Mortar Compressive Strength

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Mortar is specified by proportions or by properties. The proportion method is simply a mortar recipe or certain volumes of cementitious materials and aggregate combined with water that gives a workable mix. Experience shows that if a specified recipe is followed, mortar with certain performance characteristics is consistently obtained. Sampling, testing, or measurement of properties in the laboratory or in the field is not required of a proportion-specified mortar.

The property method of specifying mortar allows for construction flexibility but requires the mortar to have minimum average values of certain mechanical properties, including compressive strength. The values of the mortar's mechanical properties, to be compared with the minimum specified values, are determined through laboratory testing according to the requirement prescribed in ASTM C270, Standard Specification for Mortar for Unit Masonry. Once the minimum average values of the mechanical properties are obtained, the quantities of cementitious materials and aggregates used in the preparation of the laboratory mortar are converted to volumetric proportions for making the mortar at the construction site.

Compressive Strength

A property-specified mortar needs first to be developed in the laboratory, through a trial-and-error procedure, to determine a mix that meets the property specification of ASTM C270. Trial mixes must be made from the materials to be used at the construction site as specified in the project specifications and be prepared according to the strict specifications outlined in ASTM C270. One of these strict specifications is that water is added to obtain a flow of only 110 ± 5%. The amount of water to obtain such a flow is significantly smaller than that used in the preparation of the mortar at the construction site. Before construction begins, the mortar mix must go through preconstruction testing evaluation. For preconstruction testing, the mortar is mixed using the volumetric quantities of the materials to be used in construction and must have a consistency similar to that of the field mortar. To achieve such a field consistency, the amount of water added is significantly greater than that used during the laboratory trial-and-error procedure to develop a suitable mortar mix. During the preconstruction evaluation, the mortar is tested to establish baseline values for comparative evaluation of the field mortar. The values obtained during the mortar preconstruction evaluation shall not be compared to the values obtained during the development of the mix because, most importantly, during the mix development, the mortar is mixed to a drier consistency. During construction evaluation, mortar is tested to obtain values for comparison to the baseline values established during the preconstruction evaluation and to determine batch-to-batch mortar uniformity.

A property-specified mortar typically has three different values of average compressive strengths: one obtained during the trial-and-error development of the mix according to ASTM C270, one obtained during preconstruction evaluation, and one obtained during construction evaluation. The values obtained during preconstruction and construction evaluations are expected to be similar to each other but significantly lower than that obtained during the trial-and-error mix development.

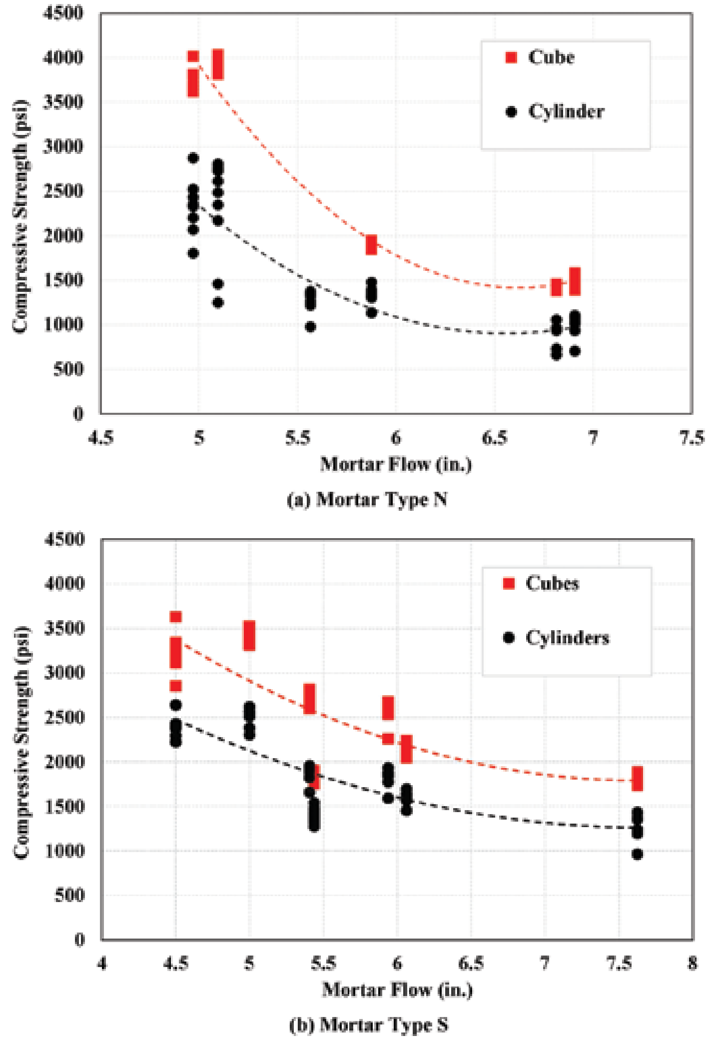

Figure 1. Cube vs. cylinder compressive strength.

Compressive strength testing of mortar specimens, such as that used during the trial-and-error development of the mix and preconstruction and construction evaluations, establishes one of the characteristics of hardened mortar. Field mortar compressive strength test values are not representative of the actual compressive strength of mortar in the masonry wall and are not appropriate for use in predicting the compressive strength that would be attained by the mortar in the masonry. The measured compressive strength of a molded mortar specimen is lower than that of the same mortar in the masonry, primarily due to differences in mortar water content and specimen shape. Mortar compressive strength is influenced by mortar water content at the time of set. Because molded mortar specimens are not in contact with absorptive masonry units and are not subjected to other mechanisms of water loss, they have a higher water content than mortar in the masonry. Higher water content results in lower compressive strength. Specimen size and shape also affect compressive

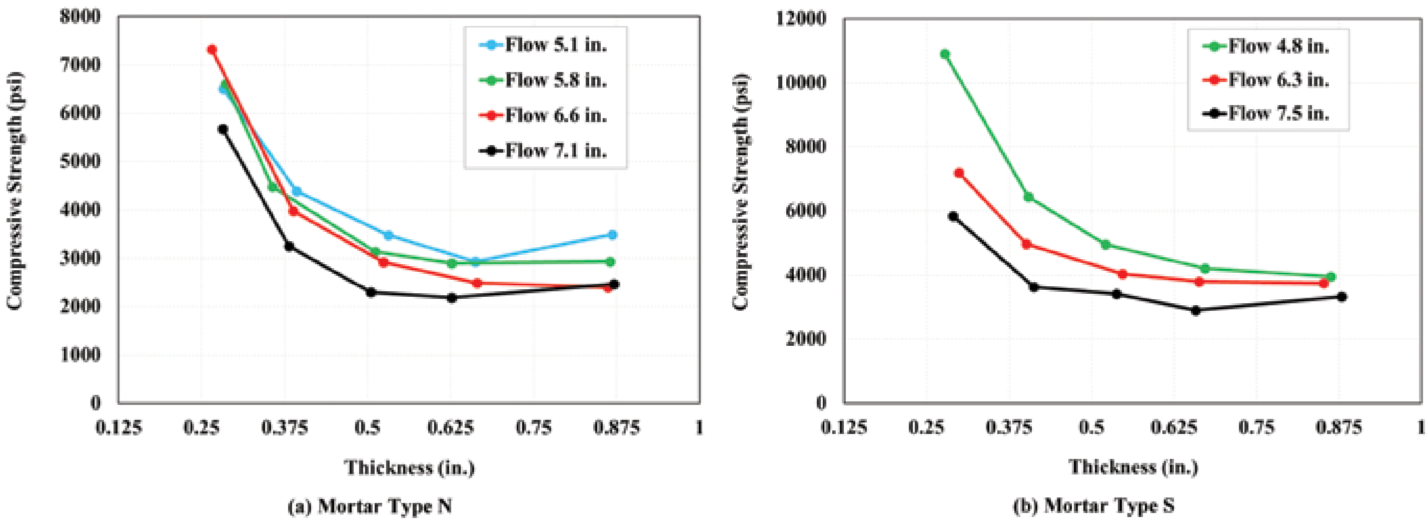

Figure 2. Double punch test results.

strength. Cylinders and cubes exhibit different strengths even when made from the same mortar mix, and the use of either specimen configurations yields lower strengths than what would be attained if a specimen having the same size and configuration of a typical mortar joint could be reliably tested. In addition, the mortar in a masonry joint is in a state of stress different from that of the cylinder or cube specimen tested for their unconfined compressive strength.

Previous Research

As described above, the measured compressive strength of a molded mortar specimen is lower than the strength of the same mortar in the masonry. Research has been conducted to try to determine the compressive strength of in-situ mortar. In most of the cases, however, research was done to determine the compressive strength of the mortar in existing historical structures, which typically were constructed with weak mortars with very low compressive strength. To the knowledge of the authors, no attempt has been made to determine a correlation between the compressive strengths of a laboratory mortar and an in-situ mortar because of the difficulties associated with obtaining undisturbed specimens from masonry and the lack of a standardized procedure for testing such specimens.

A Pilot Research Program

The objective of the research presented herein was to determine a correlation between the compressive strengths of mortar made from the same mix but using different specimen configurations. Several batches of mortars with different water content were mixed, and molded specimens of different configurations were made for compressive strength testing.

Materials

Both Type N and Type S mortar were used in this research. Pre-blended mortar mix was used to make all mortar to mitigate ingredient variability.

Water has an integral role in the compressive strength of mortar and is the sole determinant of fluidity. ASTM C1437, Standard Test Method for Flow of Hydraulic Cement Mortar, establishes a mortar flow test as the means of measuring the amount of water present in mortar paste. However, flow is seldom paired to a specific water content. In the field, masons add water until a desired workable consistency is achieved. Different preferences of mortar fluidity may even exist among different masons. Variable water contents were therefore used in this research to determine the degree to which the compressive strength of the mortar was affected.

Mixing Procedures

The mortar utilized was prepared using the procedures listed in ASTM C305, Standard Practice for Mechanical Mixing of Hydraulic Cement Pastes and Mortars of Plastic Consistency. This standard specifies the apparatus to be used for mixing the mortar, as well as the temperature and humidity, and provides a step-by-step procedure. The introduction of the material into the mixing bowl, however, was modified slightly to accommodate the use of bagged mortar mix instead of raw materials. After mixing the components of the mortar for the specified amount of time, a small mortar sample was used to perform a mortar flow test in accordance with ASTM C1437.

Specimen Shapes and Sizes

Standard 2-inch mortar cubes and 2- × 4-inch cylinder specimens were used for compressive strength testing. According to ASTM C780, Standard Test Method for Preconstruction and Construction Evaluation of Mortars for Plain and Reinforced Unit Masonry, when the compressive strengths from cube and cylinder test specimens from the same mix are compared, the cylinder compressive strength is approximately 85% of the cube compressive strength. The first phase of testing was organized to verify the compressive strength disparity between cube and cylinder specimens.

In addition, cured cubes were cut to thicknesses of approximately ¼, ⅜, ½, ⅝, and ⅞ inch. These mortar slices were also used for compressive strength testing. The thicknesses used in this research were selected to provide a wider range, even though bed mortar joint thickness is typically specified as ⅜ inch with an allowable tolerance of plus or minus ⅛ inch.

Compressive Strength of Cubes vs. Cylinders

Mortars with six water content variations were made and a minimum of seven specimens were cast from each mortar batch to compare the compressive strength of cubes and cylinders. The compressive strength of the specimens was obtained according to the requirement and methodology outlined in ASTM C109, Standard Test Methods for Compressive Strength of Hydraulic Cement Mortars. The results of the compressive strength testing of the cubes and cylinders are presented in *Figure 1 (page 7)*.

Table of compressive strengths and corresponding compressive strength increase.

Flow (in)	Compressive Strength (psi)		Strength Increase (%)	Flow (in)	Compressive Strength (psi)		Strength Increase (%)
	Type N Mortar Cube	⅜-inch-Thick Specimen			Type S Mortar Cube	⅜-inch-Thick Specimen	
5.1	3541	4731	34	4.8	3073	7481	143
5.8	2111	4316	104	6.3	2056	5539	169
6.6	1419	4337	206	7.5	1794	4310	141
7.1	1304	3408	161				

The results show small discrepancies as the expected compressive strength of the Type N mortar with 5.6-inch flow appears to be slightly lower, the compressive strength of the Type S mortar with 5-inch flow appears to be slightly higher, and the cube compressive strength of the Type S mortar with 5-inch flow appears to be slightly higher. In general, the results indicate that as the flow increases, attributable to water content increases, the compressive strength decreases. Average test results indicate that the cylinder compressive strength is approximately 73% and 65% of the cube compressive strength for Type S and Type N mortar, respectively. The smaller compressive strength of the cylinders was expected due to their higher slenderness ratio and the probability of a greater number of flaws and failure planes due to their greater size. Although the ratios are slightly smaller than that given in ASTM C780, the values are similar to that obtained by other researchers (Elwell and Fu 1995, Parsekian et al. 2014).

Compressive Strength of Thin Mortar Specimens

There is no ASTM standard to determine the compressive strength of mortar specimens extracted from a masonry assembly. The Double Punch Test (DPT), however, has been used to determine the compressive strength of thin mortar specimens. The DPT determines the compressive strength of thin mortar specimens by means of compressing the center area of the specimen with steel rods. The DPT allows for some simulation of mortar joint confinement. The DPT involves the use of two steel rods tapered at the ends to create a circular loading surface with a ¾-inch diameter. The rods or punches compress both sides of a layer of mortar.

Each type of mortar used three variations of water content, and two batches were made for each water content. In most cases, the two batches with the same water content yielded nearly identical mortar flows, and they were simply combined. However, in one instance, despite careful measurements, a batch of the Type N mortar did not produce similar flows, so they were kept separate. Several 2-inch mortar cubes were cast: some tested according to ASTM C109 and some sliced to thicknesses of approximately ¼, ⅜, ½, ⅝, and ⅞ inch for double punch testing.

Results of the Double Punch tests are shown in *Figure 2*. The results clearly show that the thickness of the specimen affects the compressive strength of the mortar and, for the results presented herein, the compressive strength increased with decreased thickness. There is a small increase in compressive strength from the ⅝-inch to the ⅞-inch specimens since the ⅞-inch specimens are thicker than the diameter of the puncher. Another general observation is that compressive strength increases with the decrease of mortar flow, or decreased water content. The small discrepancies observed for Type N are due to normal variations of mortar testing (Jessop and Langan 1979).

The *Table* shows the compressive strengths of the cubes that were tested for comparisons to the DPT results. Also presented are the approximate compressive strengths of a ⅜-inch-thick specimen for each mortar flow; these values were obtained from the interpolation of the values presented in *Figure 2*.

The *Table* also shows the percentage increase in compressive strengths for cube mortar specimens compared to a ⅜-inch specimen. For all cases, except for Type N mortar with a 5.1-inch flow, the compressive strength more than doubled when comparing cube strength to the typical mortar joint ⅜-inch-thick specimen strength.

These results have significant implications related to the compressive strength of mortar in a masonry assembly. During construction evaluation, the mortar is tested and a compressive strength value is determined. The obtained value should, however, not be used to make any judgment of the mortar compressive strength in the masonry assembly. If, however, the mortar compressive strength in the masonry assembly is erroneously compared to that of the mortar tested during construction evaluation, the research results presented herein confirm that the compressive strength of the standard mortar cube will be significantly lower than the compressive strength of the in-situ mortar. The reasons are (a) the cubes are thicker yielding lower compressive strengths; (b) the cubes are cured in non-absorbent molds having higher water content and therefore lower compressive strength; and (c) the cubes are tested under unconfined compression which results in lower compressive strength.

Conclusions

The following conclusions are made from the research presented:

1) Water content affects the compressive strength of mortar.
2) Specimen shape influences the compressive strength of mortar.
3) Specimen thickness influences the compressive strength of mortar.

The results presented show that a ⅜-inch in-situ mortar joint will have significantly greater compressive strength over a cube specimen made of the same mortar and tested according to prescribed ASTM standards.▪

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