

Aggregate Concentration	Sample Number	Suspended Weight (g)	Dry Weight (g)	Baked Weight (g)	Density (g/cc)	Average Density	Standard Deviation
1	1	2.8982	5.2976	4.6775	1.9494		
1	2	3.4953	6.3764	5.6136	1.9484		
1	3	3.6772	6.7553	5.9291	1.9262		
1	4	2.8797	5.2540	4.6219	1.9466		
1	5	3.2148	5.8766	5.1610	1.9389	1.9419	0.0087
1.25	6	3.3475	6.1021	5.3833	1.9543		
1.25	7	3.5080	6.3721	5.6169	1.9611		
1.25	8	3.7445	6.8270	6.0000	1.9465		
1.25	9	3.5308	6.4492	5.6841	1.9477		
1.25	10	3.4546	6.2778	5.5283	1.9582	1.9536	0.0057
1.5	11	4.0683	7.3756	6.4996	1.9652		
1.5	12	4.0254	7.3185	6.4502	1.9587		
1.5	13	3.6742	6.6744	5.8754	1.9583		
1.5	14	4.1445	7.4885	6.6204	1.9798		
1.5	15	4.7505	8.6102	7.6132	1.9725	1.9669	0.0083
1.75	16	3.4410	6.2308	5.5399	1.9858		
1.75	17	3.2605	5.8932	5.2439	1.9918		
1.75	18	3.4453	6.2110	5.5345	2.0011		
1.75	19	3.5353	6.4000	5.7031	1.9908		
1.75	20	3.5308	6.3472	5.6290	1.9987	1.9936	0.0056
2	21	3.8554	6.9505	6.1982	2.0026		
2	22	3.6638	6.5784	5.8635	2.0118		
2	23	3.6550	6.5566	5.8665	2.0218		
2	24	3.6306	6.5433	5.8380	2.0043		
2	25	3.5456	6.4173	5.7096	1.9882	2.0057	0.0111
2.5	26	3.5202	6.3150	5.6472	2.0206		
2.5	27	3.5235	6.3296	5.6553	2.0154		
2.5	28	3.3575	5.9966	5.4062	2.0485		
2.5	29	3.1687	5.7074	5.0917	2.0056		
2.5	30	3.4297	6.1440	5.5413	2.0415	2.0263	0.0161
3	31	5.3971	9.5520	8.6508	2.0821		
3	32	4.6296	8.2130	7.4362	2.0752		
3	33	4.3119	7.6596	6.9286	2.0697		
3	34	4.5219	8.0436	7.2738	2.0654		
3	35	4.6943	8.3391	7.5413	2.0691	2.0723	0.0058
4	36	4.3355	7.6243	6.9109	2.1013		
4	37	5.2277	9.3457	8.3466	2.0269		
4	38	5.1335	9.1550	8.1822	2.0346		
4	39	5.6143	9.8911	8.9548	2.0938		
4	40	4.9107	8.6503	7.8268	2.0930	2.0699	0.0322

Table 2 – Density Data: Original Sample Set

Sample Number	Suspended Weight (g)	Dry Weight (g)	Baked Weight (g)	Density (g/cc)	Average Density
1	11.1590	19.5515	17.8162	2.1229	
2	7.3515	12.8753	11.6887	2.1161	2.1195
3	15.5465	27.6540	24.8383	2.0515	
4	11.9889	21.3503	19.1531	2.0460	2.0487

Table 3 – Density Data: Reanalysis Set

as used in the tests. Data from this second set of samples is listed in Table 3. Figure 4 again shows the graph location of the data, this time including the second set of samples. Again, the locations on the graph are located by the slope formula Y = 0.0478X + 1.9021 where Y is the average density of the tested samples and X is the cement:aggregate ratio. The ratios of 1:3 and 1:4 were selected for retesting in order to examine the "scatter" at the higher cement:aggregate ratios, and also because "problem" plaster (i.e.: plaster that is deficient due to cement:aggregate ratio problems) may be concentrated in this area of the graph.

As a result of the testing that has been thus far undertaken, the density method appears to be an acceptable method for determining the weight ratio of cement to aggregate in swimming pool and spa plaster. The method appears most accurate in the ranges of 1:1 to 1:2½, with decreasing but still acceptable accuracy as the aggregate concentration increases above 2½.

Aggregate Density

Although the density of white portland cement is considered relatively constant at 3.15 g/cc, further investigation and comparative analysis must be done in the area of the relative density of various brands of aggregate. The type of Pool Mix used in this study is virtually the only aggregate used and available in Tucson, Arizona where the manufacture and testing of the samples occurred.

Conclusion

After further tests are conducted to validate this study, application for ASTM certification of the method may be pursued. This article is being published at this time in order to solicit industry comment at an early stage of the application process. Significant amounts of additional trials, as well as extensive documentation are necessary before a successful application may be made. Parties interested in independent duplication of the tests, interested in additional information on the process, or interested in making comments and suggestions are invited to contact the author via the Journal.

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About the Author

J. Que Hales has been the manager of the Tucson branch office of Pool Chlor for the past 11 years, and also runs their corporate MIS, publishing, and mailing operations. In addition to serving as the Chapter Vice–President of the Southern Arizona Chapter NSPI Board, he is also the National Vice–president of the National Association of Gas Chlorinators and the editor of the *Journal of the Swimming Pool and Spa Industry*.