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BEYOND
NET ZERO to NET PLUS
Or what some are now calling
REGENERATIVE DESIGN

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by L. K. Crouch, Samantha Pittman and Daniel Badoe

LGM PCC Update

INTRODUCTION

In 2008, TCA members SEFA, Memphis Ready Mix and Southern Concrete sponsored the initial research on Lean, Green and Mean (LGM) concrete. The results of the preliminary research were published in Tennessee Concrete in the Summer 2009 issue [1]. Subsequently, in 2010, the Tennessee Department of Transportation (TDOT) Division of Materials and Tests sponsored a project entitled "Higher Volume Fly Ash (HVFA) Portland Cement Concrete (PCC) for Sustainability and Performance" which included LGM. The TDOT project recently concluded and the authors would like to thank TCA and particularly members SEFA, Memphis Ready Mix and Southern Concrete for sponsoring the initial "seed" project. Further, we would like to share some of the results of the TDOT project.

LGM PCC uses a 40 percent PC replacement rate with Class F fly ash. Current TDOT allowable PC replacement rate is 20 percent for Class F fly ash. However, 2006 TDOT standard specification section 604.03 currently allows 50 percent substitution of supplementary cementing materials (SCM) and therefore the research was not without precedent [2]. The higher PC replacement rate greatly increases the use of an industrial byproduct making more efficient use of natural resources. Protecting and preserving the environment is always a desirable goal; however, neither performance nor economy should be sacrificed for environmental concerns. Therefore, even though the literature indicates that even higher replacement rates may be viable in some applications, the research team assumed that doubling the current TDOT allowable replacement percentage was a prudent first step. LGM PCC also requires lower cementing materials and water contents than a typical TDOT Class A PCC mixture.

LGM AND TDOT CLASS A MIXTURE DESIGNS

LGM PCC has a total cementing materials content of only 500-lbs/CY and therefore it was decided that LGM PCC would fare better competing with TDOT Class A (general use, 564-lbs/CY minimum cementing materials) than with TDOT Class D (bridge decks, 620-lbs/CY minimum cementing materials). In mixed martial arts and concrete, it is never good to select an opponent very far out of one's weight class. Table 1 shows TDOT Class A and LGM PCC mixture designs for both above and below 85°F that were used in the study. Table 2 shows comparisons of TDOT Class A and LGM PCC attributes with current TDOT 604.03 Class A requirements.

Material cost is always an important concern; the cost assumptions used for the TDOT LGM research are shown in Table 3. Applying the cost assumptions in Table 3 to the mixture designs in Table 1 produces the material costs per cubic yard shown in Table 4.

RESULTS

Table 5 shows the results of plastic property tests on TDOT Class A and LGM PCC for mixtures above and below 85°F. The research team wanted a fair fight and attempted to produce mixtures with very similar plastic properties. For the mixtures below 85°F, the LGM PCC has statistically significantly higher air contents than TDOT Class A according to both pressure meter and gravimetric results. Other properties measured (slump, unit weight and temperature) were not significantly different. For the mixtures above 85°F, the LGM PCC has statistically significantly higher unit weight than TDOT Class A PCC. Other properties measured were not significantly different.

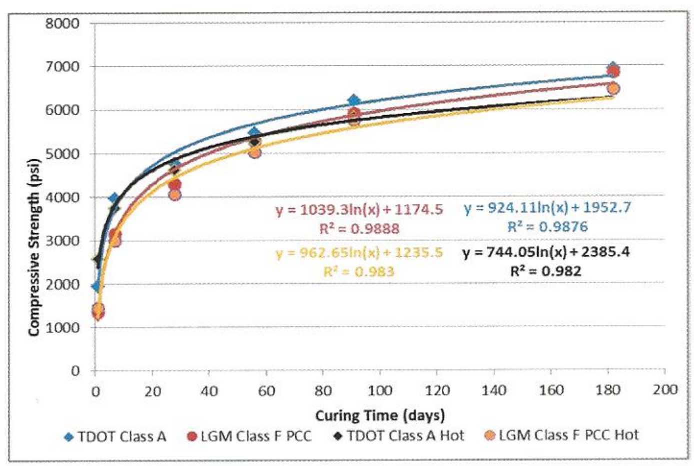

Figure 1. Compressive Strength Development of LGM and TDOT Class A Mixtures

Figure 1 shows a graphical comparison of compressive strength development of LGM and TDOT Class A PCC. The figure shows that the compressive strength of all mixtures was greater than 750-psi at one day, as recommended for form wrecking without excessive damage [3]. Although LGM PCC required a chemical accelerator to achieve the compressive strength in the 70°F range,

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TABLE 1. TDOT CLASS A AND LGM MIXTURE DESIGNS

Component	TDOT Class A	TDOT A Hot	LGM PCC	LGM PCC Hot
Type I PC (lbs/CY)	451	451	300	300
Class F Fly Ash (lbs/CY)	113	113	200	200
No. 57 Limestone SSD (lbs/CY)	1773	1773	1959	1959
River Sand SSD (lbs/CY)	1324	1324	1266	1266
Water (lbs/CY)	228.5	228.5	195	195
Design Air Voids (%)	6	6	6	6
Air Entrainer, oz/cwt (oz/CY)	0.7 (3.9)	0.55 (3.1)	0.65 (3.3)	0.7 (3.5)
Mid-range Water Reducer, oz/cwt (oz/CY)	1 (5.6)	0	7 (35)	12 (60)
Non-chloride Accelerator, oz/cwt (oz/CY)	0	0	16 (80)	0
Retarder, oz/cwt (oz/CY)	0	1.5 (8.5)	0	0

TABLE 2. COMPARISON OF MIXTURE DESIGN ATTRIBUTES AND TDOT CLASS A PCC REQUIREMENTS

Quantity/Ratio/Percentage	TDOT 604.03 Class A PCC Requirements	TDOT Class A and Class A Hot	LGM and LGM Hot
Cementing Materials Content	564 lbs/CY minimum	564 lbs/CY	500 lbs/CY
Water-Cementing-Materials Ratio	0.45 maximum	0.405	0.39
Percent Fine Aggregate by Total Aggregate Volume	44 maximum	43.5	40.0
Percent Fly Ash Substitution (by weight) for Portland Cement	20 maximum for Class F Fly Ash	20 Class F Fly Ash	40 Class F Fly Ash

TABLE 3. MATERIAL COST ASSUMPTIONS

Component	Assumed Cost Delivered to Ready Mix Producer
Type I Portland Cement ($/ton)	110.00
Class F Fly Ash ($/ton)	50.00
No. 57 Limestone ($/ton)	18.00
River Sand ($/ton)	15.00
Air Entrainer ($/gallon)	4.50
Mid-range Water Reducer ($/gallon)	8.50
Accelerator ($/gallon)	9.00
Retarder ($/gallon)	7.50
High-range Water Reducer ($/gallon)	12.00

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LGM PCC UPDATE

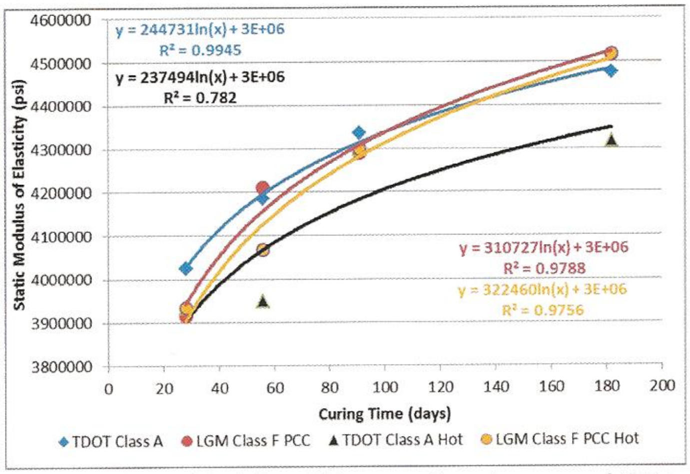

Figure 2. Static Modulus of Elasticity Development of LGM and TDOT Class A Mixtures

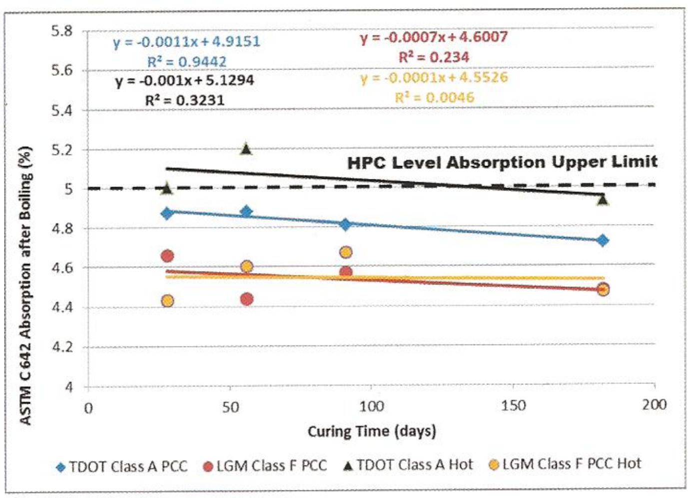

Figure 3: Concrete Absorption after Boiling Development of LGM and TDOT Class A Mixtures

as the temperature increased above 85°F LGM PCC mixtures no longer required the chemical accelerator, and had no need of a chemical retarder to maintain plasticity for placement and finishing operations. Figure 2 shows a graphical comparison of static modulus of elasticity development of LGM and TDOT Class A PCC. Durability is the key to a long service life for PCC. Reducing the amount of water absorbed should reduce freeze-thaw damage to PCC mixtures. The Portland Cement Association (PCA) indicates that the upper limit of water absorption after boiling for high performance concrete (HPC) is five percent [4]. Figure 3 shows the reduction of PCC absorption after boiling over time for LGM and TDOT Class A PCC as well as the PCA HPC upper limit.

ANALYSIS OF RESULTS

Table 6 shows the relative mean values of properties of LGM and TDOT Class A PCC. Thus, the numbers shown are a percentage of the mean TDOT Class A PCC results that the mean LGM PCC results obtained. A cell shaded in blue indicates that at a specified age, TDOT Class A PCC was significantly different and superior to LGM PCC. A cell shaded in yellow indicates that at a specified age, LGM PCC was significantly different and superior to TDOT Class A PCC. It is important to note that sometimes "greater" is superior and sometimes "greater" is inferior depending on the property being measured. Table 7 is a similar comparison of hot LGM and hot TDOT Class A PCC.

SUMMARY

This was certainly a close fight (no knockout). Going to the judge's scorecard (Table 8), this fight is still almost too close to call. Below 85°F, TDOT Class A had superior compressive strength. However, LGM PCC met all compressive strength requirements and was closing the gap as time progressed. TDOT Class A also had a lower material cost, however the cost advantage was less than $3/CY. LGM PCC had superior (lower) concrete absorption after boiling (a measure of durability). Since durability is the most common failure mode in Tennessee, the judges gave a slight edge to LGM PCC. However, the "cooler" mixtures (below 85°F) were cast, cured and tested in the upper 70s. At lower casting and curing temperatures TDOT Class A's superiority in compressive strength and cost (due to LGM requiring more chemical accelerator) would probably have been overwhelming. TDOT Class A is therefore much more widely applicable (over a wider range of temperatures) than LGM PCC at lower temperatures.

The fight was not nearly as hard to call above 85°F. Hot LGM PCC got a draw in compressive strength (after 7 days) and static modulus of elasticity. Further, hot LGM PCC was superior in concrete absorption after boiling (a measure of durability) and had a slightly lower material cost per cubic yard. As the mixing, casting and curing temperature rises, hot LGM PCC's advantage over hot TDOT Class A PCC would certainly increase. Fortunately, one of the many, many advantages of living in Tennessee is a climate favorable for extensive hot LGM PCC usage.

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TABLE 4. MATERIAL COST PER CUBIC YARD

Component	TDOT Class A	LGM PCC	TDOT Class A Hot	LGM PCC Hot
Type I Portland Cement ($/CY)	24.81	16.50	24.81	16.50
Class F Fly Ash ($/CY)	2.83	5.00	2.83	5.00
No. 57 Limestone ($/CY)	15.96	17.64	15.96	17.64
River Sand ($/CY)	9.93	9.50	9.93	9.50
Air Entrainer ($/CY)	0.14	0.12	0.11	0.13
Mid-range Water Reducer ($/CY)	0.38	2.33	0	3.99
Accelerator ($/CY)	0	5.63	0	0
Retarder ($/CY)	0	0	0.50	0
Estimated Total Material Cost (excluding water) in $/CY	54.05	56.72	54.14	52.76

TABLE 5. TDOT CLASS A AND LGM PLASTIC PROPERTIES AND TDOT CLASS A REQUIREMENTS

Property	TDOT 604.03 Class A PCC Requirement	TDOT Class A Mean Value of 10 Batches	LGM PCC Mean Value of 10 Batches	TDOT Class A Hot Mean Value of 3 Batches	LGM PCC Hot Mean Value of 3 Batches
Slump (inches)	2 to 4	3.48	3.58	3.50	2.92
Air content by pressure method (%)	4 to 8	5.88	6.13	5.87	5.73
Air content gravimetric (%)	None	5.70	6.36	5.77	5.67
Unit Weight (pcf)	None	144.5	144.7	144.4	145.7
Temperature (°F)	Normal <85, Hot ≥85	76.1	78.6	89.3	91.0

TABLE 6. COMPARISON OF MEAN RESULTS (LGM/TDOT CLASS A)* 100

Age	Mean Compressive Strength	Mean Static Modulus of Elasticity	Mean Concrete Absorption after Boiling
1	69		
7	80		
28	90	97	96
56	96	101	91
91	95	99	95
182	99	101	95

TABLE 7. COMPARISON OF MEAN RESULTS (HOT LGM/HOT TDOT CLASS A)* 100

Age	Mean Compressive Strength	Mean Static Modulus of Elasticity	Mean Concrete Absorption after Boiling
1	57		
7	80		
28	88	100	89
56	96	103	88
91	99	100	Not Available
182	99	105	91

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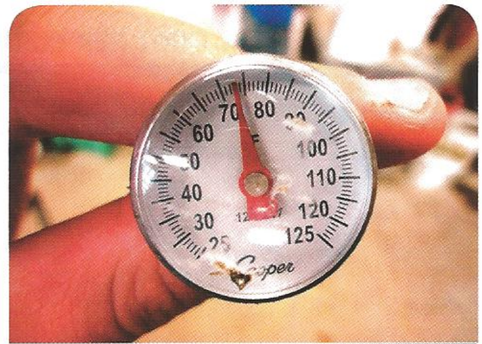

TABLE 8. FINAL SUMMARY COMPARISON OF LGM & TDOT CLASS A

Property of Attribute	< 85° F	≥ 85° F
Compressive Strength	TDOT Class A	No Clear Winner
Static Modulus of Elasticity	No Clear Winner	No Clear Winner
Absorption after Boiling	LGM	LGM Hot
Material Cost	TDOT Class A	No Clear Winner
Overall Superiority	No Clear Winner (Edge to LGM)	No Clear Winner (Edge to LGM)

WHAT'S NEXT FOR LGM PCC?

LGM PCC is currently competing with TDOT Class A PCC in a TDOT Materials and Tests Division sponsored project on lower heat of hydration PCC mixtures. Preliminary results indicate that LGM PCC is superior to TDOT Class A PCC in this property due to a higher Class F fly ash substitution percentage.

The authors hope that LGM PCC mixtures, particularly hot LGM PCC will have opportunities to compete with TDOT Class A PCC mixtures in side-by-side field trials.

RECOMMENDATION

For more information on using LGM PCC (especially at higher temperatures) contact the Tennessee Concrete Association (TCA) or a local TCA producer member. Go "green" and help improve both the environment and PCC performance simultaneously.

REFERENCES

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ACKNOWLEDGEMENTS

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