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FULL-SCALE POST-TENSIONING GROUT OPTIMIZATION TESTING

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ABSTRACT

Grouting is a key element of the overall corrosion protection strategy for bonded tendons. Grout is often considered to be the last line of defense against the corrosion of the prestressing steel. A comprehensive grouting plan is essential to a successful grouting operation. Several components make up a good grouting plan: high quality materials, proper equipment, good procedures and trained personnel. It is important to test the grout plan under simulated site conditions to optimize the combination of each of these components for a smooth and successful grouting operation. Optimization process typically involves performing a series of tests under simulated site conditions to establish and fine tune the characteristics of the grout and the equipment that will be used during the grouting operations.

In the current study full scale optimization tests were conducted to evaluate the performance and compatibility of two colloidal mixers, a paddle mixer and a continuous flow mixer using five different grout products. Four of the grout mixes were pre-bagged proprietary grouts and one was site mixed grout using Portland Cement and admixtures. All of the tests were conducted in full scale field simulated conditions. A grout segregation test was used to evaluate the thoroughness of mixing for durations up to 10 minutes. Segregation and sedimentation were confirmed by measurement of the density of hardened grout at different heights and by observation of the grout color. Also, the Wick Induced Bleed Test, Schupack Pressure Test, Wet Density Test, Strength Test and Fluidity Test were performed to evaluate the various characteristics of the grout. In addition to the modified flow cone and standard flow cone tests, a fluidity test was also introduced to evaluate the fluidity of the grout mix. Based on the test results, an optimized mixing time was proposed for each combination of mixer and grout material.

KEYWORDS

bleed; colloidal mixer; flow cone; fluidity; grout; optimization; segregation

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1.0 INTRODUCTION

Grout is often treated as the last line of defense against the corrosion of prestressing steel in bonded post-tensioned concrete[1]. However a high-quality grout product alone cannot guarantee high-quality of grout in the tendon[2-4]. In addition, experienced, well-qualified and trained personnel together with optimized grouting equipment are critical to the success of the overall result. A series of tests were conducted to evaluate the performance and compatibility of two types of high speed mixers with five different grout materials. All of the tests were conducted on a full scale level with full batch sizes to simulate the job site conditions.

A grout segregation test was used to evaluate the thoroughness of the grout mixing for a period of up to 10 minutes. Segregation and sedimentation was confirmed by measurement of the density of hardened grout at different heights in a question note tall column and by observation of the variation of grout color[5-6]. The Wick Induced Bleed Tests, Schupack Pressure Tests, Wet Density Tests, Strength Tests and Fluidity Tests were also performed according to PTI specification[7]. The slump method was used in the fluidity test to evaluate the fluidity of grout[6] in addition to the modified flow cone and standard flow cone methods. It was concluded from the testing that colloidal mixers were more effective than paddle mixers in mixing homogeneous grouts. The colloidal mixers were also effective in controlling bleeding. They produced grout with higher strength as compared to paddle mixers when mixed for the same time[8]. It was noted in the tests that a certain grout mixer was very sensitive to water. There seemed to be a threshold at which the segregation suddenly became significant. Finally, an optimized mixing time was proposed for each mixer mixing with each individual grout product.

2.0 BACKGROUND ON GROUT MATERIAL AND EQUIPMENT

Much of the grout produced for bonded post-tensioned application since the 1960's simply consists of a mixture of Portland cement and water with perhaps some expansive and/or non bleed admixtures, mixed on site. This is commonly described as "common grout". In general, these common grouts appear to be perform satisfactorily.

However on some projects, especially in very aggressive environments such as marine and northern climates where chlorides or sulfates were encountered, the common grout has not always performed as expected[9-10].

Grout mixers are classified into two main types: paddle mixer with a speed of about 1000 rpm and high-speed mixers (high speed shear or colloidal mixer), with a minimum speed of about 1500 rpm[7]. VSL H-135 is classified as paddle mixers, while DTL Highshear 7/14 and ChemGrout CG 600 are examples of high-speed mixers. PTI currently allows both paddle as well as high speed shear mixers to be used. However, Florida DOT has specified only high speed shear mixers for projects in Florida based on the following advantages[11]: 1) it distributes the cement more uniformly, 2) it improves the bleeding characteristics, and 3) it minimizes cement lumps.

2.1 BACKGROUND ON TESTING METHODS AND SPECIFICATIONS

There were no rigorous specifications available for grouting prior to 2001. In February 2001 the Post-Tensioning institute released the *PTI Guide Specification for Grouting of Post-Tensioned Structures*[7]. The document introduced new test methods such as wick induced bleed test, modified flow cone test and the Schupack pressure test.

3.0 TESTING

3.1 GROUTING MATERIALS AND MIXERS

Five commonly used grouts were selected for the grout equipment optimization tests. Grouts 1, 2, 4 and 5 are pre-bagged grouts mixes. Grout 3 is a single source Portland cement with admixtures which has been optimally designed. The main properties of the five grouts are listed in Table 1.

In this study, 4 mixers were used:

- High Speed Mixer 1 -ChemGrout CG 600 – Air powered, 2000 RPM, Pumping 20 GPM at 261 psi
- High Speed Mixer 2 -DTL Highshear 7/14 – Diesel powered engine at 3000 RPM, pumping 31 GPM at 200 psi
- Paddle mixer: VSL H-135 – Gas Powered, 500 RPM, pumping 43 GPM at 120 psi
- Continuous flow mixer: Machine Technologies

Grout mixers utilized in this study are shown in Figs. 1 through 4.

Table 1 - Typical data for grouting materials as provided by the manufacturer

		Grout 1	Grout 2	Grout 3	Grout 4	Grout 5
Package (lb./bag)		50	50	30 admixture	50	55
Water (pints/bag)		11.5 – 13	12-13.6	31.6	16	13.6–17.28
Mud Balance		125 lbs / ft^3 2.00 g. / cm^3	NA	126.7 lbs. / ft^3 2.03 g. / cm^3	NA	NA
Flow Rate (second)		7-20 modified flow cone	9 –20 modified flow cone	21 – 30 standard flow per ASTM C 1107	28	20 – 25 ASTM C 939
Compressive Strength (psi)	1 day	3000	2200	2000	150	2000
	3 days	5000	4500		5400	4000
	7 days	7000	6500	5000	7200	5500
	28 days	8000	9500	8000	8300	8000
Setting Time (hrs)		3 – 12	8 – 10	3:45 to 5:15	3:45 to 5:15	Final set < 10
Schupack Pressure Bleed Test		0.0 % at 100 psi for 5 minutes	0.0 % at 100 psi for 5 minutes	0.2 % at 35 psi for 5 minutes	NA	< 2% at 30 psi for 10 minutes
Wick Induced Bleed		0.0 % at 4 hours	0.0 % at 3 hours	0.00%	NA	0.0 %
Chloride Permeability		Less than 2500 Coulombs	NA	Less than 1000 Coulombs	2163 Coulombs	2163 Coulombs
Recommended Mixing Time (minute)		3	NA	Less than 3 minutes	5 minutes	5 minutes
Shelf Life		9 months	1 year	1 year	1 year	6 months

Fig. 1 - High Speed Mixer 1

Fig. 2 - High Speed Mixer 2

Fig.3 - Paddle Mixer

Fig. 4 -Continuous Mixer

3.2 TESTING PROGRAM AND TESTING SET UP

For each combination of grout mix and mixer a full size batch of grout, 8 bags of pre-bagged Grout 1, 2, 4, and 5 and 3 bags of Portland cement for grout 3, was introduced to the mixer, which had mixing water pre-filled in. It normally took 3 – 5 minutes to have all dry ingredients to be completely introduced and then mixed for a minimum of 1 minute. At this time, strength tests, fluidity tests, bleed tests, and wet density tests were conducted to better understand the grout behavior. Temperature of the grout components, grout mix and ambient temperature were monitored and recorded periodically during the test program.

A new segregation test adopted from VSL International was introduced to check the segregation ratio R based on the following steps at each minute interval[5]:

1. Stop the mixer and take a grout sample at each minute interval.
2. Gently fill a 1 m transparent plastic pipe standing vertically.
3. Close the top of pipe to avoid water evaporation.
4. Mark the pipe with time when the grout was taken from the mixer, the initial level of grout, and other relevant data.
5. Start the mixer, and mix the grout for 1 additional minute
6. Repeat Step 1 through 4 ten times.
7. Visually inspect the undisturbed grout samples in the clear pipes until the grout hardens, record any bleed water accumulating at the top.
8. After the grout has fully hardened, carefully remove the hardened grout columns from the tubes if possible.

9. Gently cut the grout columns into 50mm long segments and label their location and relative positions in the samples.

10. Measure the volume and the weight of each segment and determine the density = weight / volume.

11. Record all density values and vertical location of the samples and present the results in a graph.

12. Calculate the grout segregation, R, as the ratio of density of the grout slice at the top, D_{top} to the density of the grout slice at the bottom of the pipe, D_{bot}: $R = 1 - (D_{top} / D_{bot})$

13. Experience has shown that well mixed homogeneous grout will have a maximum segregation of $R_{max} \leq 5\%$.

All testing procedures performed during the optimization test are listed in Table 2.

Grout cube specimens (2 in. x 2 in. x 2 in.) were prepared and tested in accordance with ASTM C 942[12], *Standard Test Method for Compressive Strength of Grouts for Preplaced-Aggregate Concrete in the Laboratory* for the strength test.

For non-thixotropic grouts, fluidity tests were performed in accordance with ASTM C 939[14], *Standard Test Method for Flow of Grout for Preplaced-Aggregate Concrete (Flow Cone Method)*. For this test, the cone is partially filled to a mark that represents 1.725 liters of grout.

For thixotropic grouts, a modified version of ASTM C 939 was used. In the modified version of ASTM C 939, the flow cone is filled to the top of the standard cones instead of the standard 1.725 liter mark. The efflux time of the grout is measured as the time to fill a one-liter container placed directly under the flow cone.

Table 2 - Test Requirements and Equipment Needed for Grouting Optimization

No.	Test Items	Code or Specification	Acceptance Criteria	Equipment and Materials
1	Grouting Strength Test	ASTM C 942[12]	7 Days Min. 3000 psi 28 Days Min. 5000 psi (Florida 7000 psi)	2" x 2"x2" Cubes (Test on 1, 3, 7, and 28 days)
2	Wick Induced Bleed Test	PTI [7]and Modified ASTM C940[13]	0.0 % Bleed at 3 hours (0.0 % Bleed at 4 hours for Florida)	1000 ml Graduated Cylinder, one 0.5 inch strand
3	Flow Cone Test	ASTM C 939[14]	Min. 11 Sec. (FDOT 20 Sec)[15] Max. 30 Sec. Max. 30 Sec., (30 Minutes after Mixing with Remixing for 30 Second)	Flow Cone, and Containers (fill 1.725 liter grout and check discharge time)
4	Modified Flow Cone Test	ASTM C 939	Min. 9 Sec. Max. 20 Sec Max. 30 Sec. After 30 Minutes	Flow Cone, and Containers (fill all way up in flow cone and discharge 1 liter)
5	Slump Method for Flow Cone Test	VSL International "Grouting Manual", 2000[6]	Measure the grout spreads	Stainless Steel Tube (Cylinder), Glass Plate
6	Mud Balance (Wet Density Test)	PTI[7]	NA	Mud Balance
7	Schupack Pressure Bleed Test (Gelman Filtration Funnel)	PTI[7]	0.0 % Bleed at Desired Pressure Level (FDOT 0.0% bleed for 5 minutes at 100 psi)[11]	Gelman Funnel and Air Pressure Supply
9	Sedimentation Test	VSL International, Report Series 5[5]	$R \leq 5\%$ (Detail see 3.2 Testing program)	1 Meter (40 in.) Tube, Holding for 24 hrs.

As an alternative to the modified flow cone test for thixotropic grout, a new slump method was introduced in this study[6]. The slump method consists of a stainless cylinder and a glass plate. Two different sizes of cylinders were used in the test: one was adopted from VSL International Grout Manual , which utilized ID of 39 mm and height of 50 mm –Type A, the other was 1-1/2-in. stainless pipe, schedule 89, with ID of 1.5 in. and height of 2 in. –Type B. Test results from these two different cylinders were almost identical. For the reason of simplicity of cylinder fabrication with readily available domestic material, Type B is recommended for the slump method.

The Full Scale Grout Optimization Test combinations conducted by VSL are listed in Table 3 over two-year period. All of the tests were conducted in full scale field simulated conditions or on the real job site.

Table 3 - List of Grout Equipment Optimization Test

Test Date	Grout Material	Grout Mixer	Mixing Water (gallons/8 bags)	Total Mixing Time (minutes)
12/12/2002	Grout 1	High Speed 1 High Speed 2 Paddle Mixer	12 11.875 12.75	7 7 7
12/16/2002	Grout 2	High Speed 1 High Speed 2 Paddle Mixer	13.56 13.6 14.22	6 6 6
12/20/2002	Grout 3 (3 Bags)	High Speed 1 High Speed 2 Paddle Mixer	12 12.125 12.75	9 9 9
12/26/2002	Grout 1 Grout 2	High Speed 2	13 13.6	10 10
12/27/2002	Grout 1 Grout 2	High Speed 1	13 13.6	10 10
12/20/2002	Grout 1 Grout 2	Continuous Mixer	Varied	1-2 1-2
1/4/2003	Grout 1	Paddle Mixer	12.6	10
4/9/2003	Grout 1 Grout 2	High Speed 2	13 13.6	10 10
4/10/2003	Grout 3 (3 bags)	High Speed 2	12	8
4-10-200	Grout 4	High Speed 2	12	3
5/5/2003	Grout 1	High Speed 1	12	10
5/5/2003	Grout 2	Paddle Mixer	13.6	10
11/10/2004	Grout 5	High Speed 2	13.6 15 17.3	10 10 10

4.0 ANALYSIS OF EXPERIMENTAL RESULTS

4.1 STRENGTH TEST

All test results satisfied the minimum compressive strength requirements of 3000 psi at 7 days and 5000 psi at 28 days. When Grout 1 was mixed for short periods there was a significant difference in strength depending on the type of mixer used. Grout 1 mixed with high speed shear mixer resulted in a 20% higher strength as compared to paddle mixers, see Fig. 5. The high speed shear mixers clearly showed advantage over paddle mixer on early age strength, which is also very critical in grout operation especially in cold climates. However, when Grout 3 was completely mixed, no significant strength differences were observed in the grout strength between mixer types (Fig. 6.)

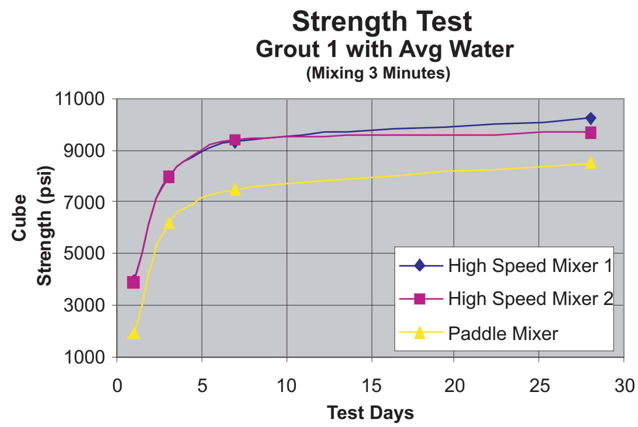

Fig. 5 - Strength Differences of Grout 1 Caused by Mixer Types

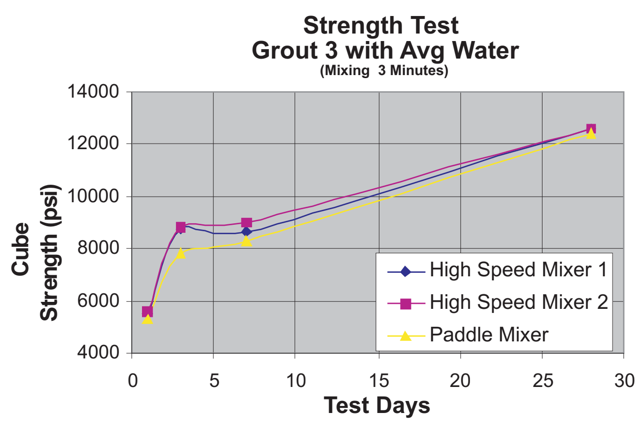

Fig. 6 - Strength Test of Grout 3 with 3 Mixers

The test results on Grout 4 indicated that strength was much higher from high speed shear mixer than regular lab paddle mixer as shown in Fig. 7. This was expected because the lab mixer more closely simulates the mixing action of the paddle mixer. This applies to all 5 grouts tested with different degrees. The manufacture recommends 16 gallons of water for 8 bags of pre-bagged Grout 4; 14 gallons of water was added for mixing with 10 bags of prebagged grout. The dramatic changes in the strength gains from high speed shear mixer clearly indicated that more energy was introduced during mixing which led to much lower water cement ratio and all these contributed to the significant strength increasing. All but Grout 4 demonstrated higher strength than those listed in Table1 when maximum amount of water or even higher than maximum recommended water had to be used in the test program to achieve the desired fluidity. However, even Grout 4 exceeded minimum PTI requirement and FDOT specification.

4.2 FLUIDITY TEST

Fig. 8 shows test set ups for both the standard flow cone and the modified flow cone.

The observed thixotropic behavior of grouts was not always consistent across the full allowance range of water dosage.

Fig. 9 shows fluidity of Grout 1 with maximum amount of water added. Test results indicated that Grout 1 demonstrated non-thixotropic behavior with maximum amount added. However, strong thixotropic behavior was observed when less water was added and in these cases the modified flow cone test was more suitable for measuring fluidity.

Grout 2 demonstrated high thixotropic behavior even with maximum amount of water added (shown in Fig. 10), it was also noted that amount of water recommended by the manufacturer needed to be increased to get the fluidity. Note that bleed may be increased to unacceptable levels and needs to be confirmed by testing.

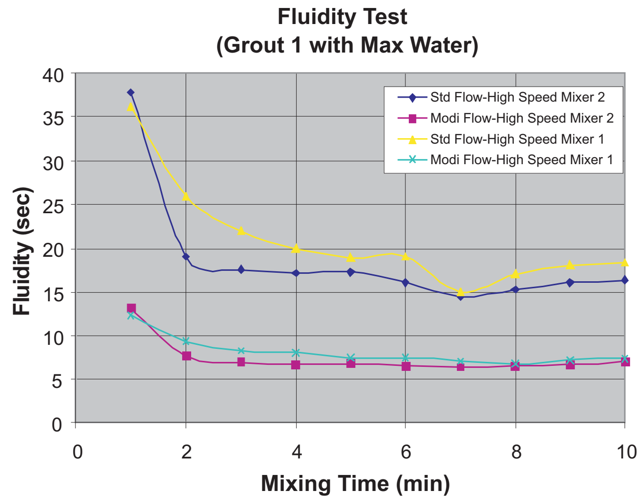

Fig. 9 - Fluidity Test of Grout 1 with Maximum Amount Water Added

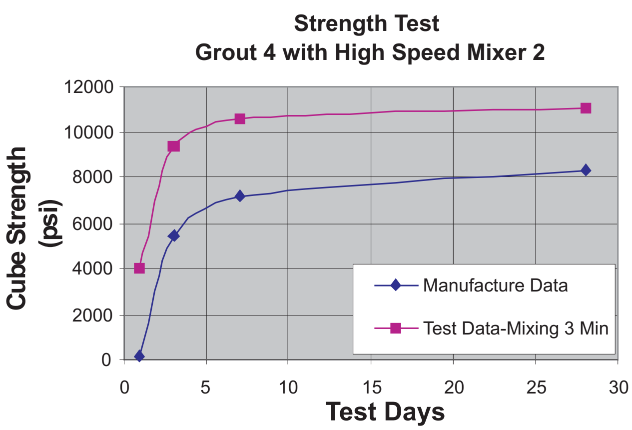

Fig. 7 - Strength Difference of Grout 4

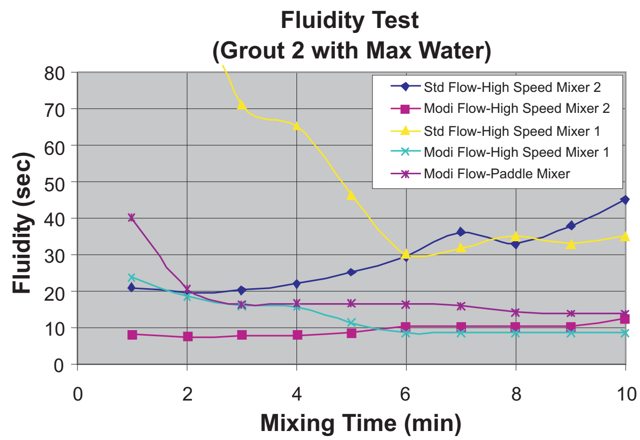

Fig. 10 - Fluidity Test of Grout 2

Fig. 8 - Modified Flow Cone on Left and Standard Flow Cone on Right Indicated with Grout Level

Fig. 11 - Cylinders for Slump Method

Fig. 12 - Test Set Up of Slump Method

Fig. 13 - Slump Method Result for Grout 2

Fig. 14 is the comparison between modified flow cone and slump method for Grout 2. Fig. 15 shows the fluidity of Grout 1 between modified flow cone and slump method. Table 4 summarizes the three fluidity tests. It was noted that fluidity test was so relax that all test conducted in this study passed the test requirement in all recommended water range.

4.3 BLEED TESTING

A defined minimum amount of water is needed in grout for the hydration of cement. However, more water is often added to achieve the required fluidity for injection[16]. The heavier cement particles tend to settle while the lighter water moves upward and collects at the top of the grout causing segregation of the grout. It has also become evident that old practice that required bleed water to be reabsorbed in 24 hours have no logical basis. If bleed water develops, reabsorption will merely create an air void. Bleed of grout is probably one of the primary reasons, if not the most important, for voids in hardened grout in tendons.

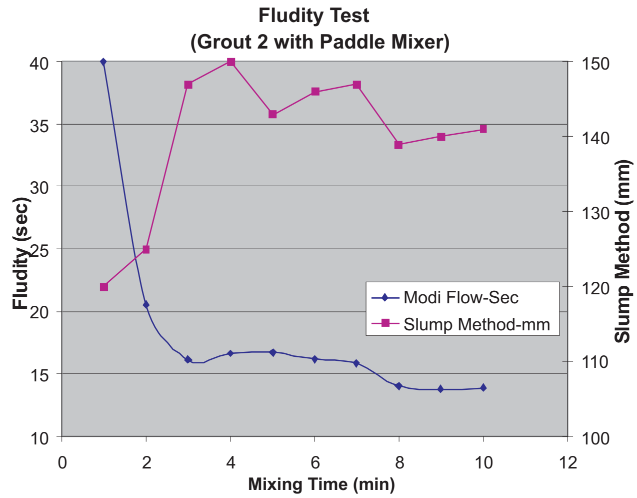

Fig. 14 - Comparison of Fluidity between Modified Flow Cone and Slump Method for Grout 2

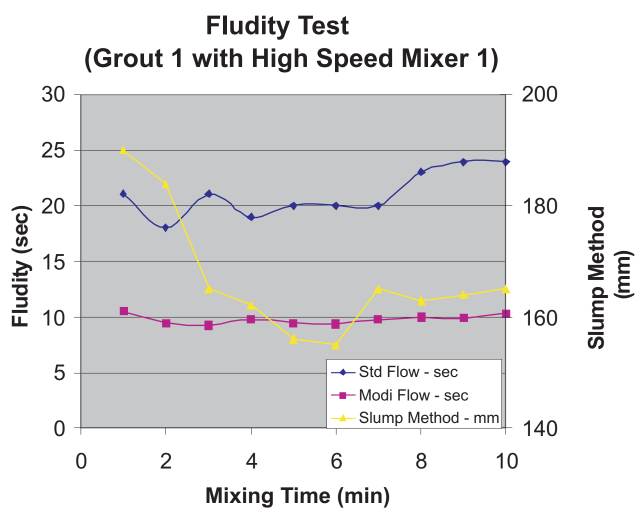

Fig. 15 - Fluidity Test of Grout 1 with Maximum Amount water Added

Research has shown that bleed in grout for post-tensioning is influenced by the interstices formed in the strand by the space between the king wire and the perimeter wires which act as a capillary tubes[17-18]. A modified wick induced bleed test was introduced in the PTI Specification[7] C4.4.6.1. This test simulates the capillary action discussed above. Another test, the Schupack Pressure Bleed Test[19], was used in this study to measure the bleed properties of the various grouts under high pressure which simulates tendons with elevation differences.

Table 4 - Summary of Three Fluidity Tests

Grout	Mixer	Water (gallons/8 bags)	Standard Flow Cone (Second)	Modified Flow Cone (Second))	Slump Method (mm)
Grout 1	High Speed Mixer 2	11.875	17 - 24	9.3 - 10.8	155 -190
	High Speed Mixer 1	13	16 - 28	7.1 - 10.6	225 - 255
Grout 2	High Speed Mixer 2	13.6	NA	10.0 - 15.0	104 - 130
	Paddle Mixer	14.22	NA	13 - 40	120 - 150
Grout 3	High Speed Mixer 2	12.125	18 - 73	7.3 - 15	79 - 113
Grout 5	High Speed Mixer 2	13.6	21 - 58	7.5 - 19.5	105 - 156
		15	14.9 - 16.9	5.8 - 7.0	143 - 178
		17.3	12 - 13.9	5 - 6.3	146 - 197

Fig. 16 shows test set up of Wick Induced Bleed Test while Fig. 17 demonstrates the bleed behavior (discoloring) of Grout 1 mixer with the maximum amount of water recommended. All grout materials tested in this study have been satisfied with wick induced bleed test requirements in Table 2 with no bleed water observed for a 3-hour period. However it was noted that discoloring of grout was observed for Grout 1 when mixed with maximum amount of water. This discoloration extended down roughly about 5 to 30 ml from the top of the cylinder, which was filled with 800 ml grout and cleaned 0.5-in. strand. Strictly speaking, this was not classified as bleed, but it was believed to be sedimentation. Another exception was Grout 3 when mixed with the paddle mixer for only 3 minutes 2 ml water was collected at end of the three hour test. It is believed through the test that Wick Induced Bleed Test for a 3-hour duration was written around high-bleeding common grout as there was no bleeding detected if there was none at first 30 minutes for pre-bagged grout mix.

The Schupack Pressure Bleed Test determines the bleed resistance of a grout under pressure. The apparatus consists of a Gelman filtration funnel, stand, and pressure supply air with gauge and valve, and bleed water collection container. Fig. 18 shows the test set up of Schupack pressure bleed test. Note that Florida DOT now requires 0.0% bleed for 5 minutes at 100 psi pressure. All four prebagged grouts exhibited zero bleed under 100 psi pressure for 5 minutes while bleed was observed for Grout 3 under the same condition. There were total of 5.5, 6.5 and 9.5 ml of bleed measured when grout 3 was mixed with High Speed Mixer 1, High Speed Mixer 2 and Paddle Mixer respectively.

Fig. 16 - Test Set Up of Wick Induced Bleeding Test

Fig. 17 - Bleeding (Discolor) of Grout 1 with Maximum Amount Water

4.4 WET DENSITY TEST

The wet density test is a test for water/cement ratio and the compactness of the grout. There is no requirement such as minimum density in PTI specifications. However there is general a targeted range to have wet density for special grout be greater than 2000 kg/m^3, and standard grout of 1900 kg/m^3.

Maximum amount of water (13.6 gallons of water per 8 bags of grout) was needed for Grout 2, the wet density varied from 1.79 to 1.81 when mixed with the paddle mixer; 1.87 to 1.92 when mixed with High Speed Mixer 1 and 1.9 to 1.93 when mixed with High Speed Mixer 2. It was noted that high speed shear mixers produced higher density compared to paddle mixer under the same water cement ratio as shown in Fig. 19.

Grout 1, Grout 3, and Grout 4 had a wet density above 2.0 even when the maximum amount of water was added and was mixed with either a high speed shear mixer or paddle mixer. When Grout 5 was mixed with High Speed Mixer 2, the wet density varied from 1.91 to 1.96 at maximum amount of water, 1.95 to 2.04 at average amount of water and 2.03 to 2.08 at minimum amount of water.

4.5 GROUT TEMPERATURE

During the study, the ambient temperatures varied from a low of 40° F in December 2002 to a high of 70° F in early May. Temperatures lower than 41° F may slow down or even stop the hydration of the cement and prevent setting /hardening of the grout. Elevated temperature accelerates setting, reduces flowability and may cause blockage during the grouting.

PTI specifies that grout temperature be lower than 90° F, it was noted during the study that this upper limit could be easily exceeded when mixing with high speed shear mixer at high ambient temperature. Test results indicated that grout performed satisfactorily even at temperature higher than 90° F.

It is also noted in the test that grout temperature from high speed shear mixer was average 10° F higher than the grout mixed by paddle mixer under the same mixing time. This is another indication that the high speed shear mixer imparts more energy as compared with the paddle mixer.

All grout materials had a narrow band of mixing time with High Speed Mixer 2 especially in a hot environment when mixing with Grout 2. It reached 90° F after mixing for 3 minutes, and 98° F at 4th minute. It was noted in the study that Grout 2 performed satisfactorily even at this high temperature judged by flowability and pumpalility.

High Speed Mixer 1 was very easy to work with. It produced homogeneous grout without overheating it. On the other hand, grout temperature remained almost constant during the test when mixed with Paddle mixer.

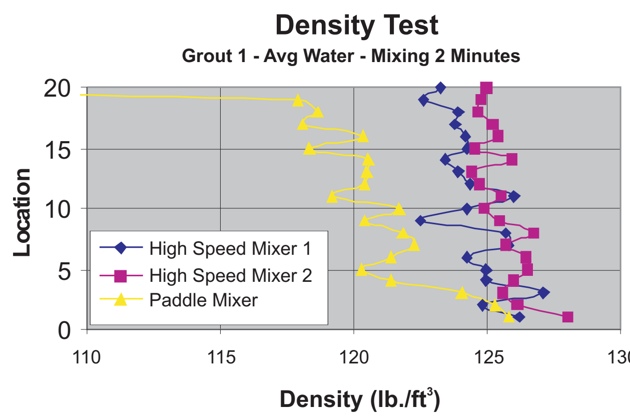

Fig. 19 - Density of Hardened Grout 1

(a) Pressure Supply and Gauge

(b) Gelman Filtration Funnel and Stand

Fig. 18 - Test Set Up of Schupack Pressure Test

Fig. 20 - Segregation Tests Specimens

4.6 SEGREGATION TEST

Segregation and sedimentation can be confirmed by measurement of density of grout at different locations and observations of the grout color (Fig. 20). It was noted in the test program that segregation often could be determined by visual examination of color of the grout, e.g. dark gray at locations with high density, and lightly gray and/or whitish or yellowish color at the top (Fig. 21). Fig. 22 illustrates the test set up for measuring grout weight and volume. Figs. 23 and 24 demonstrate mixing time and water effects on segregation behavior of Grout 1 while Fig. 25 indicates that there are no segregation issues even at the maximum amount of water for Grout 2.

No segregation behavior was observed for Grout 2 as shown in Fig. 26, neither was Grout 3, Grout 4 and Grout 5. However severe segregation was found in Grout 1 mixed with the maximum amount of water as shown in Fig. 27. The segregation remained even after 10 minutes of mixing with high speed shear mixer. However the segregation was eliminated for Grout 1 after mixing 2 minutes with high speed shear mixer or 8 minutes with paddle mixer when minimum or average amount of water was introduced. There seemed to be a threshold at which the segregation suddenly became significant.

Fig. 21 - Close Up View of Segregation of Grout

Fig. - 22 Measurement of Weight and Volume

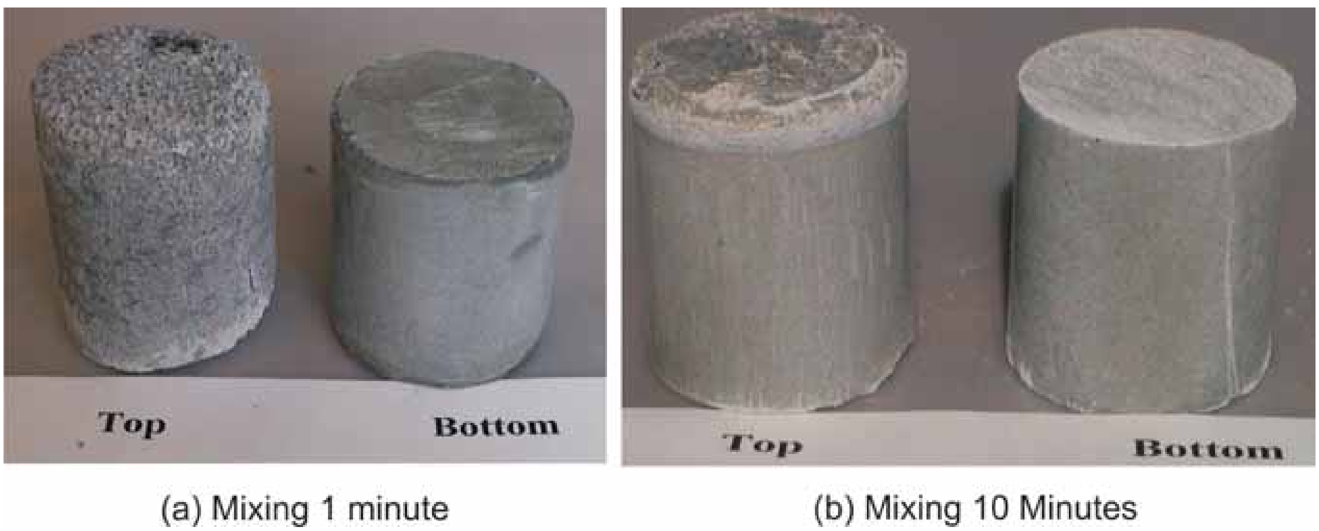

Fig. 23 - Segregation of Grout 1 with Maximum Amount of Water

Fig. 24 - Water Effect on Segregation Test

Fig. - 25 Non Segregation for Grout 2

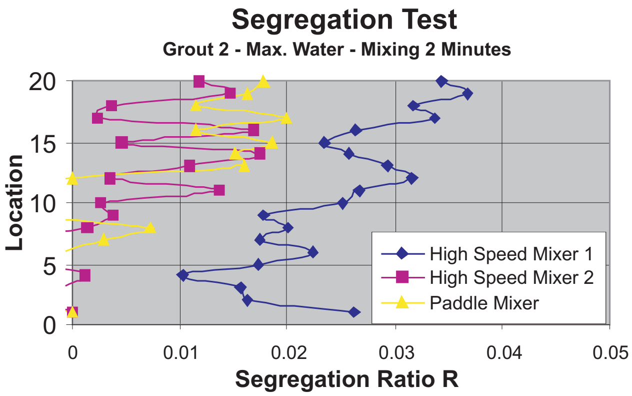

Fig. 26 - Segregation Test of Grout 2

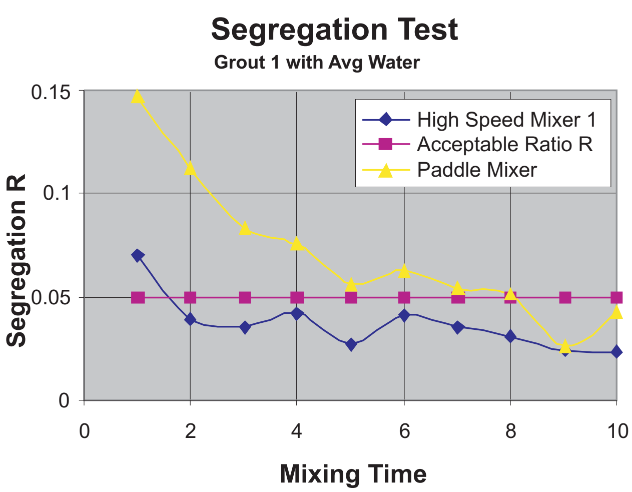

Fig. - 27 Segregation of Grout 1 with Average Water

5.0 SUMMARY AND CONCLUSIONS

5.1 WHY HIGH SPEED SHEAR MIXER

The Continuous Mixer did not have sufficient mixing action for grout materials and was also difficult to control the water cement ratio. All other mixers in the testing program produced grouts with good hydration and physical properties.

Grouts prepared with high speed shear mixers exhibited none or little bleed water . Less water was needed to achieve the same fluidity of grout when mixed with high speed shear mixers and less mixing time was needed to control the segregation of the grout. When the grouts were sufficiently mixed the compressive strength was similar with all types of mixers. However, with smaller amount of mixing time (2 minutes) high speed shear mixer gave better results.

5.2 GROUT PERFORMANCE AND OPTIMIZING MIXING TIME

Grout 1 was very friendly to work with, had very high strength and high density. It demonstrated high thixotropic behavior when minimum or average of recommended water was introduced. It also had a very good stability of flow time. However, there seemed to be a threshold at which the segregation suddenly became significant if the maximum recommended water was used.

Grout 2, Grout 3, Grout 4 and Grout 5 were not sensitive to the segregation even when maximum amount of water was introduced. The optimizing mixing time was controlled by targeted fluidity and grout temperature. Compared to other grout materials in this study, Grout 2 had a slightly lower compressive strength and much lower density. It was not very effective to mix Grout 2 with a paddle mixer. More than the maximum recommended amount of water was needed when mixed with the paddle mixer. Grout 3 worked perfectly well with all mixers used in this study. Pressure bleed was a potential problem. Mixing with high

Table 5 Optimized Mixing Time

Grout	Optimized Mixing Time (minutes)		
	High Speed Mixer 1	High Speed Mixer 2	Paddle Mixer
Grout 1	3	2	8
Grout 2	3	3	8*
Grout 3	3	3	8
Grout 4	3	3	8
Grout 5	3**	3	8

Notes: * - More than maximum recommended water is needed
** - Less than minimum recommended water is needed

speed shear mixers and mixing longer could improve the bleeding properties. Grout 4 behaved more like Grout 1 with high strength, high density. However the amount of water recommended by the manufacturer was excessive and needs to be reduced. Grout 5 demonstrated high thixotropic behavior as Grout 2. It worked perfectly well with High Speed Mixer at lower temperature. The optimized mixing time for 5 grouts with three different mixers is listed in Table 5. The mixing time recommended in this table was designed for the normal application; additional mixing time may be needed for the cold weather grouting.

5.3 THREE FLUIDITY TESTS

The introduction of Slump Method in this study was to have a reliable and simple alternative solution for checking the fluidity of the grout, thixotropic and non-thixotropic. Based on the limited test results, no quantitative relationship has been established between the Slump Method and flow cone test, and between the Slump Method and the modified flow cone test. Further research is needed to explore their relationship. However, the Slump Method did show trend with the flow cone and modified flow cone tests.

It was also noted during the test that grout can relatively easily pass the modified flow cone test criteria which causes some concerns. While the grout which passed modified flow cone test on the upper limit may be very difficult to pump. On the other hand, the thixotropic grout which fell below the modified flow cone's lower limit can have a good bleeding resistance.

5.4 GROUTING TEMPERATURE

PTI specified that grout temperatures be less than 90° F, it was observed during the testing that this upper limit could be easily exceeded when mixing with a high speed shear mixer at high ambient temperature. Full scale grout pumping tests indicated that grout with temperature greater than 90° F performed satisfactorily. Exceeding the upper limit may be a reasonable and rational solution for hot weather applications without having any detrimental effect on the finished product.

5.5 WET DENSITY V.S. FLUIDITY TEST

Wet density is an important quality control test for the site. This is because the wet density directly correlates to the water content in the grout. Test results in the study indicated that wet density correlated very well with water content and mixing time. It is also logical to use wet density to check the quality of grout discharged from anchorage outlet instead of fluidity test, thus eliminating the concerns that water in the duct may be diluting the grout mix. On the other hand, fluidity test is more general test and the requirement is so relax that all tests conducted in this study pass the requirement in all recommended water range.

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