SIMPLE MORTAR MIXTURE PROPORTIONING METHOD FOR MEETING MINIMUM AND MAXIMUM FLOW AND STRENGTH REQUIREMENTS

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ABSTRACT

The standard test for strand bond (STSB) test method has been developed to provide an assessment of the ability of steel prestressing strand to bond with cementitious materials. The test method is performed by pulling on a steel strand embedded in a 5 in. diameter steel can filled with mortar. The pullout strength is measured as the force at 0.1 in. displacement of the untensioned strand end. The test method currently requires the pullout test to be performed when the mortar has a compressive strength between 4500 and 5000 psi and between 22 and 26 hours after mixing. The mortar must also have a flow between 100 and 125 percent. It can be very difficult for laboratories to develop a mortar mixture that meets these stringent requirements with their local cement. This paper presents a simple methodology to develop mortar mixtures that meet these requirements.

Keywords: Mortar Proportioning, Flow, Strength

INTRODUCTION

Adequate bond between prestressing steel and concrete is needed so that the prestress force is transferred from the steel to the concrete in a reasonable distance that can be conservatively predicted. Previous research[1,2,3] has shown that this bond can vary significantly based on the constituents of the concrete. Other research on steel fiber bond in mortar showed that the bond increased with the sand-to-cement ratio[4].

In the past 40 years, strand pullout tests have been developed which can serve as a quality control method, to ensure a minimum inherent bond quality of the prestressing strands being supplied to precast concrete plants. The large-block pullout test (a modified form of the Moustafa test) has been successfully used as a method to determine the innate strand bond quality of different prestressing strands[5].

More recently, the North American Strand Producers funded the development of a smaller-scale, more controlled pullout test in mortar for the same purpose[3,6]. Because the bond can be significantly affected by the mixture constituents, it was believed that a pullout test in mortar would be more reproducible between different test sites (since it eliminates the coarse aggregate component).

The pullout test in mortar is now referred to as the Standard Test Method for the Bond of Prestressing Strands (STSB), and is currently being considered by ASTM for standardization. In this test method, a strand conforming to ASTM A 416[7] is placed at the center of a 5 in. diameter, 18 in long steel tube that is welded to a ¼ in. steel plate with a hole in the center for the strand to pass through. The steel tube thickness should be at least 0.119 in. thick. A 2 in. bondbreaker is placed around the strand right above the steel plate. The strand must pass through the hole in the steel plate and extend for at least 12 in. past the steel plate so that it can be gripped in a testing frame. The opposite end of the strand should extend 2 in. above the top of the steel cylinder to allow the free strand end displacement to be measured by a linear variable differential transformer (lvdt) or other displacement device. Fig. 1 shows an example specimen in a loading frame during testing. The tensile force on the strand is measured when the free end displacement is equal to 0.1 in.

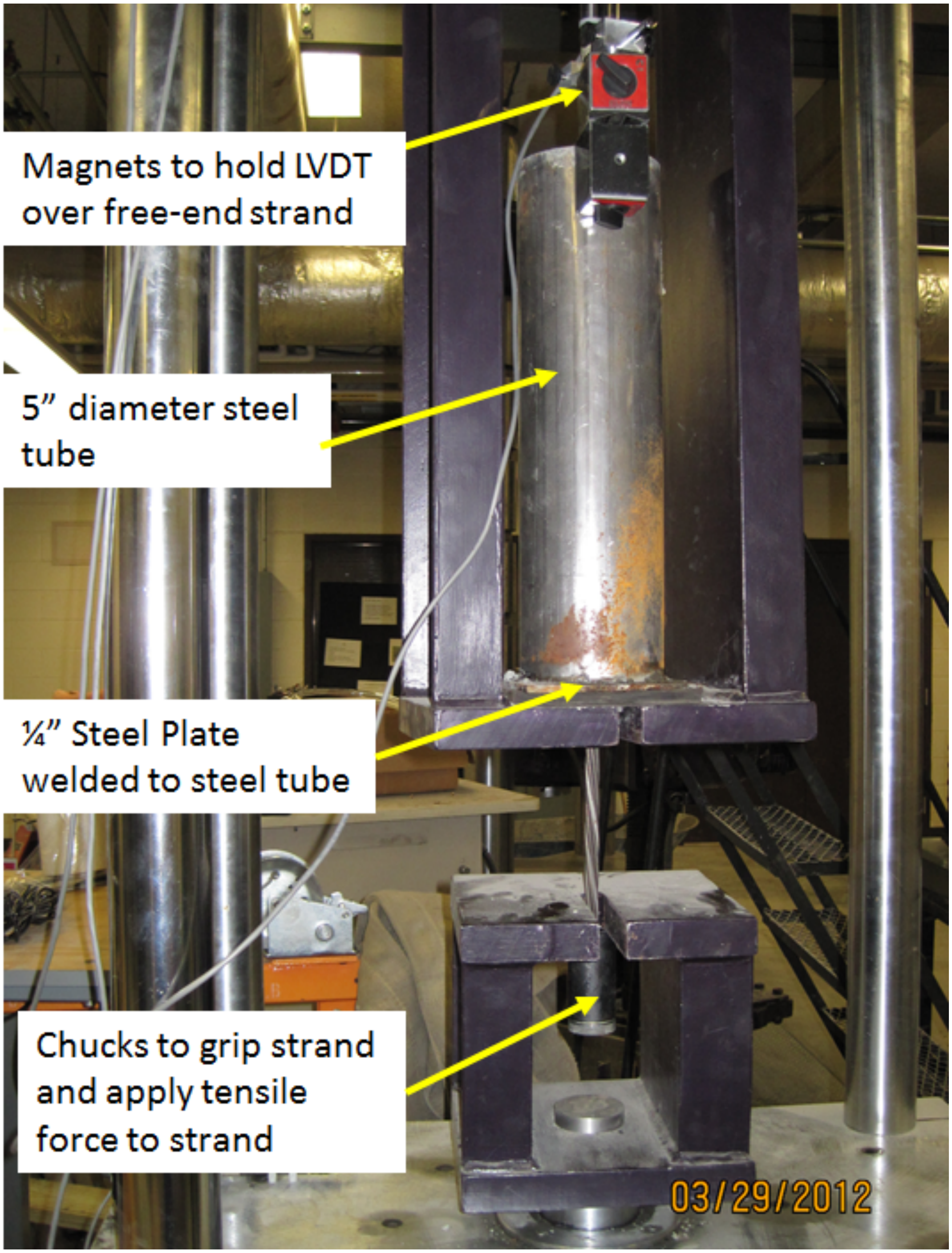

Fig. 1 - Specimen setup for Standard Test for Strand Bond

Strand testing is supposed to begin when the 2" mortar cube compressive strength is between 4500 and 5000 psi. Strand pullout testing must not begin until the mortar is 22 hours old, and cannot end later than 26 hours after mortar mixing. The mortar can use any natural ASTM C 33 sand and any ASTM C 150 Type III cement. Proportions should be adjusted to give a flow of between 100 and 125%. It can take many trial batches and iterations to proportion mortar mixtures for cements that can meet these specifications. Small variability in the materials used and test methods can also lead to a large number of tests rejected because the mixture gains strength too quickly or slowly. ASTM C 109 states that the acceptable range of test results for 2 in. mortar cubes at one day is 8.7%. The 500 psi acceptable strength testing window is 11.1% of the strength, or only 2.4% larger than the allowable test variability. This gives little margin of error for the mortar mixture made.

The developer of the test method used a water-to-cement ratio (w/c) of 0.45 and a sand-to-cement ratio (s/c) of 2.0 to meet the strength and flow requirements[8]. Different cements with different chemical compositions and fineness, the w/c and s/c needed to meet the strength and flow requirements can be quite different from the recommended values. Lacking guidance on how to adjust mortar proportions, trial and error is often used which can result in a large number of trial batches needed.

This study presents a simplified method for finding the mixture proportions for a given cement that will meet the strength and flow specifications for the STSB test method. This method can be applied to other mortar applications and used to proportion mortar mixtures for any flow and strength target desired.

MATERIALS

ASTM C 33 natural river sand obtained from Guthrie, OK was used in this study. The sand was sieved and recombined to give a standard gradation throughout the testing. Differences in sand gradation, angularity, and source would be expected to contribute to differences in the mortar strength and flow. The sand gradation used in this study was selected to be similar to the plant 6-month average gradation and is shown in Fig. 2.

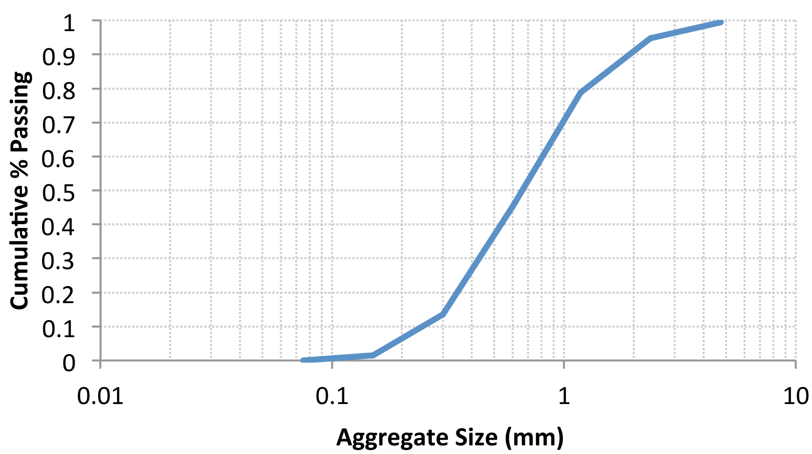

Fig. 2 - Sand Gradation

Five ASTM C 150 Type III cements were used in this study. The cement chemical and physical properties are given in Table 1.

Table 1 - Cement Chemical and Physical Properties

Cement	1	2	3	4	5
SiO2 (%)	21.8	21.0	19.6	18.9	20.4
Al2O3 (%)	4.3	4.4	5.1	5.3	3.9
Fe2O3 (%)	3.3	3.7	2.3	3.0	3.7
CaO (%)	63.3	63.4	62.3	62.8	63.4
MgO (%)	1.9	2.4	3.1	3.2	2.5
SO3 (%)	3.3	3.2	4.7	4.1	3.4
Na2Oeq (%)	0.	0.6	0.9	0.8	0.5
Blaine Fineness (m^2/kg)	577	660	522	577	536
Potential Composition					
C3S (%)	49	54	54	61	61
C2S (%)	25	19	16	8	12
C3A (%)	6	5	10	9	4
C4AF (%)	10	11	7	9	11

METHODOLOGY

A simple three step procedure was developed to obtain mortar mixture proportions for the STSB test method. First, because the mortar strength is primarily dependent on the w/c, two small mortar batches were made and tested for compressive strength at 24 hours according to ASTM C 109[9] at two different w/c. Three mortar cubes were made and tested at 24 hours after mixing commenced. The 24 hour compressive strength values were plotted against their corresponding w/c used. A linear fit was then made for the data. The w/c that would give a 24 hour compressive strength between 4500 and 5000 psi was found from the linear fit as shown in Fig. 3. Although the relationship between w/c and strength in general is known to be non-linear according to Abram's w/c ratio law[10], over small w/c it can be well approximated by a linear fit.

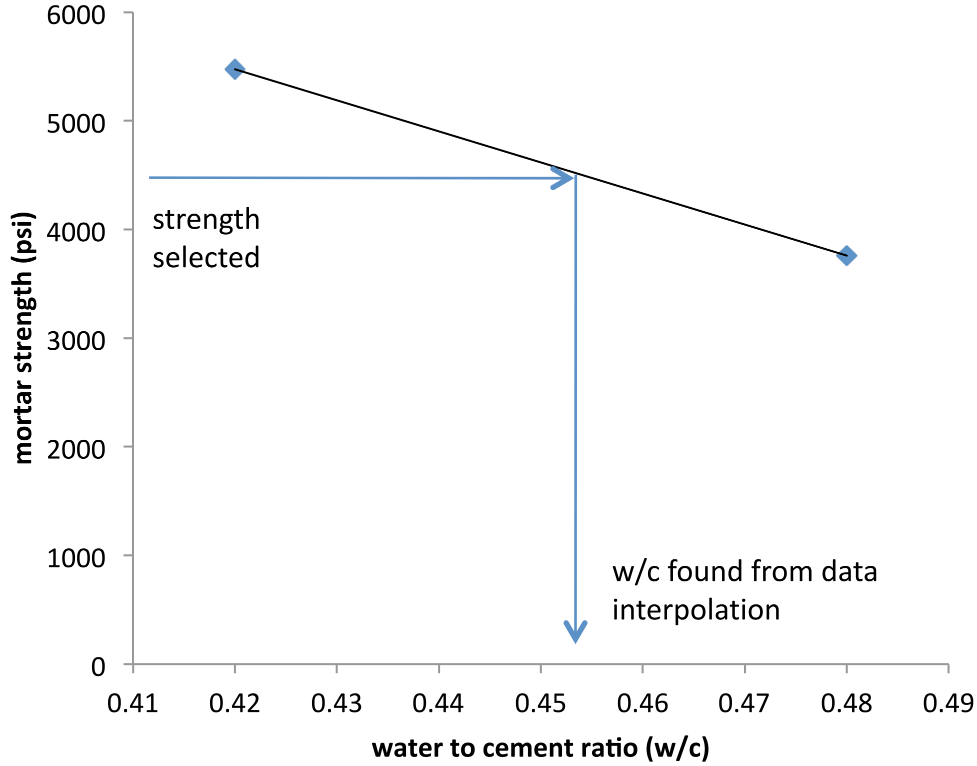

Fig. 3 - Strength interpolation procedure used to select w/c for Cement 1

After the w/c is selected, the s/c must be selected to achieve the required flow. Although the w/c and s/c both affect the flow, by first selecting the w/c for strength only the s/c can then be varied to meet flow requirements. Two small mortar batches were made according to ASTM 109 with the w/c previously selected and two different s/c ratios. The flow was then tested according to ASTM C 1437[11]. The s/c was plotted versus the measured flow values for the two mixtures. The desired mortar flow was selected and used to find the mortar s/c from the linear fit of the measured values as shown in Fig. 4.

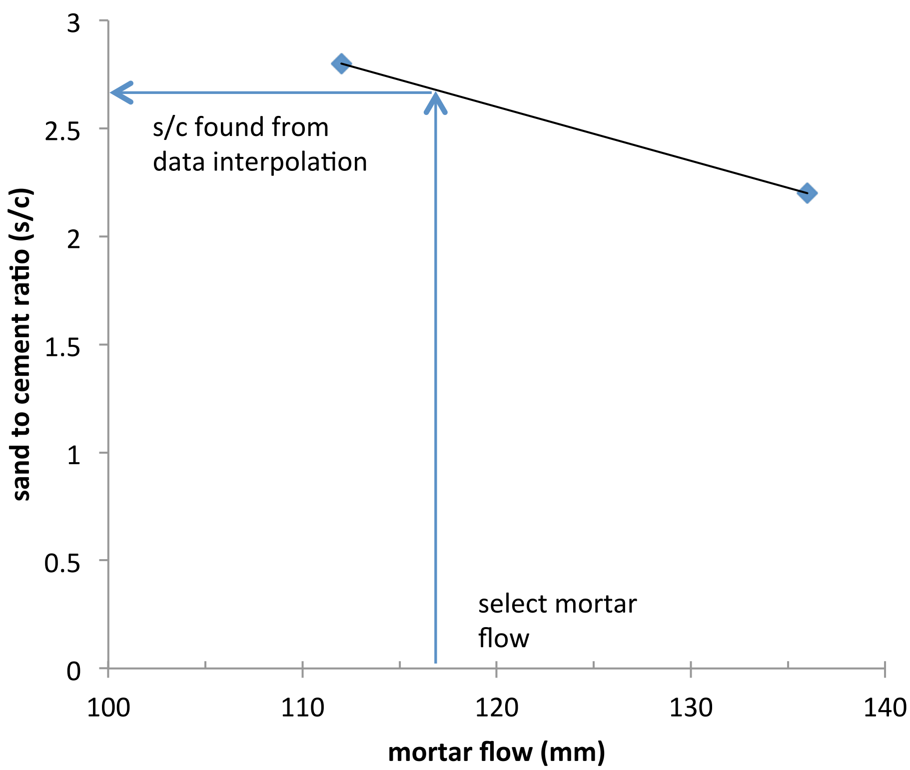

Fig. 4 – Interpolation procedure used to select s/c for Cement 1

After selecting the w/c and s/c, a large trial batch was needed to confirm that the mortar mixture proportions selected will also meet specifications. The mixing action achieved in a large batch may be different than that found in the small laboratory mortar mixer, giving slightly different flow and strength. For this study, a 12 ft^3 commercial grade mortar mixer was used to mix the larger trial batches. Material addition to the mixer, mixing times, and rest times used were as specified in ASTM C 192[12]. After adding the constituent materials to the mixer, the mortar was mixed for 3 minutes, followed by a 2 minute rest period, and finally mixed for 3 minutes. Mortar flow was measured immediately after mixing was stopped. 2 in. mortar cubes were made for compressive strength right after the flow test. Three mortar cubes were tested for each mortar mixture at 24 hours after mixing.

RESULTS / DISCUSSION

For the five cements tested, the mortar strength trial batch results, flow trial batch results, and large batch results are shown in Table 2. The measured compressive strength results for each cement matched up well with those predicted from linear interpolation/ extrapolation, with a maximum difference of 170 psi or 3.8%. This difference is lower than the 8.7% acceptable difference between two tests given by ASTM C 109 and is quite good considering the difference in mixing action and time between the large and small mixtures. It was found that small changes in the w/c when the s/c was held constant made only a minor change in the flow. For cement 2, mortar with s/c of 2.0 and w/c of 0.45 was found to have a flow of 112, whereas mortar with s/c of 2.0 and w/c of 0.5 had a flow of 117. This was important because if the large trial batch strength is slightly different than that predicted because of the difference in mixing action the w/c can be slightly adjusted without concern that it will significantly impact the flow.

Table 2 Mortar Strength and Flow Results

			Cement				
	Batch	Property	1	2	3	4	5
Strength Trial Batches	1	w/c	0.42	0.45	0.4	0.4	0.4
		s/c	2	2	2.5	2	2.5
		Compressive Strength	5480	5040	5590	6290	5120
	2	w/c	0.48	0.5	0.45	0.45	0.45
		s/c	2	2	2.5	2	2.5
		Compressive Strength	3760	4420	4500	5200	4160
Flow Trial Batches	3	w/c	0.455	0.48	0.45	0.475	0.45
		s/c	2.2	1.8	2.5	2.5	2.5
		Flow	136	128	117	128	114
	4	w/c	0.455	0.48	0.45	0.475	0.45
		s/c	2.8	2.5	2	2.8	2
		Flow	112	113	129	116	139
Large Trial Batch	5	w/c	0.455	0.47	0.45	0.475	0.425
		s/c	2.6	2.2	2.65	2.9	2.5
		Predicted Flow	120	119	113	112	114
		Measured Flow	116	120	116	124	109
		Predicted Strength @ 24hr	4470	4800	4500	4650	4640
		Measured Strength (psi)	4640	4870	4570	4600	4800

If the large trial batch has a strength or flow slightly different from that desired, small adjustments could be made. A trial batch that is slightly over strength at 24 hours could be expected to be corrected by a small increase in the w/c without changing the s/c ratio. A mixture with a high flow value would be expected to be corrected by raising the s/c ratio without changing the w/c. Any attempts to change the flow by adjusting the w/c instead of the s/c will likely lead to unwanted changes to the strength and will only slightly affect the flow.

For the five cements tested in this study, the s/c and w/c required to achieve the strength and flow requirements varied considerably. The w/c ratio varied from 0.425 to 0.475, whereas the s/c varied from 2.2 to 2.9. Based on the results found in this study, it is recommended to use a w/c of 0.42 and 0.48 and s/c of 2.6 for the first two trial batches. The sand used in this study was from a single source and was sieved and graded to ensure consistency batch to batch. ASTM C 33 states that the wide range of sand gradations allowed "are by necessity very wide in order to accommodate nationwide conditions.[13]" Although the mixture proportioning method developed in this study should work with different sands, the wide range of gradations allowed by ASTM C 33 could lead to an even larger difference in s/c ratios required to meet the flow requirements. It is possible that this larger difference in s/c ratios could lead to more variability in pullout strength results.

It has been observed during this study that strict adherence with the requirements of ASTM C 1437 are needed for reliable use of this method. During initial trial experiments, when the bronze table vertical shaft was not oiled evenly or oil was found on the mating frame the flow measurements were dramatically different. This lead to implementation of strict oiling procedures being followed before every test reported which resulted in consistent and repeatable flow results.

CONCLUSIONS

A simple method for determining mixture proportions required to meet the flow and strength requirements of the Standard Test for Strand Bond in just over 24 hours with 4 small mortar mixtures was presented. It was found that w/c required to meet strength at 24 hours could be determined from a linear interpolation/ extrapolation from two mortar mixture strength and w/c relationships even if the s/c was different than that ultimately used. It was also found that the s/c required to meet the standard flow requirements could be found using a linear interpolation from the flow and s/c from two mortar mixtures. Small differences in the w/c were also found to have only a minimal impact on the mortar flow at a given s/c.

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