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LEAN, GREEN, and MEAN RESEARCH

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by L. K. Couch and Jason Phillips—

Lean, Green, and Mean PCC

INTRODUCTION

The political conflict between "developers" and "environmentalists" is virtually a thing of the past. Rather, it is imperative that a proper balance between economic development and environmental awareness be developed. Unfortunately, Portland cement (PC) poses several threats to the environment. Estimates have revealed that the production of one ton of PC will release approximately one ton of CO_2 into the atmosphere [1]. CO_2 is recognized as a greenhouse gas that is believed to contribute to global warming [1]. It is estimated that the concrete industry is responsible for about seven percent of CO_2 released into the atmosphere [1]. Furthermore, producing PC is a very energy-intensive process requiring temperatures in excess of 2500°F.

Replacing percentages of PC with a variety of supplementary cementing materials (SCM) that are byproducts of industrial processes will greatly improve the environmental quality of the mix [1]. Capitalizing on the use of wastes will contribute to the best use of a nation's landfill space. The research described in this paper attempts to improve sustainability by using forty percent SCM substitution for Portland cement without sacrificing performance. In order to ensure state-wide applicability, lean, green and mean (LGM) Portland cement Concrete (PCC) mixtures were developed with river sand and limestone manufactured sand as fine aggregate. TCA LGM goals and ACI 332 Residential Concrete [2] requirements for the mixtures are shown in Table 1 (see page 11).

LGM AND COMPARISON MIXTURE DESIGNS

Table 2 shows LGM PCC mixture designs in columns two through five and typical commercial comparison mixtures used in the study in columns six and seven. Limiting the PC content to 300 lbs/CY makes LGM PCC lean. A forty percent SCM substitution makes LGM PCC green. What makes LGM PCC mean? A superiority complex, LGM PCC exhibits similar or superior performance (in strength and durability) to PCC mixtures with much higher PC contents. The performance of LGM PCC embarrasses users of higher PC content PCC mixtures (cement guzzlers).

RESULTS AND ANALYSIS

Table 3 shows results and estimated costs for LGM PCC and comparison mixtures. LGM PCC mixtures clearly outperform the commercial comparison mixtures and are similar in estimated material costs. LGM PCC mixtures can be cheaper than the comparison mixtures if used correctly. LGM PCC requires an accelerator to achieve 750-psi 1–day compressive strength at approximately 70°F. However, as the temperature increases LGM PCC mixtures no longer require the accelerator, and have little (or no) need of a retarder to maintain plasticity for placement and finishing operations.

Figure 1 shows a graphical comparison of compressive strength development of the LGM and typical commercial PCC mixtures. Two TDOT class A PCC (from previous research), one with Class F fly ash and one with Class C fly ash, have also been added for comparison purposes. LGM PCC is clearly superior to the commercial comparison mixtures and similar to the TDOT Class A PCC mixtures. However, LGM PCC mixtures contain only 67 and 71 percent of the PC that the TDOT Class A mixtures with Class C and F fly ash, respectively. Less Portland cement for similar performance is a definite win for the environment. Figure 2 shows that LGM PCC mixtures produce more 28-day compressive strength per pound of PC than typical commercial mixtures or TDOT Class A PCC mixtures.

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) agrees. PCA indicates that the upper limit of water absorption [3] for high performance concrete (HPC) is five percent [4]. Figure 3 shows the reduction of PCC absorption over time for LGM, commercial comparison mixtures, and TDOT Class A PCC mixtures. LGM PCC mixtures achieve HPC level by 28-days and clearly outperform both commercial comparison mixtures and TDOT Class A PCC with Class F fly ash. The water absorption of LGM PCC mixtures containing only Class F fly ash as an SCM is similar to that of the TDOT Class A PCC containing Class C fly ash. The water absorption of the LGM PCC mixtures containing both Class F fly ash and Grade 120 slag cement is superior to all other mixture at ages of 28 days or more.

Figure 4 shows that LGM PCC mixtures have similar 28-day static modulus of elasticity values to TDOT Class A PCC mixtures. The 28-day static modulus of elasticity values of LGM PCC are clearly superior to those of typical commercial comparison PCC mixtures.

TABLE 1. TCA LGM GOALS AND ACI 332 RESIDENTIAL CONCRETE REQUIREMENTS

Property	TCA LGM Goal	ACI 332 Type 3 Severe Exposure
Slump (inches)	4 to 7	5 maximum without water reducer
Air Content (%)	4 to 8	4 to 7
1-day Compressive Strength (psi)	750	–
28-day Compressive Strength (psi)	4,000	4,500

TABLE 2 LGM AND TYPICAL COMMERCIAL COMPARISON PCC MIXTURE DESIGNS

Component	FMS	FRS	SFMS	SFRS	ComMS	ComRS
Type I PC (lbs/CY)	300	300	300	300	350	350
Class F Fly Ash (lbs/CY)	200	200	100	100	150	150
Grade 120 Slag (lbs/CY)	0	0	100	100	0	0
No. 57 Limestone SSD (lbs/CY)	1890	1899	1897	1906	1708	1717
LS Manufactured Sand SSD (lbs/CY)	1274	0	1277	0	1360	0
River Sand SSD (lbs/CY)	0	1239	0	1244	0	1322
Water (lbs/CY)	217.5	212.5	222.5	216.5	260	255
Design Air Voids (%)	6	6	6	6	6	6
Non-chloride Accelerator (oz/cwt)	12	16	12	10	10	10
Air Entrainer (oz/cwt)	0.6	0.7	0.85	0.4	0.6	1
Mid-range Water Reducer (oz/cwt)	6	7	6	5	0	0

F – Class F Fly Ash
S – Grade 120 Slag Cement
MS – Limestone Manufactured Sand
RS – River Sand
Com – Typical Commercial Comparison Mixture

TABLE 3 LGM AND TYPICAL COMMERCIAL PCC MIXTURE PROPERTIES AND ESTIMATED COSTS

Property	FMS	FRS	SFMS	SFRS	ComMS	ComRS
Slump (inches)	4.5	4	6	4.25	5.75	6.75
Air content (%)	4.5	4.2	5.5	5.6	6	8
1-day Compressive Strength (psi)	1000	1300	1200	880	940	550
28-day Compressive Strength (psi)	5050	5060	6190	5690	4160	3210
Meets TCA Goals	Yes	Yes	Yes	Yes	Yes	No
Meets ACI 332 Type 3 Severe	Yes	Yes	Yes	Yes	No	No
Estimated Material Cost ($)	45.74	43.98	48.63	44.13	45.61	42.01

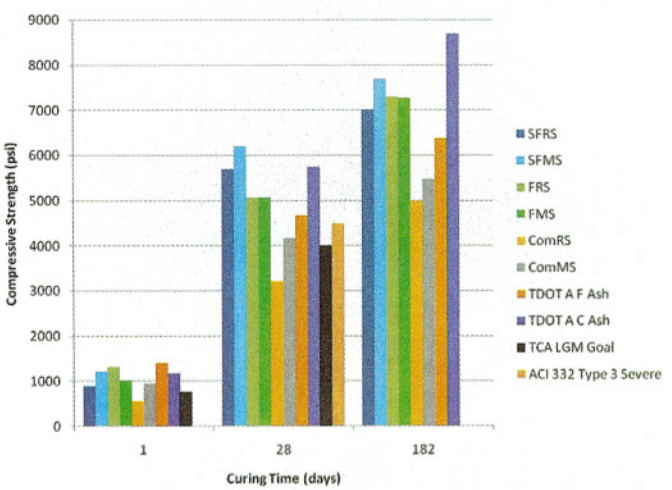

FIGURE 1: COMPRESSIVE STRENGTH DEVELOPMENT OF LGM AND COMPARISON PCC MIXTURES

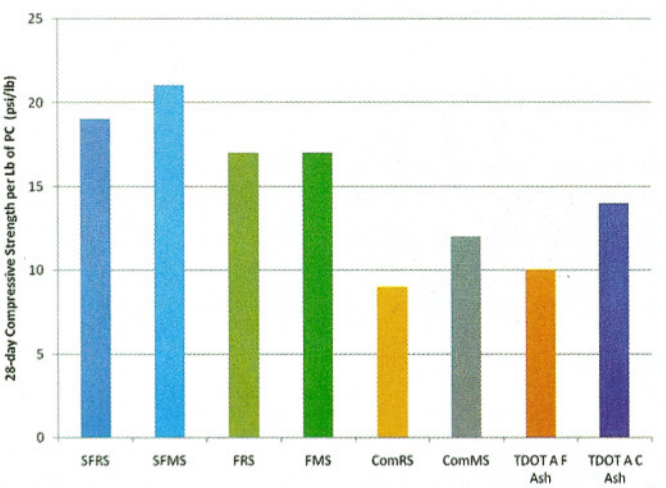

FIGURE 2: PORTLAND CEMENT COMPRESSIVE STRENGTH EFFECIENCY COMPARISON

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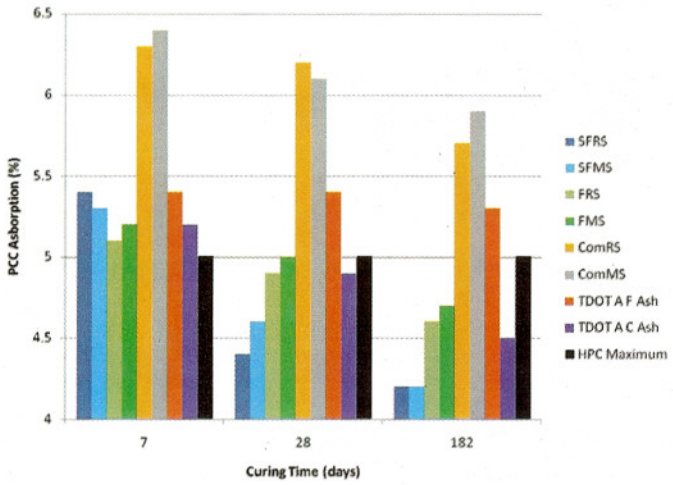

FIGURE 3 COMPARISON OF ASTM C 642 PCC WATER ABSORPTIONS OVER TIME

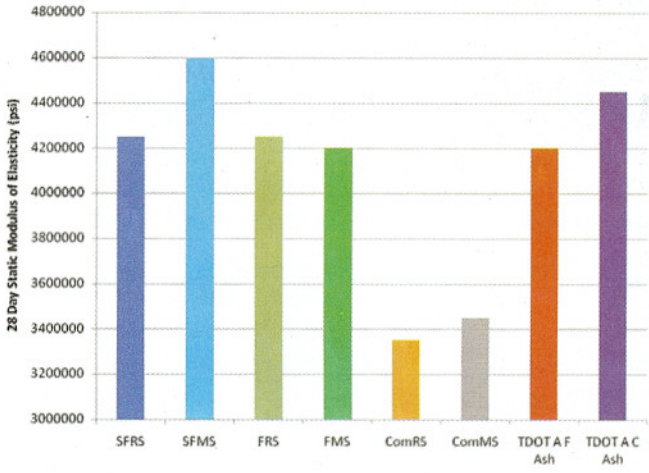

FIGURE 4 COMPARISON OF 28-DAY STATIC MODULUS OF ELASTICITY VALUES

SUMMARY

Sustainable development is about making smart choices for the environment that do not hinder development. LGM PCC mixtures have a more positive environmental impact than mixtures with higher PC contents and lower SCM substitution rates. Further, LGM PCC mixtures have similar or superior performance to typical commercial or TDOT Class A PCC mixtures in compressive strength, durability, static modulus of elasticity, and material cost. However, no PCC mixture is perfect, universally applicable or without weaknesses. LGM PCC mixtures are not the best choice for cold weather placements, the substitution rate and low PC content will either delay set or increase cost by requiring additional accelerator. Fortunately, one of the many, many advantages of living in Tennessee is a climate favorable for extensive LGM PCC usage.

WHAT'S NEXT FOR LGM PCC?

The authors hope that LGM PCC mixtures will have opportunities to compete with commercial and TDOT Class A PCC mixtures in side-by-side field trials. For more information on using LGM PCC contact the Tennessee Concrete Association (TCA) or a local TCA producer member. Go "green" and help improve both the environment and PCC performance simultaneously.

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