Manufactured Sand – Impacts on Concrete Pavement Design Inputs, Construction, and Predicted Performance

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Overview

1) Background
   - Drivers of increased manufactured sand (MS) use
   - Characteristics of MS vs. natural sand (NS)
   - Advantages and disadvantages of MS
   - State specifications regarding MS
2) North/South Carolina experience with MS in paving mixtures
   - Past / future projects
   - Forecast
3) NCDOT research on MS
   - new pavement design inputs
   - predicted performance
4) Closing thoughts/questions

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Drivers of increased MS use

- Growing demand for fine aggregates
- Remote location of natural sand pits
- Issues with less-desirable NS sources (silts/clay)
- Issues with permitting new sand pits
- Environmental issues with dredging
- Increased emphasis on resource recovery and sustainability
- Risk and cost

Jeff Greenburg, Getty Images

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Worldwide problem

- US sand and gravel market valued at $8.3B in 2015 (USGS)
- Global demand for sand expected to increase 5.5% per year 2014-2018 (Freedonia Group)
- China 1/5 of world sand imports, used more sand in last 4 years than US has in last century (UN Trade Statistics Branch, 2016)
- Illegal quarrying, mafia activities, removal of sand from beaches

Police officer guarding quarry near Bogata, Colombia

(Getty Images via BBC.com)

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Worldwide problem

- UAE imported $456M of sand/stone/gravel in 2014
- Desert sand is too smooth!
- Burj Khalifa, Dubai, UAE – sand imported from Australia

BBC.com

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Characteristics of MS

- MS is produced during crushing of rock for other products
  - Byproduct of coarse aggregate production
  - Can be viewed as a waste product
- Coarse aggregate production yields 25% to 45% fines/dust (Kaya et al. 2009)
  - parent rock
  - crushing equipment - jaw, impact, roll crushers
  - crushing conditions

- MS is often more angular
  - higher water demand
  - often requires increase in water/admixture dosage
  - improved bond
  - improved aggregate interlock

	Opportunities/ Advantages of MS	Drawbacks/ Disadvantages of MS
Cost	• Cost is often lower than NS • Often available closer to job than NS, reducing hauling costs	
Sustainability (Environment / Community Impacts)	• Reduced land use • Use of waste/byproduct • Reduced emissions from hauling • Reduced traffic from hauling	• Energy consumption associated with production (?)
Performance	• MS is manufactured product – QC ensures consistency • Reduced potential for impurities • Improved bond/interlock and increased particle packing potential • Allows MS concrete to often obtain similar or improved strength properties to NS concrete • Can provide reduced permeability and improved abrasion resistance	• Increased water demand: - decreased workability - bleedwater issues - finishability challenges • Potentially higher cement requirement if source aggregate for MS is of lower quality than NS • Potential impact on equipment • Can reduce skid resistance, depending on source

LIMESTONE SAND IN CONCRETE MIXTURES

Introduction

The use of stone sand as a fine aggregate i
ion has been in disfavor not only in Michigan, but a
where this material is available. The main objectio
crete are reduced workability, excessive bleeding, d
and a tendency to produce scaling of pavement surfac

There has been a feeling on the part of cer
some of the available local sources of desirable mat
become depleted and because of the fact that there i
tain areas of Michigan a supply of stone sand, the R
the Michigan State Highway Department has been requeste
of the advisability of using stone sand in concrete construction.

The purpose of the study is to establish futur
policies in regard to the use of stone sand as a fine a
crete construction.

A REPORT ON

MANUFACTURED STONE SAND

AND ITS USE

IN CONCRETE MIXTURES

By

E.A. Finney

MICHIGAN
STATE HIGHWAY DEPARTMENT
G. Donald Kennedy
State Highway Commissioner

Research Laboratory
Testing and Research Division
Report No. 15
May 15, 1941

State Specifications Regarding MS

- Many agencies do not allow MS in concrete
- Many agencies do allow MS in concrete

- Acceptance requirements for MS:
  - Some agencies allow MS if it meets requirements for NS
  - Often conformance to AASHTO M 6 is required
  - Some agencies require MS to come from an approved source
  - Some agencies provide enhanced testing for deleterious substances

- Use restrictions for MS
  - Some agencies do not allow MS on a frictional surface
  - Some agencies restrict certain types of MS to avoid polishing issues

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Proposed (adopted today?) Iowa DOT Specifications

Section 4110. Fine Aggregate for Portland Cement Concrete

4110.01 DESCRIPTION.
Natural sands resulting from disintegration of rock through erosional processes unless specified otherwise on the source approval. Acquire mineral aggregate from an approved source as described in Materials I.M. 409.

4110.02 GRADATION.
Meet the requirements for Gradation No. 1 of the Aggregate Gradation Table, Article 4109.02.

4110.03 QUALITY.
Meet the requirements of Table 4110.03-1:

Proposed (adopted?) Iowa DOT Specifications

A. The DME may approve a gravel source to allow up to 20 percent crushed particles in the fine aggregate with the concurrence of the Chief Iowa DOT Geologist. This allowance would require a new source approval with a revised target fineness modules.

Meet the following requirements:

- The proportioning must be through a controlled and measured process.
- The crushed material must be from an approved Class 3 or 3i source with not less than 70 percent igneous and metamorphic particles and meeting the requirements of Article 4115 of the Standard Specifications.
- The fine aggregate angularity as determined using AASHTO T 304 (modified) may not exceed 42%.
- The crushed fine aggregate must meet Gradation 1 and the fineness modules restrictions listed in this section.
- The crushed material must be compared to the uncrushed and tested using ASTM C 1260 *Standard Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)* and shall not exceed the uncrushed results by 0.10% which is the Precision and Bias of the Test Method.

North/South Carolina Experience with MS in Paving Mixtures

North Carolina DOT specifications

SECTION 1014
AGGREGATE FOR PORTLAND CEMENT CONCRETE

1014-1 FINE AGGREGATE

(A) General

Use fine aggregate from sources participating in the Department's Aggregate QC/QA Program as described in Section 1006. A list of sources participating in the Department's QC/QA Program in North Carolina and adjoining states is available from the Materials and Tests Unit.

Use fine aggregate consisting of natural sand or manufactured sand having clean, durable, hard, uncoated particles, or other inert materials having similar characteristics. Produce manufactured sand from fractured stone material. Use fine aggregate free from dirt, wood, paper, burlap and all other foreign material.

MS must meet same requirements as NS for:

- Soundness (AASHTO T 104, sodium sulfate, ≤ 15% loss)
- Clay content (sand equivalent, AASHTO T 176, min % specified in table)
- Deleterious materials (AASHTO T 112, ≤ 3%
- Fine aggregate angularity (AASHTO T 304)

North Carolina DOT specifications

When natural sand is blended with natural sand, the blend shall meet the gradation for No. 2S fine aggregate. When manufactured sand is blended with natural sand or with manufactured sand, the blend shall meet the gradation for No. 2MS fine aggregate and neither component shall exceed the gradation limits on the No. 200 sieve shown in Table 1005-2.

TABLE 1005-2
AGGREGATE GRADATION FINE AGGREGATE

Std. Size #	Percentage of Total by Weight Passing								Remarks
	3/8"	#4	#8	#16	#30	#50	#100	#200	
1S	100	90-100		40-85		0-20		0-3	Blotting Sand, Asphalt Retreatment
2S	100	95-100	80-100	45-95	25-75	5-30	0-10	0-3	Concrete, Shotcrete, Grout, Subsurface Drainage, Blotting Sand
2MS		95-100	80-100	45-95	25-75	5-35	0-20	0-8[A]	Concrete, Shotcrete, Grout, Subsurface Drainage
4S		100	95-100			15-45	0-10	0-5	Mortar

North/South Carolina Experience with MS in Paving Mixtures

Greg Dean, Carolinas Concrete Paving Association

MS not preferred by contractors at this time
however,
Contractors aware MS use is likely to be increasingly necessary

- Sometimes MS mixtures trial batched for comparison, not used
- MS mixtures used as 100% replacement in a few projects
- In one notable project MS mixture was initially used, contractor needed to switch to NS mixture due to workability/strength issues
- Combination of MS/NS mixtures used on a few Carolinas paving projects
  - Improves mixture economics and workability

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I-85 Widening – Concord, NC

Interview with QC Manager

- Contractor's batch plant was basically on quarry site
- "MS was stupid cheap. There was no way we were NOT going to use it."

https://www.laneconstruct.com/portfolio/i-85-widening

- 100% MS mixture used
  - Higher water demand
  - More bleedwater
  - More difficult to finish
  - Strengths slightly lower than NS mixtures
  - "We made it work."

I-85 Widening – Concord, NC

- 80 lane miles successfully completed
- Finishability may affect initial IRI
  - paving rate may have also played a role

- Adjacent I-485/85 interchange project
  - 100% NS
  - IRI 30-40 in/mile after first diamond grind
- I-85 Concord, NC widening project
  - 100% MS
  - IRI approx. 70 in/mile after first grind, needed some localized additional grinding

I-85 Widening – Concord, NC

Interview with Paving Superintendent

- Confirmed higher initial IRI from initial profilograph readings
- Finishers disliked MS mixture
- Tougher on equipment
  - Use Dowel Bar Inserter technology
  - Harsher MS mixture resulted in additional wear to nose pieces, overbuild devices on oscillating correcting beam
  - Similar sized projects
    - 100% NS mixture – required 1 replacement set of nose pieces, 1 set of overbuild devices
    - 100% MS mixture – required 5 sets of each

Company Execs:
"More of it is coming (MS), so you better get used to it."

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I-85 Reconstruction and Widening – Gaffney, SC

- 21 miles, 6 lanes = 126 lane miles
- Contractor concerned about consistent availability of NS
- Also concerned about availability of trucks to haul NS
  - Potential impacts to schedule

Using 50/50 MS/NS blend

- Capitalize on some cost savings
- Mitigate mixture impacts of MS
- Mixture is "a little bit stickier and a little bit tougher to work with" but do-able
- Higher strengths on the back end from MS mixture

http://www.85widening.com

I-85/I-385 Gateway – Greenville, SC

Interview with Project Manager

- 260,000 SY of pavement, with 10-15% shoulders
- 100% MS mixture utilized
- Water demand was considered, mitigated

- Paving in mid-day, summertime no issues with bleedwater
- Paving at night when temperature cooler – more bleeding
- Somewhat lower strength than NS mixtures, depending on source

http://www.85385gateway.com

Other Considerations

From Project Manager

- Consider available plant equipment/operations
  - Use of blends of MS/NS helps improve mixture workability, but requires an extra bin
  - If adding intermediate aggregate to optimize mixture gradation, would require ANOTHER bin

- If plant can support blends, can optimize MS
  - 70/30 blends have been used in other Southeastern US projects
  - Balance between economy and workability/other impacts

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Impact of Local M-EPDG Calibration Using Sustainable Materials

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Background

Mechanistic-Empirical Pavement Design (M-EPDG)

- NCDOT has used Pavement ME Design software program for design of pavements (based on M-EPDG)
- Best results are obtained using locally calibrated input values
- Local inputs for concrete pavements needed
- Thermal inputs are of particular interest

Durable/Sustainable Materials

- Portland Limestone Cements (PLC) have been shown to reduce the carbon footprint of concrete
- MS increasingly utilized
- Increased use of fly ash

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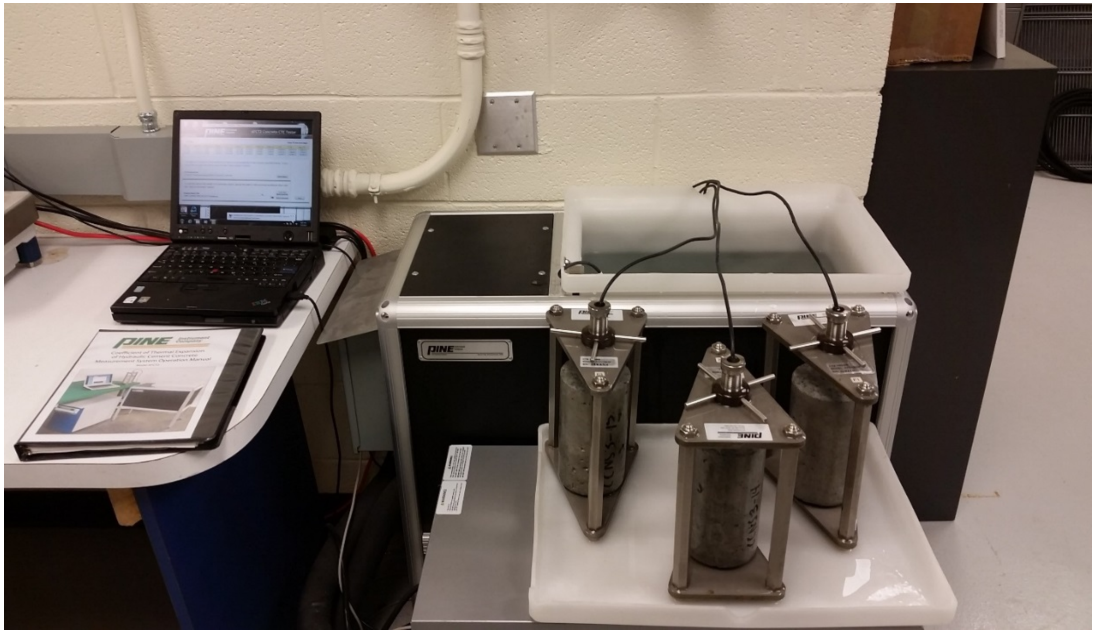
Mixture ID*	Material Types				Selected Proportions, pcy	
	Cement	Fly Ash	Coarse Aggregate	Fine Aggregate	Cement	Fly Ash
C.A.N.M	OPC Source A	None	Coastal	Manuf. Sand	573	0
M.A.N.M		None	Mountain	Manuf. Sand	573	0
P.A.N.M		None	Piedmont	Manuf. Sand	573	0
P.A.N.N		None		Natural Sand	573	0
P.A.A.M		Source A		Manuf. Sand	460	137
P.A.B.M		Source B		Manuf. Sand	460	137
C.B.N.M	OPC Source B	None	Coastal	Manuf. Sand	573	0
M.B.N.M		None	Mountain	Manuf. Sand	573	0
P.B.N.M		None	Piedmont	Manuf. Sand	573	0
P.B.N.N		None		Natural Sand	573	0
P.B.A.M		Source A		Manuf. Sand	460	137
P.B.B.M		Source B		Manuf. Sand	460	137
C.BL.N.M	PLC (produced from OPC Source B)	None	Coastal	Manuf. Sand	573	0
M.BL.N.M		None	Mountain	Manuf. Sand	573	0
P.BL.N.M		None	Piedmont	Manuf. Sand	573	0
P.BL.N.N		None		Natural Sand	573	0
P.BL.A.M		Source A		Manuf. Sand	460	137
P.BL.B.M		Source B		Manuf. Sand	460	137

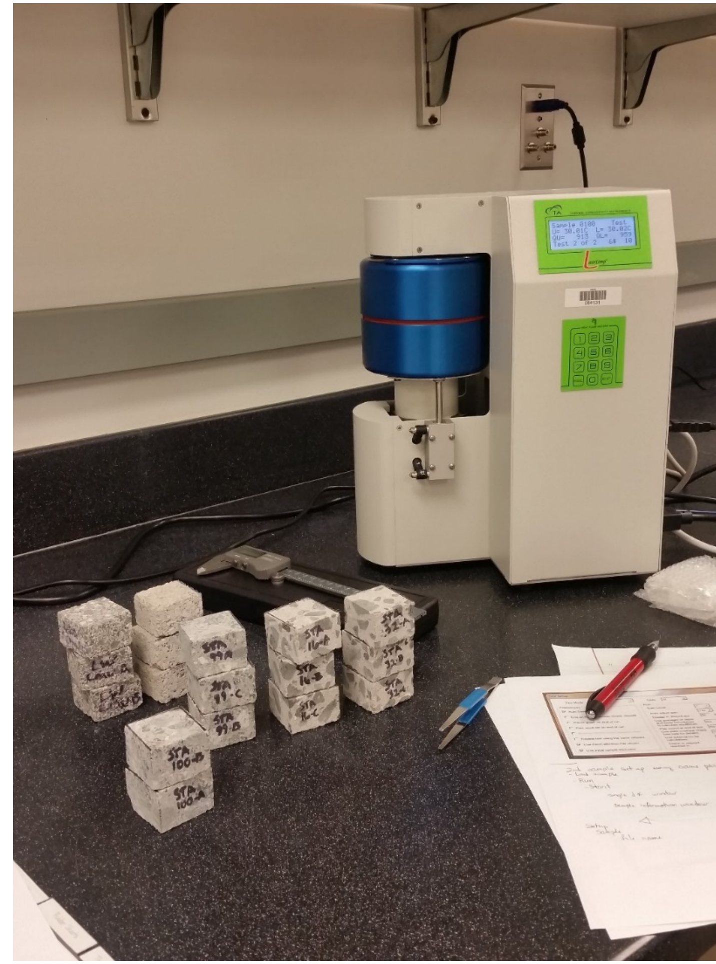
*Note: Explanation of Mixture ID coding: First letter, coarse aggregate type (C = Coastal, P = Piedmont, M = Mountain), Second letter, cement type (A = OPC source A, B = OPC source B, BL = PLC), Third letter, fly ash type (N = None, A = fly ash source A, B = fly ash source B), Fourth letter, fine aggregate type: M = manufactured sand, N = natural sand

Laboratory Testing Program

	Test	Protocol	Age(s) in days	Replicates
Fresh	Air content	ASTM C231 and Super air meter	Fresh	1 each type of test, each batch
	Slump	ASTM C143	Fresh	1
	Fresh density (unit weight)	ASTM C138	Fresh	1
	Temperature	AASHTO T309	Fresh	1
Hardened	Compressive strength	ASTM C39	3, 7, 28, 90	3 each age
	Resistivity	AASHTO TP95-11	3, 7, 28, 90	3 each age
	Modulus of rupture	ASTM C78	28	2
	Modulus of elasticity and Poisson's ratio	ASTM C469	28	2
	Coefficient of thermal expansion	AASHTO T336	28	3
	Heat capacity	ASTM C2766	56	3
	Thermal conductivity	ASTM E1952	56	3
	Shrinkage	ASTM C157	per standard	3
	Cracking potential	ASTM C1581	per standard	3
	Rapid chloride permeability	ASTM C1202	28	2
	Freezing and thawing resistance	ASTM C666, procedure A	per standard	3
	Thaumasite attack **	CSA A3004-C8	per standard	6

Thermal Property Test Equipment





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Summary of Findings - Thermal Properties

Coefficient of Thermal Expansion

- Measured CTE values are consistently lower than the CTE values currently used by NCDOT and significantly lower than the recommended values suggested in the MEPDG literature for granitic gneiss and limestone.

GOOD NEWS! :)

- Mixtures containing NS had a notably higher coefficient of thermal expansion than those containing the MS.
  - Movement towards use of MS associated with lower CTE and potentially improved thermal performance
  - Implications on CTE for concrete mixtures that are blends of manufactured and natural sand?

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Summary of Findings - Thermal Properties

Thermal Conductivity

- MS mixtures – suggested input 0.80 to 0.90 BTU/(ft·hr·°F)
  - Significantly lower than the default input value is 1.25 BTU/(ft·hr·°F).
- NS mixtures - had a higher thermal conductivity, closer to the default value of 1.25 BTU/(ft·hr·°F).

Heat Capacity

- All measured values for heat capacity (typically around 0.20 BTU/lb·ft) were notably lower than the default values suggested in the MEPDG literature (0.28 BTU/lb·ft)
- The effect of sand type on heat capacity is not readily evident.

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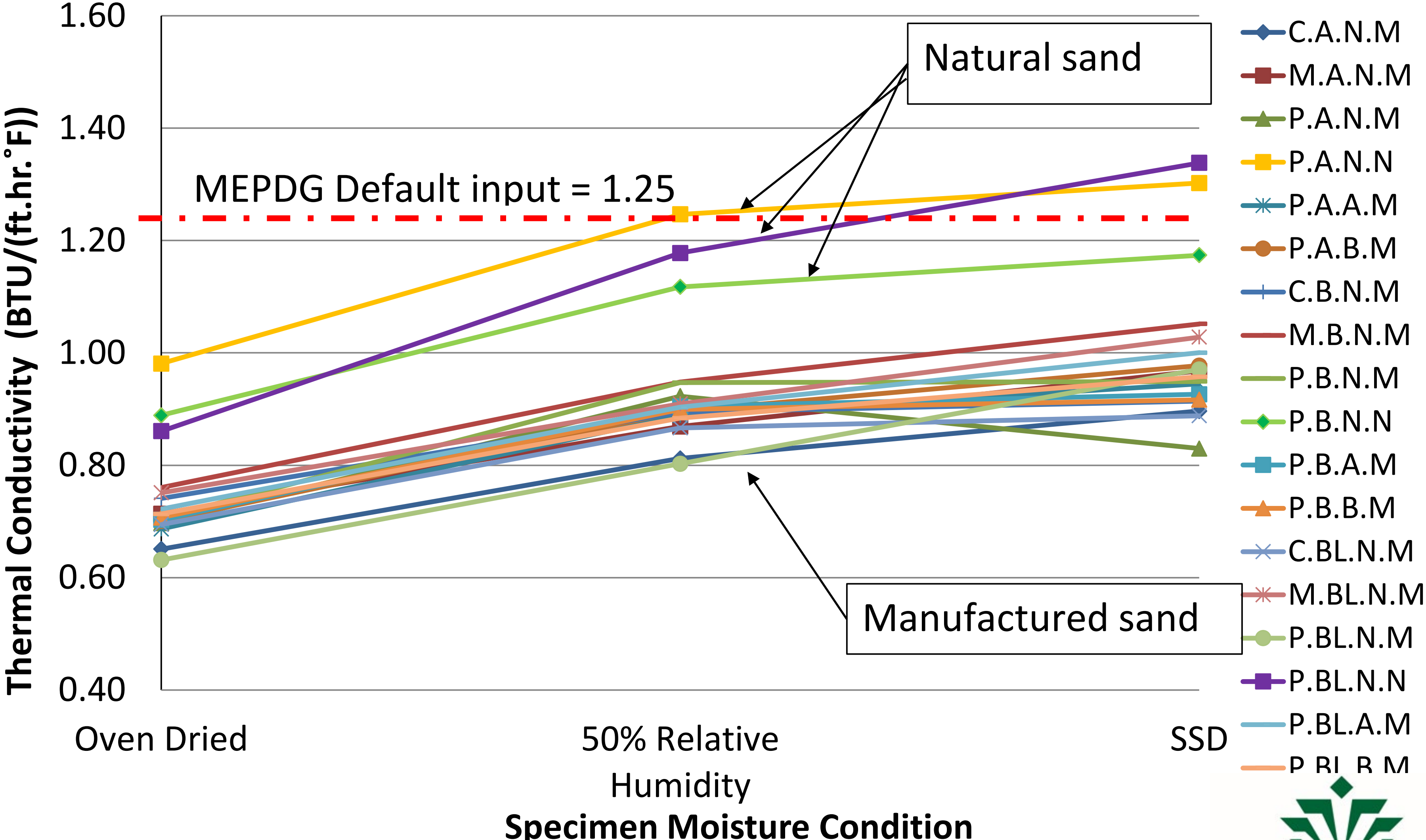
Influence of Specimen Moisture Condition on Thermal Conductivity



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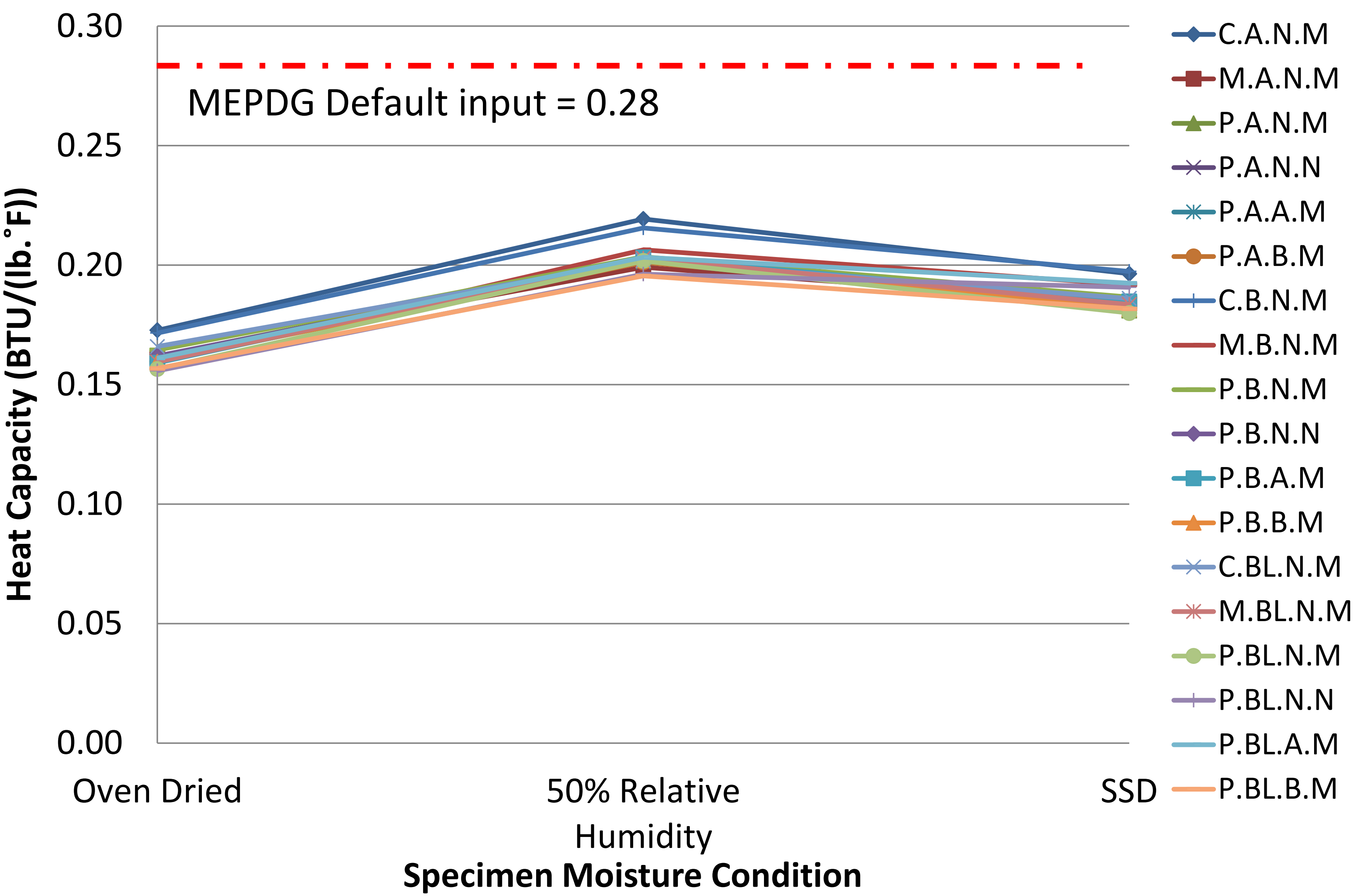
Impact of Specimen Moisture Condition Heat Capacity



Proposed Catalog of Inputs

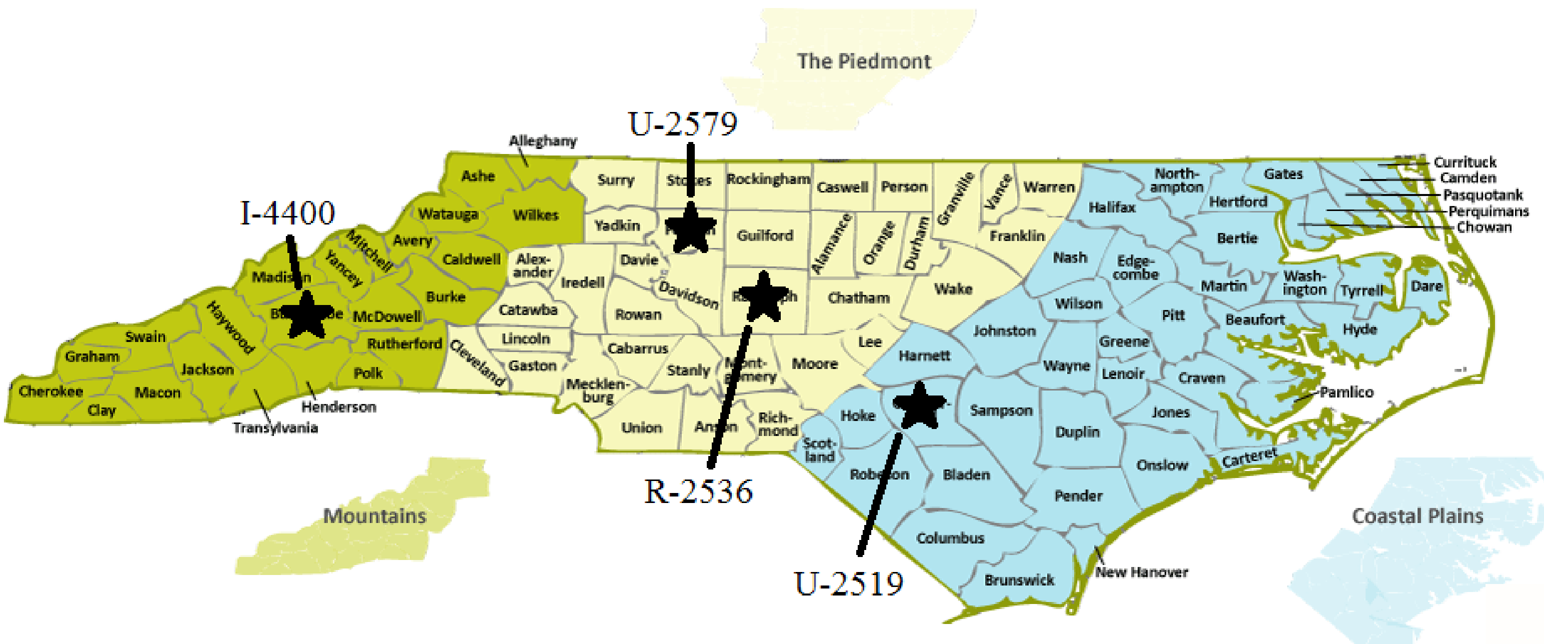
Materials			M-EPDG Input							
Coarse Aggr.	Fine Aggr.	Fly Ash	Unit Wt (pcf)	MOE (psi)	Pois. Ratio	MOR (psi)	CTE, (in/in/°F)	Heat Cap. BTU/(lb·°F)	Thermal Cond. (BTU/(ft·hr·°F)
Piedmont	Man. Sand	No	145	3,000,000	0.19	660	4.63×10^{-6}	0.22	0.95
Piedmont	Man. Sand	Yes	142	2,500,000			4.57×10^{-6}		0.90
Piedmont	Natural Sand	No	142	3,400,000	0.16	740	5.40×10^{-6}		1.20
Mountain	Man. Sand	No	146	2,700,000	0.19	660	4.56×10^{-6}		0.95
Coastal	Man. Sand	No	139	3,500,000			4.30×10^{-6}		0.90

NCDOT often utilized	150	4,200,000	0.17 0.20	650 690	6.0×10^{-6}	0.28	1.25
MEPDG suggested	150	4,200,000	0.20	690	5.5×10^{-6}	0.28	1.25

Implications of New Inputs on Concrete Pavement Design

NCDOT Selected Projects of Interest

- Project: I-4400 – I-26 in Buncombe Co.
- Project: U-2579 – W-S Northern Beltway, Forsyth Co.
- Project: R-2536 – Asheboro Bypass, Randolph Co.
- Project: U-2519 – Fayetteville Outer Loop, Cumberland Co.



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Sensitivity Analysis Results
Effect of Increase of Each Input on Predicted Distress

Input	Terminal IRI (in/mile)	Mean Joint Faulting (in)	Transverse Cracking (% slabs cracked)
Unit weight ↑	Decrease (VS)	Decrease (S)	Decrease (N)
Modulus of rupture ↑	Decrease (VS)	Neutral (N)	Decrease (VS)
Modulus of elasticity ↑	Increase (S)	Increase (S)	Increase (S)
Poisson's ratio ↑	Increase (S)	Increase (S)	Increase (S)
CTE ↑	Increase (VS)	Increase (VS)	Increase (S)
Thermal conductivity ↑	Increase, then decrease (N)	Increase (S)	Decrease (VS)
Heat Capacity ↑	Decrease (N)	Neutral (N)	Decrease (S)

VS = Very Sensitive, S = Sensitive, N = Neutral

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Implications on Concrete Pavement Design

- Recommended catalog of PCC inputs for M-EPDG was presented for use in local calibration efforts.
- Some recommended inputs differ significantly from MEPDG default/recommended values

- Coarse aggregate type not highly influential in MEPDG inputs

Shift in use from NS to MS may have performance implications on North Carolina PCC pavements

Predicted to be mostly favorable if workability challenges are not an issue

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Thank you!

- Greg Dean – Carolinas Concrete Paving Association
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- John Romaine, Adam Bruner – Zachry Construction
- Clark Morrison, Brian Hunter, Sam Fredrick, Chris Peoples, Nilesh Surti - NCDOT

- Brett Tempest – UNC Charlotte
- Edward Blanchard, Clayton Medlin, Rohit Chimmula – formerly UNC Charlotte

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Resources

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