Illinois Tollway
Concrete Research Update

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How The Move Illinois Capital Program is Driving the Future for Concrete in Illinois

New Concrete Initiatives Implemented and Coming

1. Performance Related Material Specifications
2. Implementation of AASHTO M 240 Standard For Cements
3. More SCM's in Ternary / Binary Concrete Mixes
4. Optimized Gradations in Mixes
5. Crack Resistant High Performance Mixes for Bridge Decks / Structures
6. More Use of By-Products as Virgin Aggregate Substitutes
   a. Virgin stone black rock (Coarse FRAP)
   b. Steel Slag Black Rock (Coarse FRAP)
   c. RCA aggregates
   d. Stone screenings in concrete
7. Development of more durable crack resistant calcium aluminate cement high early strength concretes

More By-Products as Aggregate in Concrete

Options to be provided

- Black rock (coarse FRAP) as a coarse aggregate, with and without steel slag content
- Options given for RCA as a coarse aggregate
- Stone screenings as an optional fine aggregate source

Tollway requires 100% of existing pavements to be recycled

Two Lift Concrete Paving – A Returned Practice Allows For More By-Product Use in Concrete

Popular back in the 50's, 60's and 70's when the Tollway was originally built

University of Illinois Study On The Use Of Steel Furnace Slag FRAP In Lower Lift Concrete

Study co-sponsored by National Slag Assoc. & Tollway

- Steel furnace slag (SFS) is an industrial by-product of the steel making processes
  - The most common in Chicago-land are basic oxygen furnace (BOF) and electric arc furnace (EAF) slags
- One issue with SFS is the content of free CaO and free MgO, which react with water and expand volumetrically by upwards of 100%
- With this expansive potential, SFS is typically not used in cement concrete applications
  - BUT successfully utilized as an aggregate in asphalt concrete, mainly for increased friction

Study Problem Statement

- 50% coarse (dolomite) FRAP can be used in concrete, but can coarse SFS FRAP also be used?

1. Main concern is that there is residual, unhydrated free CaO and/or free MgO
   - Asphalt coating may prevent water ingress
   - Aged SFS may have already fully reacted and will not expand
2. How will this all affect the strength, durability, shrinkage, and fracture properties of the concrete?

Testing At The Univ. of Illinois (UIUC)

- **Task 1** Literature and Project Review of SFS Aggregates
  - Limits on the use of SFS aggregates in pavement applications in the US and internationally
- **Task 2** Chemical Composition and Microstructural Analysis
  - Chemical and mineralogical composition of SFS aggregates
  - Free lime content of SFS aggregates (virgin SFS and SFS from FRAP)
- **Task 3** Laboratory Expansion Test of SFS Aggregates for Concrete
  - Autoclave expansion of unbound SFS aggregates and SFS FRAP
- **Task 4** Laboratory Investigation of SFS Aggregate in Concrete
  - Strength, durability, shrinkage, and fracture properties

Autoclave Expansion

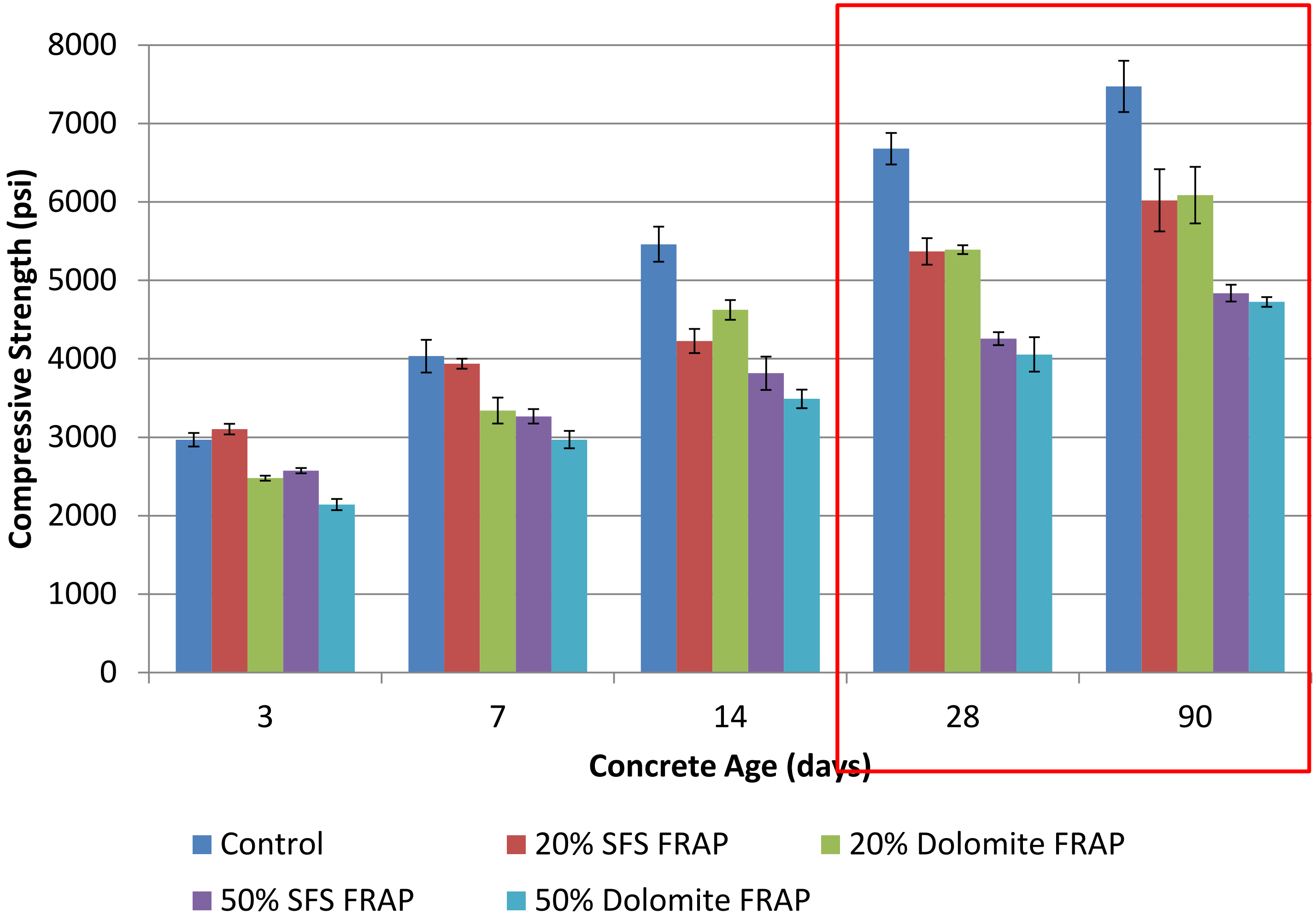
- Sample compacted with a Proctor hammer
- Three hours at 300 psi and 420°F
- Limits set by Edw. C. Levy Co.: 0-5% suitable (normal), 5-10% marginal (retest in 30 days), 10+% reject
- Gradation can have a significant effect on the expansion results of SFS (Emery 1974, 1977)
  - All tests conducted with the same “monoparticle” size gradation
  - Particle size was limited to passing 1/4“ and retained on #4

Mix Designs

	0% SFS FRAP	20% SFS FRAP	50% SFS FRAP
Cement	409.5		
GGBFS	157.5		
Fly Ash	63.0		
Total Coarse Aggregate (SSD)	1895.4	1892.4	1888.0
Virgin Coarse Aggregate (SSD)	1895.4	378.5	944.0
Coarse SFS FRAP (SSD)	0.0	1513.9	944.0
Virgin Fine Aggregate (SSD)	1167.7		
Water	230.9		
Air Entraining Admixture (fl oz per 100 lbs cementitious)	1.0		
Mid-Range Water Reducer(fl oz per 100 lbs cementitious)	4.5	4.25	4.0

SFS FRAP Amount	0%	20%	50%
Blended Specific Gravity	2.72	2.72	2.71
Total Coarse Aggregate (lb/yd^3)	1895.4	1892.4	1888.0
SFS FRAP (lb/yd^3)	0.0	378.5	944.0
Virgin Coarse Aggregate (lb/yd^3)	1895.4	1513.9	944.0

Compressive Strength



SFS and Dolomite FRAP are not statistically different at later ages

Summary of Results To Date

- In terms of concrete properties, SFS FRAP does not appear to differ from Dolomite FRAP
  - Similar concrete strength
  - Possibly higher concrete modulus
  - Slightly higher shrinkage than virgin aggregate
  - Similar fracture properties
- Expansion tests wrapping up with SFS FRAP

Stone Screenings As A By-Product for Concrete

- Improves sustainability by limiting depletion of natural resources & reduces cost
- Investigate unprocessed fines for lower lift paving
- Investigate processed or partially processed fines for finished lifts
- % Passing 200:
  - Processed FM-20: 8% limit, 5% typ.
  - Partially processed FM-21: 18% limit, 17% typ.
  - Unprocessed FA-5: 30% limit, 21% typ.

Carbonate Stone Screenings Available

Partially controlled screenings for asphalt (FM-21)

Hanson's Thornton Averages			
Sieve	**Tests**	**Average**	**Spec.**
3/8"	37	100	100-100
1/4"	37	99.8	
#4	37	98.6	94-100
#8	37	77.8	69-99
#16	37	49.9	39-75
#30	37	34.8	27-53
#50	37	26.0	20-40
#100	37	20.7	10-40
#200	37	16.8	0-18

Uncontrolled screenings only for landfills (FA-5)

Hanson's McCook Averages			
Sieve	**Tests**	**Average**	**Spec.**
3/8"	10	100	100-100
1/4"	10	100	
#4	10	99.3	84-100
#8	10	82.4	
#16	10	58.5	
#30	10	40.9	
#50	10	30.4	
#100	10	25.2	0-40
#200	10	21.0	0-30

Manufactured Sands vs. Natural Sands

Typical natural sand (FM-2)

Typical Gradation		
Sieve	% Passing	Spec.
3/8”	100	100
1/4”	-	-
#4	99	94-100
#8	88	-
#16	69	45-85
#30	49	-
#50	18	10-30
#100	4	0-10
#200	1.1	-

Processed manufactured sand (FM-20) for concrete

Typical Gradation		
Sieve	% Passing	Spec.
3/8”	100	100
1/4”	100	-
#4	99	94-100
#8	75	80-100
#16	47	35-65
#30	30	-
#50	17	8-30
#100	9	3-17
#200	5.2	0-8

Evaluating Fine Aggregate

- #50 sieve is critical for the control of air entrainment in concrete mixes
- #200 sieve is critical for the control of water demand. Good consistency is critical.
- Can today's admixtures improve control?

Typical % Passing #50 & #200 Sieves				
Sieve	FM-02	FM-20	FM-21	FM-5
#50	18	17	26	No Control
#200	1.1	5.2	16.8	21.0

First Step in Study - Testing The Use of FM-21's in Finished Surface Mixes (Top Lift / Single Lift)

- Many mix designs and plant trials are being conducted by Ozinga Ready Mix, Vulcan Materials, and W.R. Grace
- QC data is being submitted by all major aggregate suppliers (Vulcan, Lafarge, and Hanson)
- QA samples are being collected and tested for gradation & quality by Tollway
- Many successful trials are to be field tested for finishability
- Field trials found to be constructable will be analyzed for performance (through CTL Group)
- Performance based specifications will then be written

Phase 1 of Step 1 - Initial Field Trials For Finished Concrete Performed Oct. 2013

- All mixes using Superstructure CM11, with varying amounts of CM16 blended in for optimization
- Mix A: 50% natural sand (FM02)/50% screenings (FM21)
- Mix B: 100% manufactured sand (FM20)
- Mix C: 30% natural sand/70% manufactured sand (FM20)
- Mixes A & C: Super plasticizer
- Mix B: Mid-range water reducer
- 335# Cement + 100# Fly ash + 100# GGBFS
- All mixes contained retarder
- All mixes compared to control mix (no stone screenings)

Phase 2 of Step 1 of the Study

- Extensive field samples taken of recently produced stone screenings from all sources
- Field trial placements to verify good finishing and workability with pavers
- Final mixes to be analyzed by CTL Group for performance & durability

Second Step in Study – Testing the Use of FM-5 Screenings for Bottom Lift Placements

Phase 1 of Step 2

- Prairie, Hanson, Lafarge, & BASF lab batched composite bottom lift mixes with 100% unprocessed stone screenings (FM5)

Field Trials To Be Performed

<u>Phase 2 of Step 2</u>

- **Field trials to test tear resistance and workability. Sampling being performed to test physical properties.**

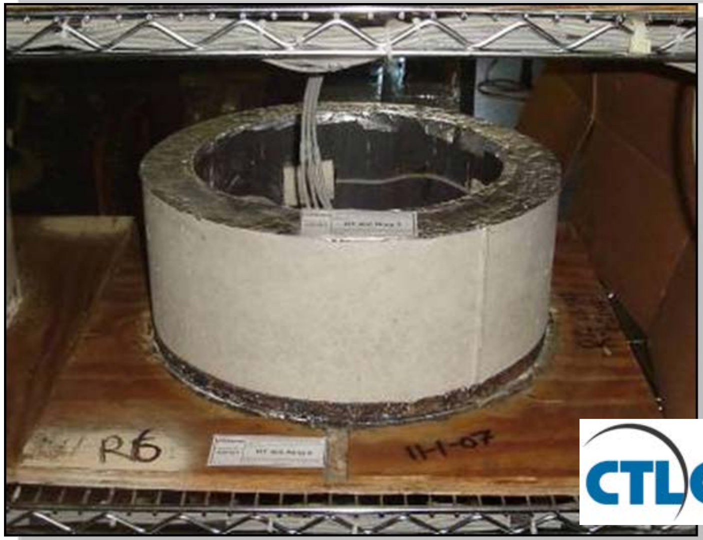
Initial Field Trials Performed March 14, 2014

- Used for Lee Street interchange / bridge project's temporary pavements (manual placement)
- Finishers noticed only minor differences between the 3 mixes
- More test placements coming to test compatibility with pavers

Step 3 Of The Study – CTL Group to Evaluate The Performance and Durability of All Mixes

- Sources of fines tested for impurities & other properties

- Field trial concrete samples tested for:
  - Shrinkage
  - ASR
  - Freeze Thaw
  - Chloride penetration
  - Sulfate resistance
  - Scaling resistance



Step 3 Of The Study – CTL Group to Evaluate The Performance and Durability of All Mixes

- **Field Validation and Practical Issues Investigated**
  - **Trial batching in cooperation with local industry**
  - **Air loss / slump loss**
  - **Slump test vs. other workability measures**
  - **Aggregate moisture checks and total water content using microwave method**
  - **Admixture dosage impacts: *air & dispersion***
  - **Variability in day to day batching, water demand, air, etc.**
  - **Bin issues**

Production Adjustments Needed

- Stone screenings must be kept dry
- Consistency more important to control
- Hopper adjustments needed to maintain a continuous plant feed

CTL Group Develops Performance Specs For More Durable Ca Al Cement Concrete

- Phase I will consist of literature and specification review
- Phase II will consist of laboratory evaluation once input is collected from the Tollway to develop a testing plan
  - Early age properties & workability
  - Open-working time
  - Strength development
  - Bond strength & early age shrinkage
  - Freeze-thaw resistance
  - Sulfate attack & ASR
  - Abrasion resistance
- Phase III will include the implementation and evaluation of a full scale bridge or roadway repair using trial mixes

Success Of Tollway Crack Resistant HPC Mixes Developed Through Research

- Only 1 micro shrinkage crack to be found in 13 bridge decks constructed in 2013 with Tollway HPC concrete
- More than 20 new decks being built in 2014
- Can we further improve it to produce 75 year life bridge decks without the need for stainless steel?

Life Cycle Assessment - Quantitative Measurement of Sustainability

Why must we quantify?

- **If it is not quantified, it is not valued**
  - Without value, it won't get done
  - Without value, it cannot be improved upon
  - Without value, there is no incentive

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The Illinois Tollway

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THANK YOU