SYSTEM DESIGN, LAB AND FIELD EVALUATION OF DRY PROCESS CRUMB RUBBER MODIFIED ASPHALT

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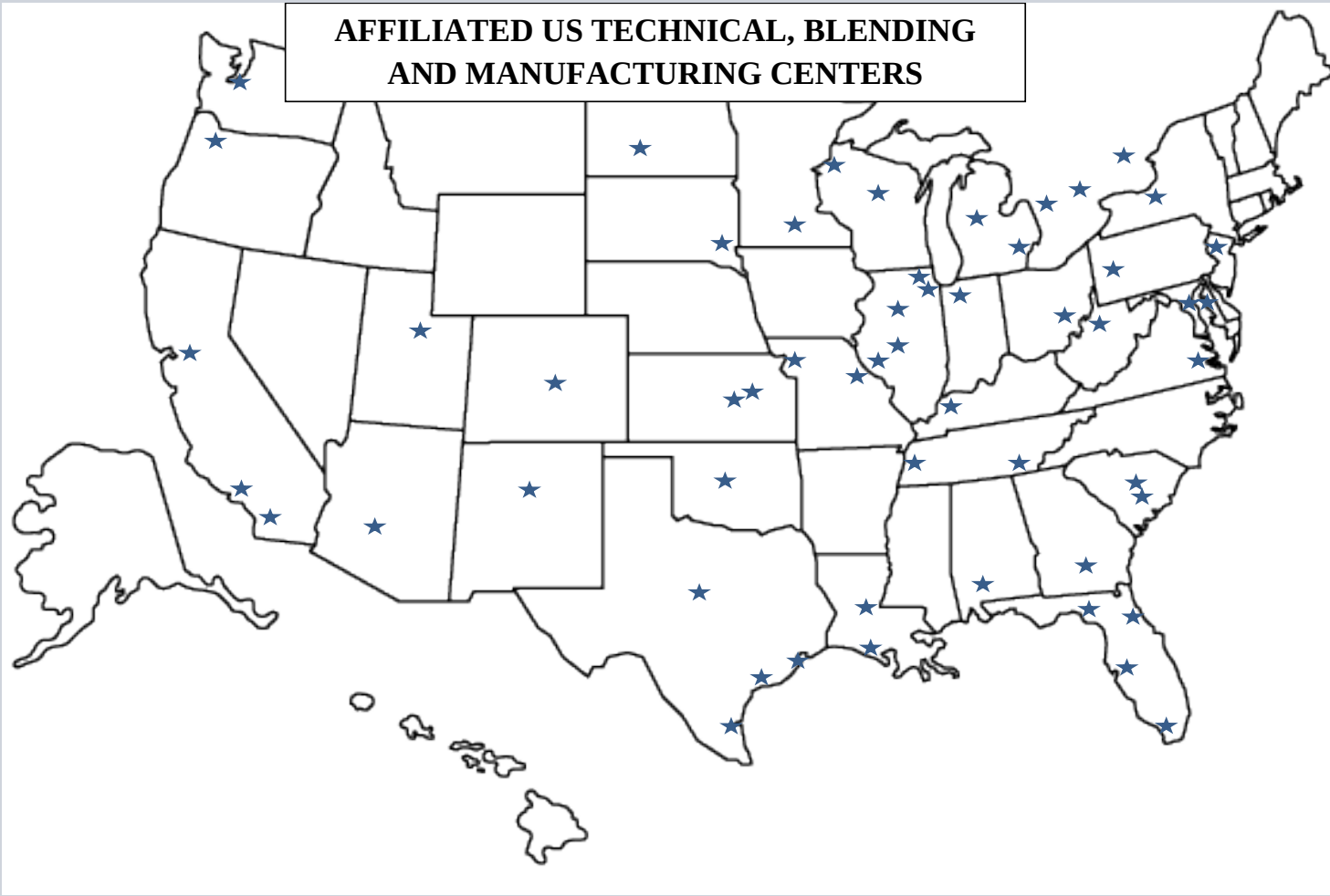
- FOCUS ON SUSTAINABILITY



MY TAKE ON “RUBBER ASPHALT PHILOSOPHY”

- RECYCLED RUBBER MARKET IN TROUBLE: BURNER MARKET GOING AWAY
- RUBBER IS COMING TO ASPHALT
- WHERE DO WE GET MORE VALUE?
  - PAY A PREMIUM TO USE IT AS A PART OF AN ENGINEERED BINDER MODIFIER
  - USE IT AS A MIX ADDITIVE
- THE LATTER ALTERNATIVE DESERVES CAREFUL CONSIDERATION

WHAT IS THE PROBLEM WITH RUBBER USE IN ASPHALT?

- DIFFERENT PARTIES, DIFFERENT ANSWERS
- DOTS
  - QUALITY PAVEMENT
  - RELIABLE DELIVERY SYSTEM
  - VERIFICATION
  - SUSTAINABILITY
- CONTRACTORS
  - EASE OF USE
  - TRUE COST SAVINGS
- STATES HAVE OPTIONS: REQUIREMENT OR MARKET SOLUTIONS
- GIVEN A CHOICE, CONTRACTORS WILL OPT OUT OF WET PROCESS RUBBER FOR PMA

WET PROCESS RUBBER MODIFICATION

- AT TEMPERATURES OF 325-350F, -10 TO -80 RECYCLED CRUMB RUBBER BLENDED, “DIGESTED” WITH BINDER
- CRUMB RUBBER ABSORBS BINDER LIGHTER ENDS INTO PORES
- RUBBER SOFTENS AND SWELLS UP TO 3-5 TIMES ITS ORIGINAL SIZE
- ABSORPTION INCREASES BINDER VISCOSITY AND RUT RESISTANCE
- REACTED RUBBER INCREASES FLEXIBILITY OF PAVEMENT AND CRACKING RESISTANCE
- DIFFICULT TO MANUFACTURE AND PLACE
- SETTLEMENT, VERIFICATION ISSUES

DRY PROCESS CRUMB RUBBER MODIFICATION OF ASPHALT

- DIFFICULT HISTORY
  - PROBLEMS IN THE LAB
  - FIELD EXPERIENCE HAS HAD BOTH SUCCESSES AND FAILURES
- TECHNOLOGY PROBLEMS
  - LAB PROCEDURES NOT WELL UNDERSTOOD
  - RUBBER/BINDER INTERACTION NOT WELL UNDERSTOOD
  - BINDER VARIABILITY
  - BINDER TEMPERATURE
  - TYPE OF CRUMB RUBBER (CRYO OR AMBIENT)
  - RUBBER PSD
  - CURING OR DIGESTION TIME
  - FIELD ISSUES
    - WORKABILITY
    - COMPACTION

PERFORMANCE/RELIABILITY IMPROVING

- IN 2006, GDOT BEGAN USING DRY PROCESS IN MA PROJECTS
- GDOT WANTED MORE SUSTAINABLE ROADS, PRICE COMPETITION
- APPROACH WAS DESIGNED TO MANAGE THE PROCESS AND REDUCE UNCERTAINTIES
- THE PROGRAM EXPANDED, NOW 2000 LANE MILES IN SERVICE
- IN 2012 AND 2015, GDOT CONTRACTED GEORGIA SOUTHERN UNIVERSITY (SHEN ET AL) TO EVALUATE THREE INTERSTATE PROJECTS
- HERE IS A BRIEF SYNOPSIS OF THEIR FINDINGS

DRY PROCESS DESCRIPTION

- ENGINEERED RUBBER PRODUCT
- ASTM COMPLIANT MINUS 30 CRUMB RUBBER
- ISO-COMPLIANT QUALITY CONTROL PROCESS FOR RUBBER PRODUCTS
- PNEUMATIC CONVEYANCE INTO PLANT (RAP COLLAR)
  - MODIFIED FIBER MACHINE
  - MANAGED ACCURACY/LOSS IN WEIGHT
  - PLUS OR MINUS 1% 1 MIN. WT VARIABILITY
- CR OUTPUT SLAVED TO BINDER PUMP

PNEUMATIC INJECTION UNIT

UNIT REPLENTISHMENT

METERED FEEDING AND INJECTION

FEED INTO PLANT

GDOT DRY PROCESS PROGRAM

- 1 MM TONS OF PAVEMENT PLACED SINCE 2007
- SMA, PEM, VARIOUS SUPERPAVE MIXTURES
- THREE EARLY INTERSTATE PROJECTS
  - I-75 PERRY, 2007, PEM
  - I-20 AUGUSTA, 2009, PEM OVER SMA
  - I-75 VALDOSTA, 2009, PEM
- ALL PROJECTS USED A 76, -22 PMA LANE AS A CONTROL

Test Section			Thickness (Inch)	Date (Year)	Length (Mile)	Orientation
I-75 Valdosta	Rubberized PEM	Surface	1.25	2009	17	Southbound
	Control PEM	Surface	1.25	2009	17	Northbound
I-20 Augusta	Rubberized PEM	Surface	1.25	2009	2.15	East- and Westbound
	Rubberized SMA	Underlayer	2.0	2009	2.15	Eastbound
	Control SMA	Underlayer	2.0	2009	2.15	Westbound
I-75 Perry	Rubberized PEM	Surface	1.25	2007	1	Northbound
	Control PEM	Surface	1.25	2007	1	Northbound

MATERIALS: I-75 VALDOSTA, PERRY

- RUBBERIZED PEM, PMA PEM
- 30 MESH ECR, 10% OF BINDER WEIGHT ADDED TO RUBBERIZED MIX
- OAC: 6%
- CONTROL AND RUBBERIZED BINDER MET PG 76, -22 AASHTO M 320 SPEC
- 78 DEGREE PHASE ANGLE FOR RUBBERIZED ASPHALT
- AGGREGATE:

Sieve	3/4"	1/2"	3/8"	N0. 4	N0. 8	N0. 200
Percentage Passing (%)	100	90	50	14	8.0	3.0

MATERIALS: I-20 AUGUSTA

- PEM: CONTROL RUBBERIZED, SAME AS I-75
- SMA OAC 6% FOR BOTH MIXES
- SMA WESTBOUND: HYBRID SMA WITH 11.4% CRUMB RUBBER ADDED
- SMA EASTBOUND: RUBBERIZED SMA, 10% RUBBER CONTENT, NO PMA
- SMA AGGREGATE

Sieve	3/4"	1/2"	3/8"	NO. 4	NO. 8	NO. 50	NO. 200
Percentage Passing (%)	100	87	59	26	21	12	9

THREE AND FIVE YEAR FIELD EVALUATIONS

- GDOT PACES FIELD EVALUATION PROCESS FOLLOWED
- TWENTY REPRESENTATIVE SECTIONS SELECTED FOR INSPECTION, CORING AND ANALYSIS

I-75 PERRY FIELD EVALUATION

Item		Control PEM	Rubberized PEM
Rut Depth (1/16 inch)	section 1	2	1
	section 2	2	1
	section 3	3	1
	section 4	2	2
	section 5	3	1
	section 6	2	2
	section 7	2	1
	section 8	2	1
Raveling (%)		0	Length of 24' at the beginning
Bleeding (%)		0	0
Pushing (%)		0	0
Reflection Cracking		Interval: 30´3´´, Length: 12´, Width: 0.5´´-2´´	

I-20 AUGUSTA FIELD EVALUATION

Item		Westbound	Eastbound
Rut Depth (1/16 inch)	section 1	0	0
	section 2	0	0
	section 3	0	0
	section 4	0	0
Cracking (%)		0	0
Raveling (%)		0	0
Bleeding (%)		0	0
Pushing (%)		0	0

I-75 VALDOSTA FIELD INVESTIGATION

Item		Control PEM	Rubberized PEM
Rut Depth (1/16 inch)	section 1	0	0
	section 2	0	0
	section 3	0	0
	section 4	0	0
	section 5	0	0
	section 6	0	0
	section 7	1	0
	section 8	1	0
Cracking (%)		0	0
Raveling (%)		0	0
Bleeding (%)		0	0
Pushing (%)		0	0

STATE ROUTE 247 SMA FIELD EVALUATION: 3 YRS.

Item		Control OGFC	Rubberized OGFC (dry)	Rubberized OGFC (wet)
Rut Depth (1/16 inch)	section 1	2	3	2
	section 2	2	2	3
	section 3	3	2	2
	section 4	2	3	3
	section 5	2	N/A	0
Cracking (%)		0	0	0
Raveling (%)		0	0	0
Bleeding (%)		0	0	0
Pushing (%)		0	0	0

FIELD EVALUATION CONCLUSIONS

- NO SIGNIFICANT DIFFERENCE IN MEASURED RUTTING, RAVELLING, BLEEDING, PUSHING, REFLECTION BETWEEN RUBBER AND PMA PAVEMENTS
- THE NSD TREND CONTINUES INTO YEARS 8 AND 10
- PERRY 2016: BOTH PEM PAVEMENTS ARE ONE-TO TWO YEARS OUT FROM REPLACEMENT: SIMILAR MAINTENANCE CYCLE

LAB INVESTIGATION: PHASE 1

CORING PLAN

- SAMPLES SPLIT BETWEEN CRM ASPHALT AND CONTROL
- I-75 PERRY: 12 CORES
- I-75 VALDOSTA: 24 CORES
- I-20 AUGUSTA: 12 CORES
- TESTING PLAN INCLUDED:
- MARSHAL STABILITY: AASHTO T-245
- PERMEABILITY: ASTM FALLING HEAD PROCEDURE (ASTM 129-01)
- CANTABRO

THREE AND FIVE YEAR CORE EVALUATIONS

DRY PROCESS

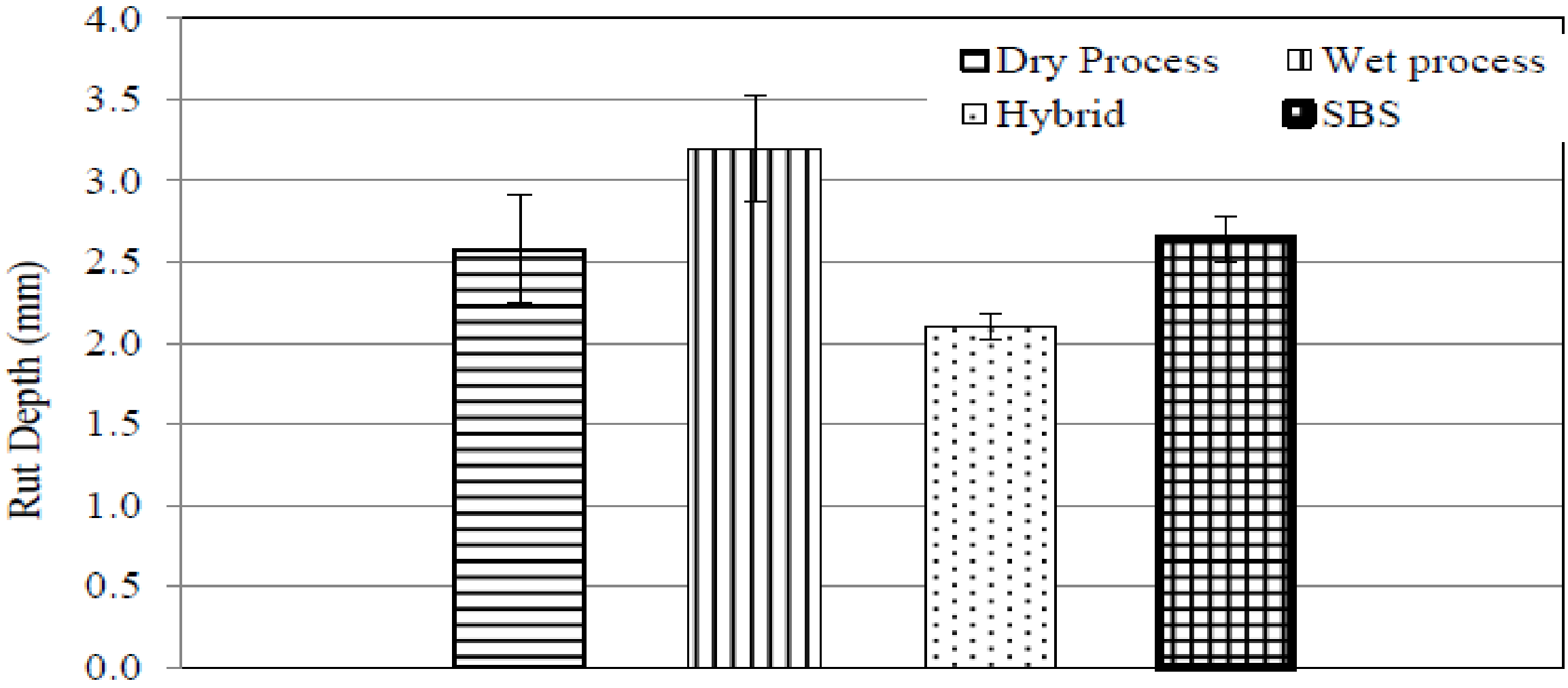
- HIGHER PERMEABILITY
- GREATER MARSHALL STABILITY
- LESS FLOW
- SIMILAR RESISTANCE TO PERMANENT DEFORMATION
- BOTH WHEEL PATH AND CENTER EVALUATED

PMA

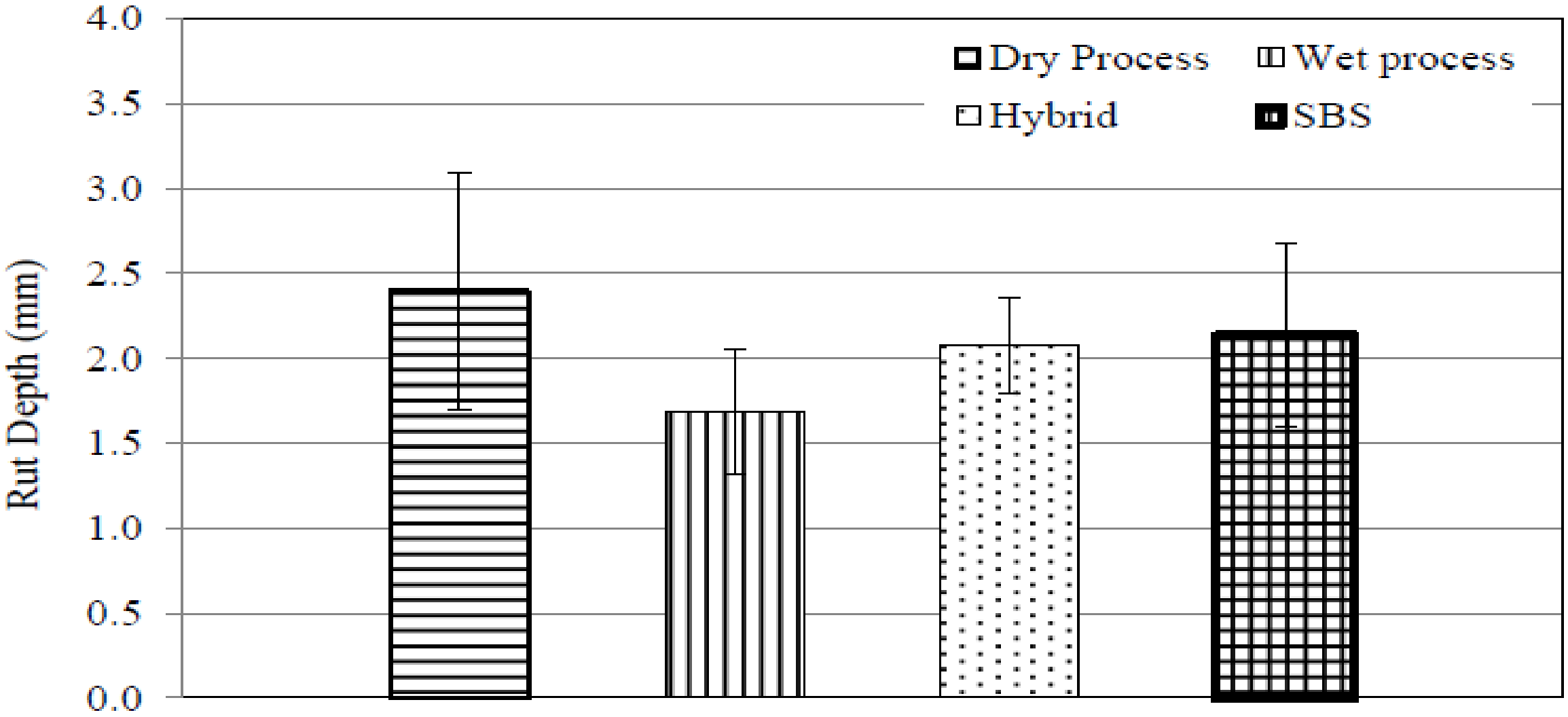
- LOWER CANTABRO LOSSES
- SIMILAR RESISTANCE TO PERMANENT DEFORMATION
- BOTH WHEEL PATH AND CENTER EVALUATED

LAB INVESTIGATION PHASE 2: IMPACT ON BINDER AND MIX DURABILITY

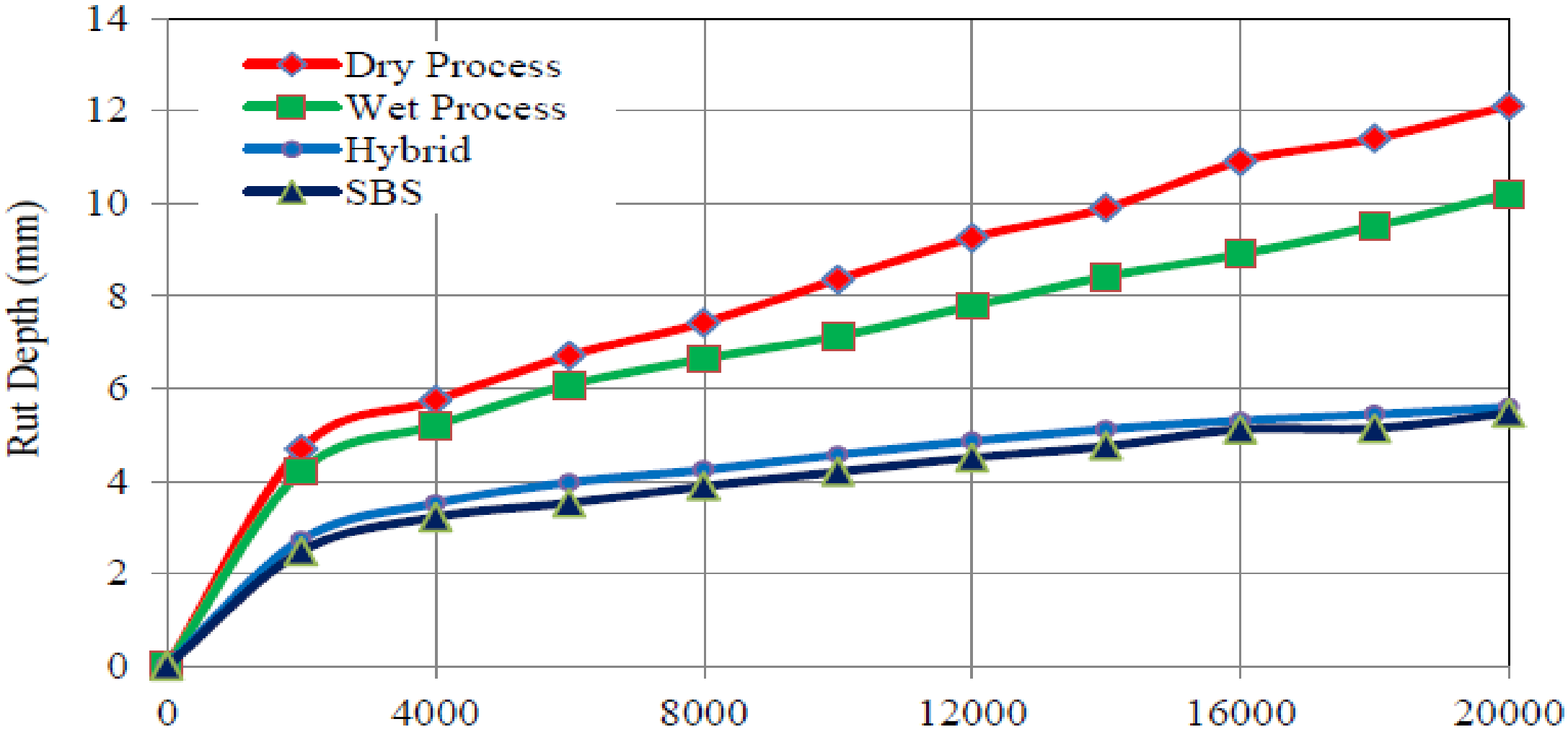
PEM AVERAGE RUT DEPTHS



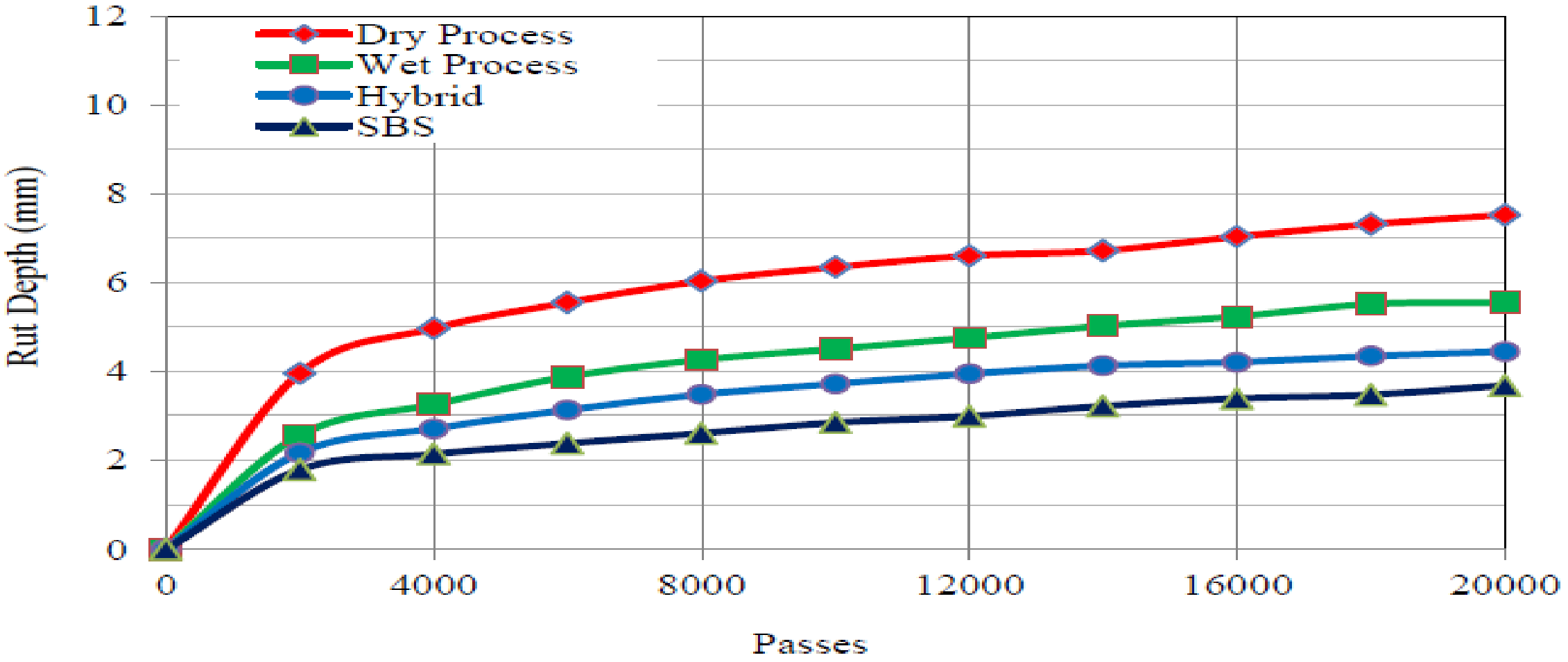
SMA AVERAGE RUT DEPTHS



RETROFITTED APA EVALUATION OF MOISTURE SUSCEPTIBILITY: PEM



RETROFITTED APA EVALUATION OF MOISTURE SUSCEPTIBILITY: SMA



MOISTURE SUSCEPTIBILITY

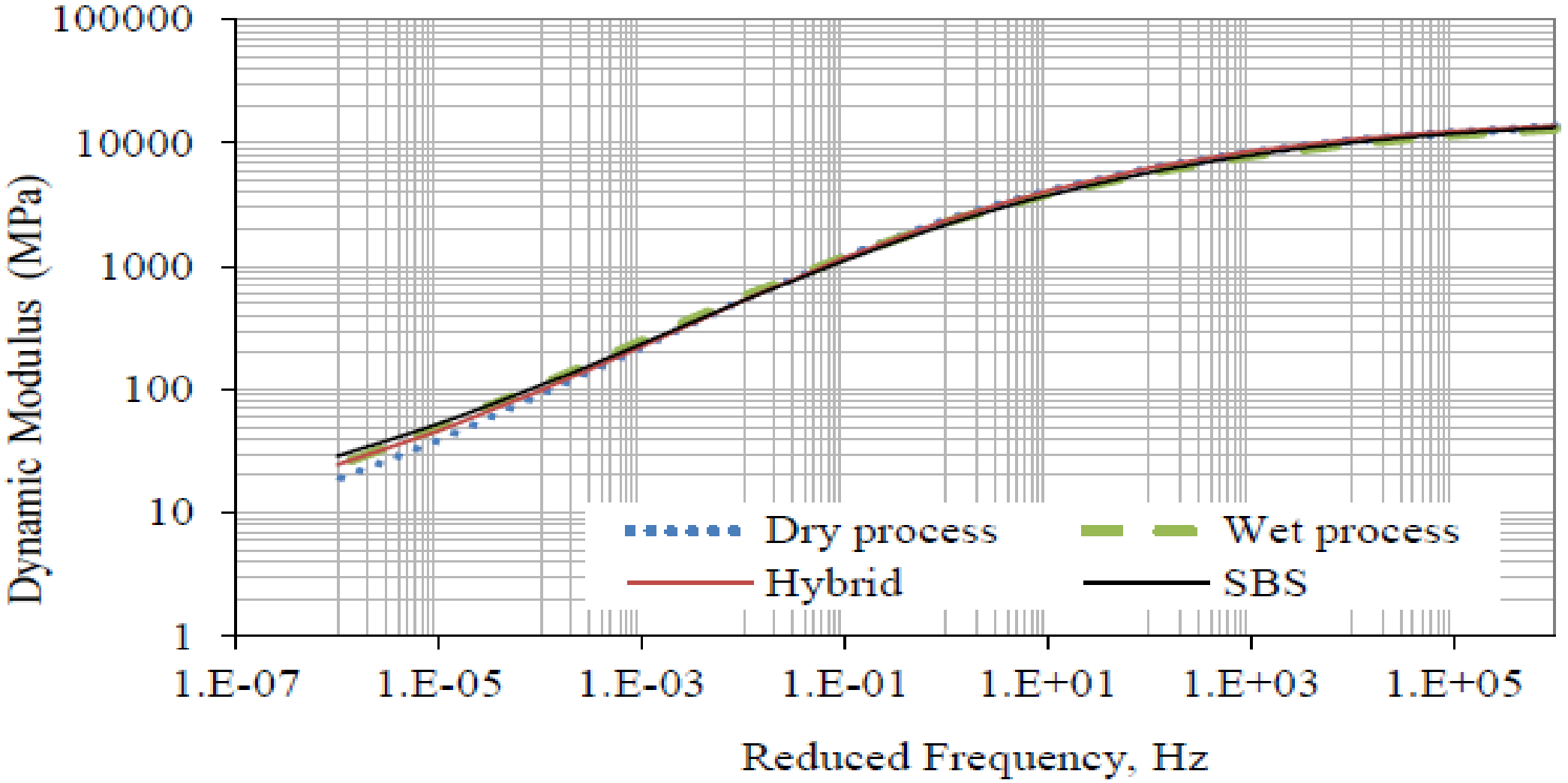
- NONE OF THE SAMPLES HAD SIGNIFICANT MOISTURE DAMAGE AFTER 20,000 PASSES, BUT RUBBER MIXES WERE MOST SUSCEPTIBLE
- NO INFLECTION STRIPPING POINTS
- ALL MIXES PASSED GDOT MINIMUM STANDARD

DRAIN DOWN TESTING

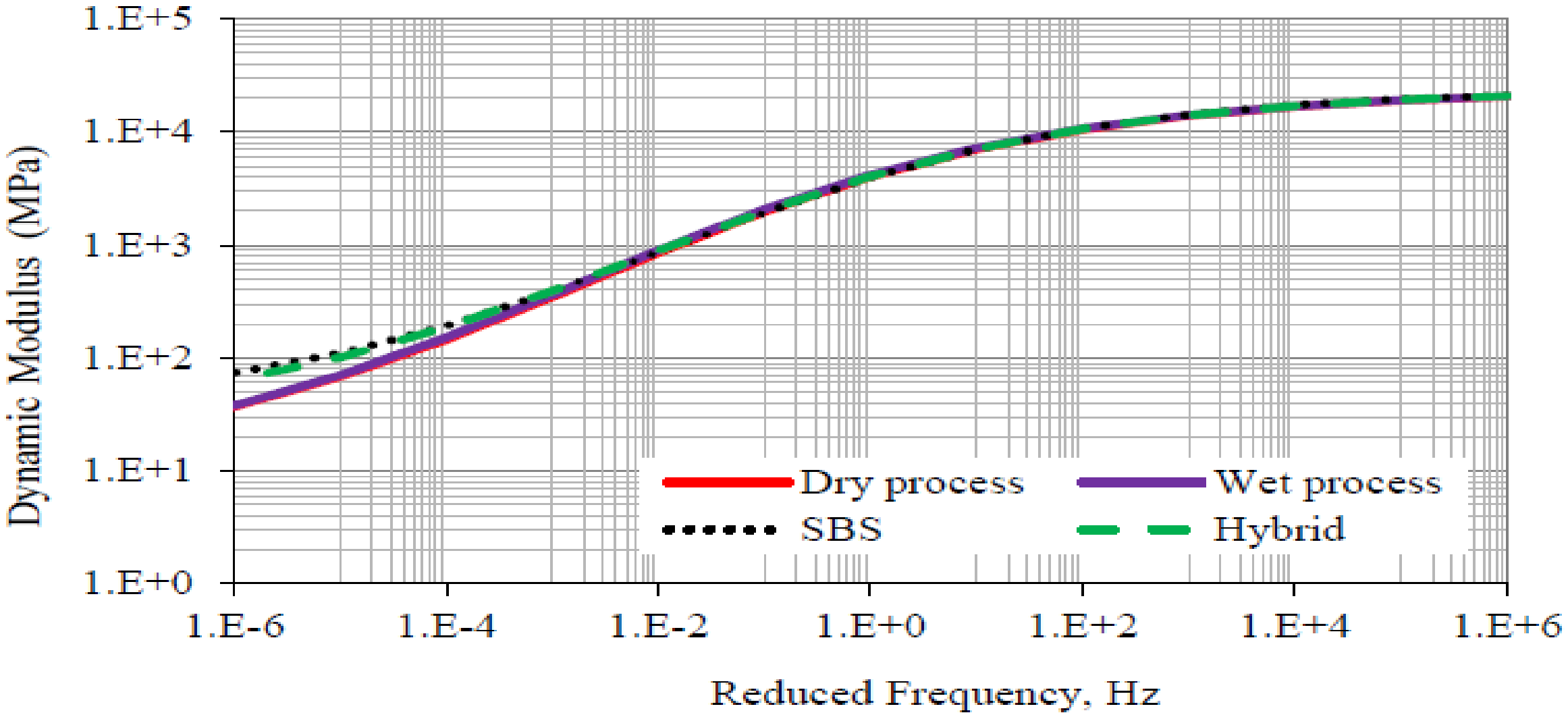
- ALL MIXES PASSED GDOT REQUIREMENTS WITH FIBER ADDITIONS

Mix Type		Drain-down (%)
PEM	Dry process	0.00
	Wet process	0.00
	Hybrid	0.04
	SBS	0.08
SMA	Dry process	0.00
	Wet process	0.00
	Hybrid	0.00
	SBS	0.00

PEM MASTER CURVE OF DYNAMIC MODULI



SMA MASTER CURVE OF DYNAMIC MODULI



DYNAMIC MODULUS CONCLUSIONS

- NSD BETWEEN MIX DESIGNS AT ALL FREQUENCIES
- DRY PROCESS SLIGHTLY LOWER THAN PMR AT LOWER FREQUENCIES

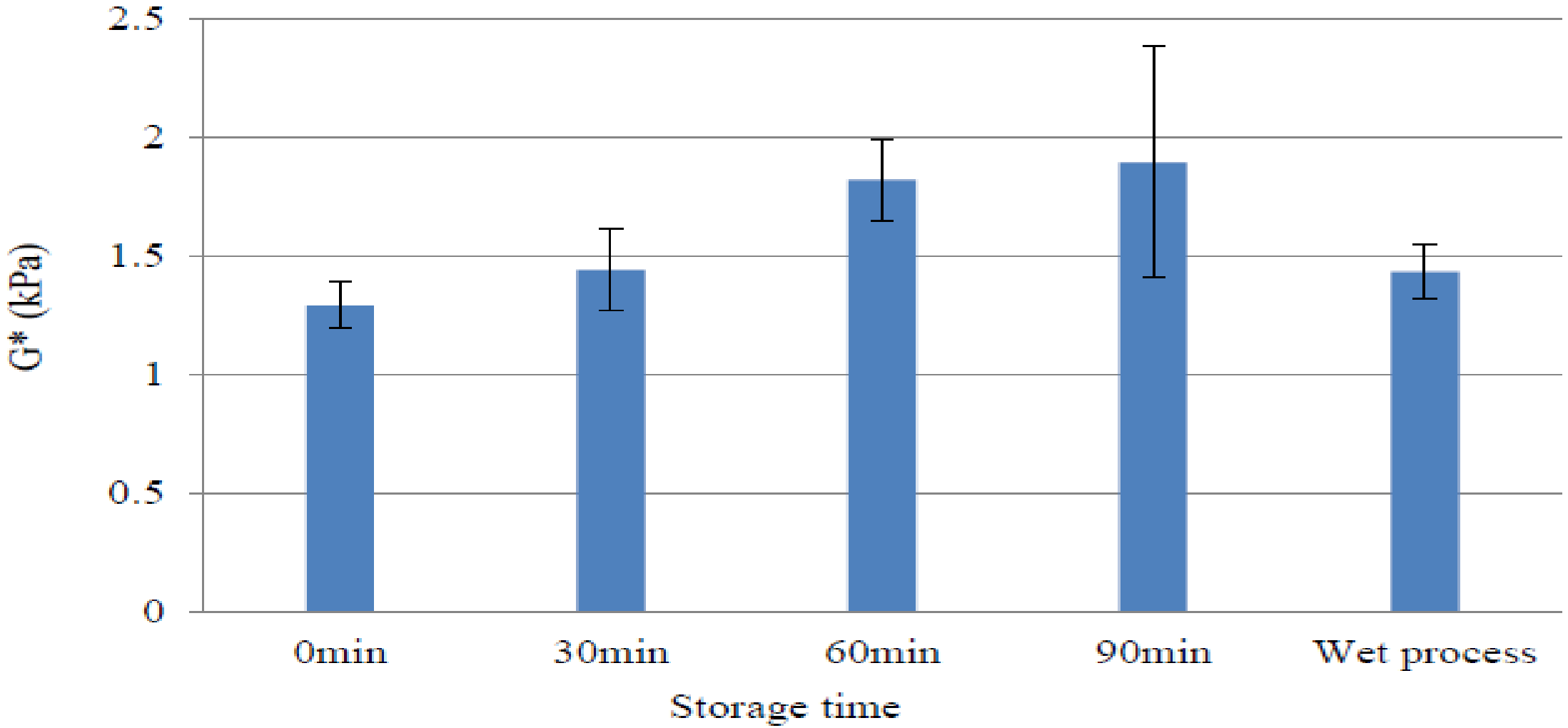
FATIGUE EVALUATION

- SIMPLIFIED VISCO-ELASTIC CONTINUUM DAMAGE MODEL USED TO ASSESS FATIGUE
- PEM
  - WET AND DRY PROCESS RUBBER, SIMILAR RESULTS
  - PMA AND HYBRID MUCH BETTER THAN RUBBER MIXES
- SMA
  - WET AND DRY PROCESS RUBBER, SIMILAR RESULTS
  - BETTER THAN PMA AND HYBRID AT LOWER TEMPS, WORSE AT HIGHER TEMPERATURES

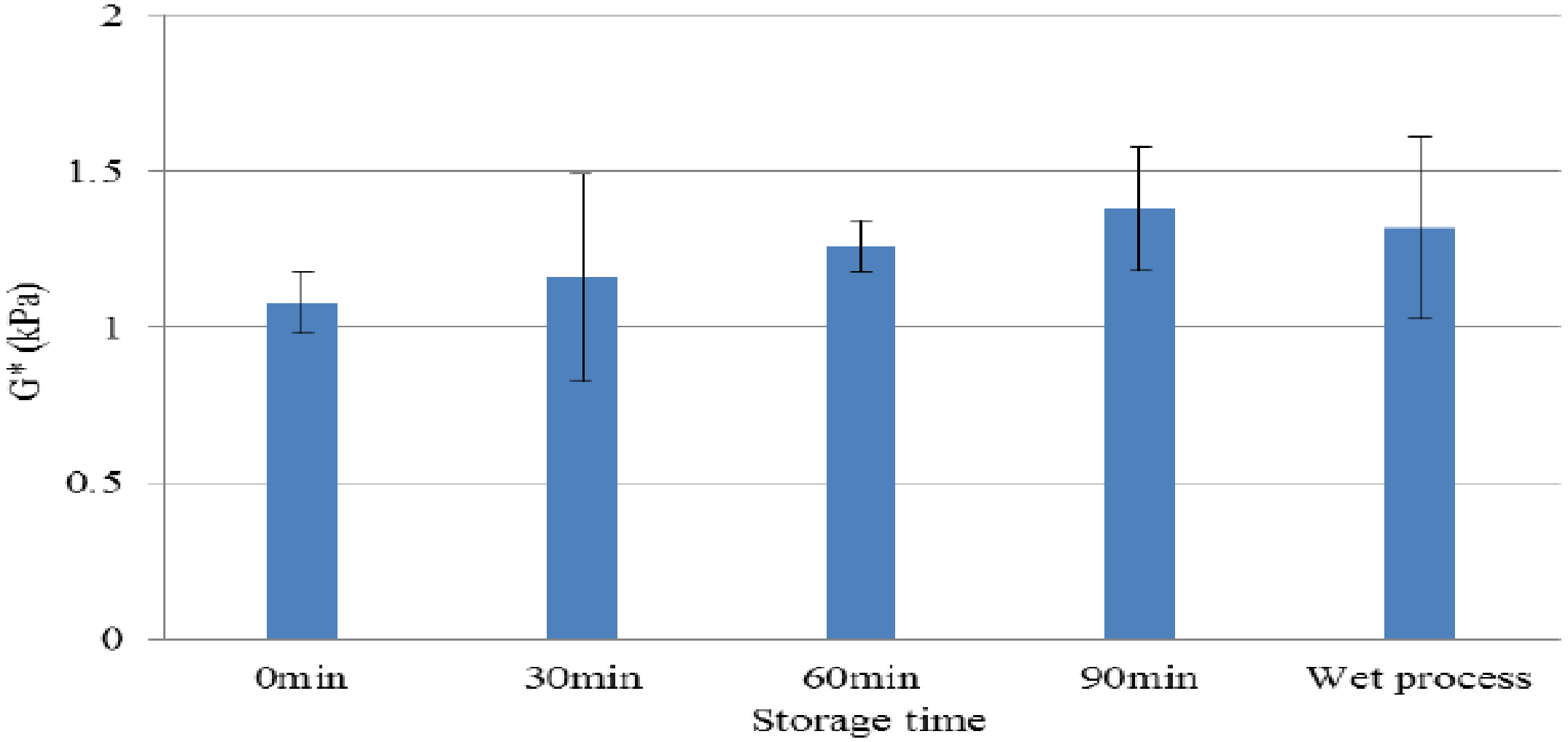
BINDER-RUBBER INTERACTION

- PROCESS IS PRIMARILY MECHANICAL (NCAT)
- BINDER REMOVED FROM TEST MIXES USING THE ROTOVAPOR METHOD (ASTM D5404), THF AFTER VARIABLE STORAGE TIMES
- DSR EVALUATION OF THE RECOVERED BINDERS SHOWED THAT DYNAMIC SHEAR INCREASES OVER TIME IN PEM AND SMA
- AT 03-60 MIN, NSD WITH WET PROCESS RUBBER
- SURROGATE FOR LIGHT END ABSORPTION BY RUBBER
- CONSISTENT WITH RESEARCH SUGGESTING THE PERIOD OF MAXIMUM INTERACTION IS BETWEEN 30 AND 90 MIN.

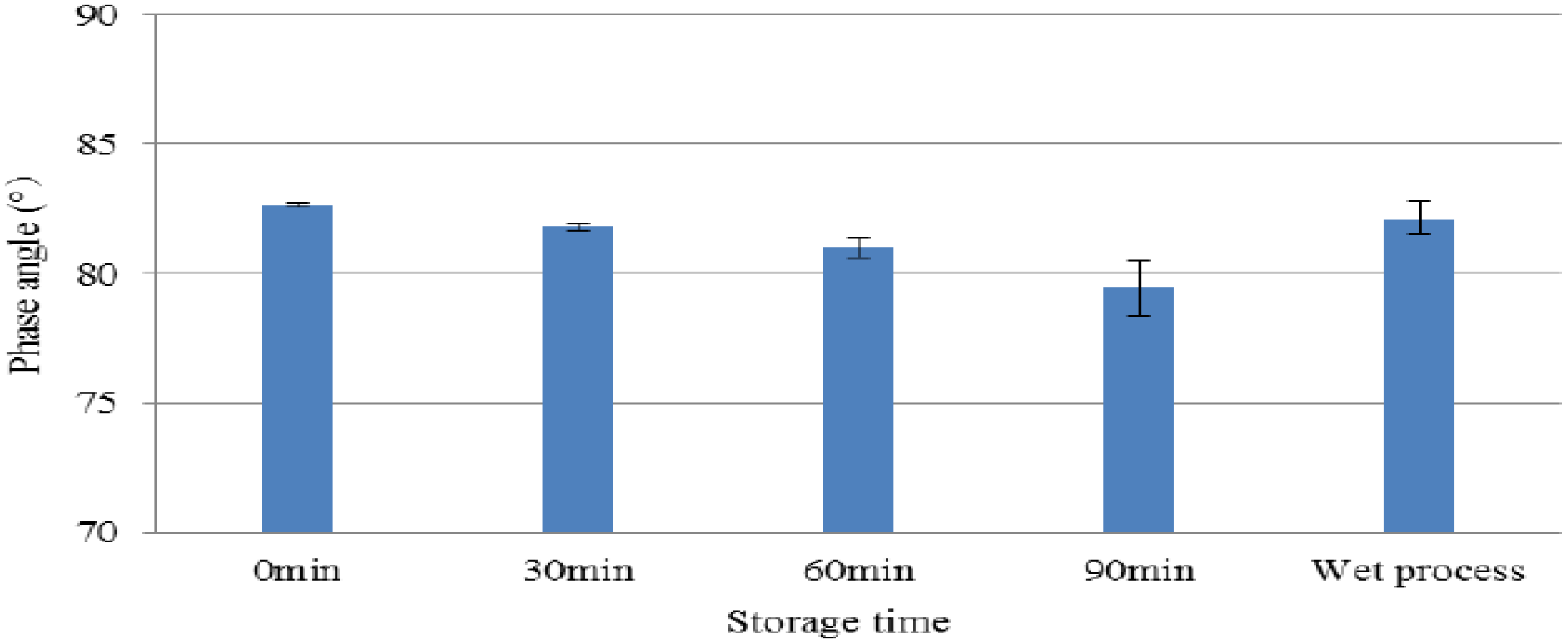
PEM COMPLEX DRY PROCESS SHEAR MODULUS OVER TIME FOLLOWING PRODUCTION



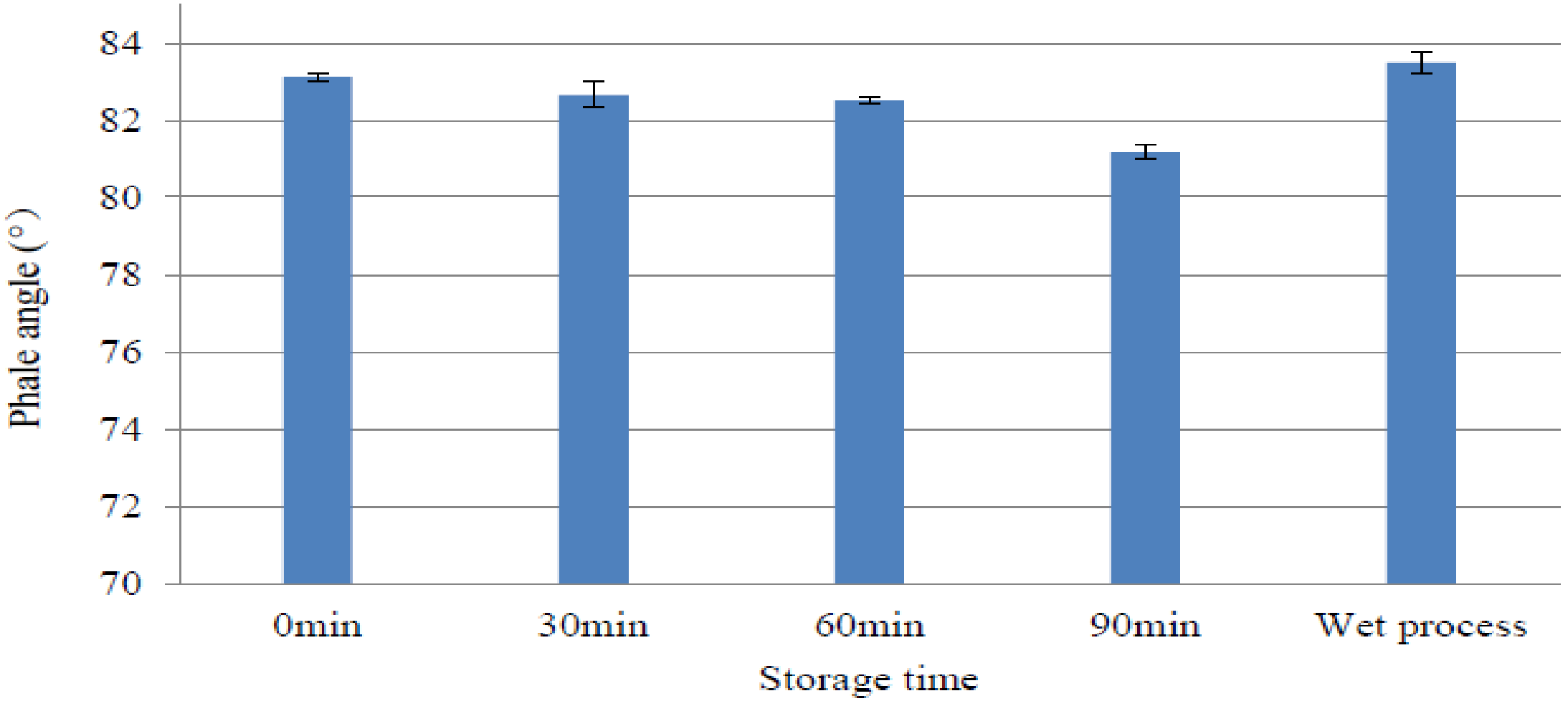
SMA COMPLEX DRY PROCESS SHEAR MODULUS OVER TIME FOLLOWING PRODUCTION



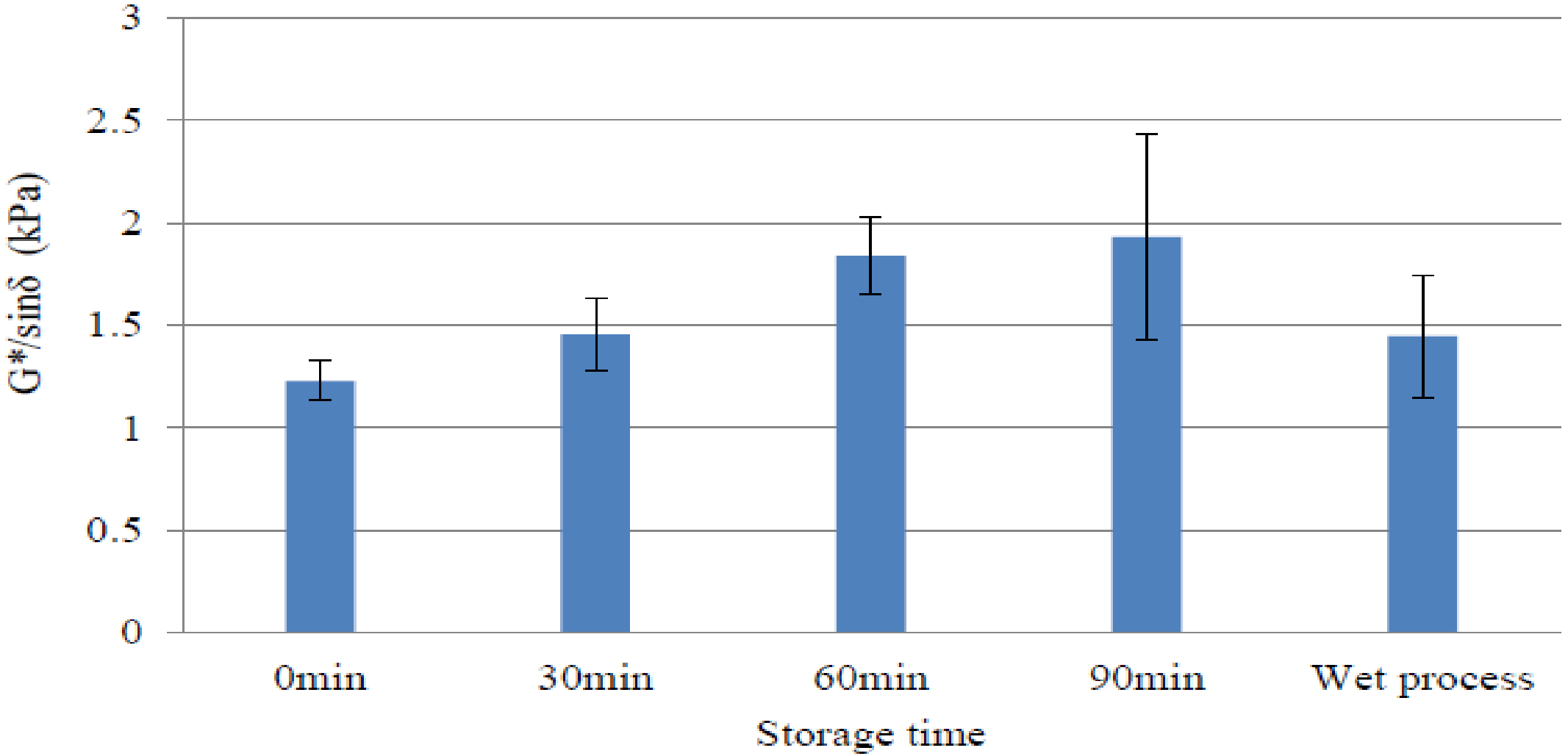
PEM-EXTRACTED BINDERS: PHASE ANGLE EVOLUTION OVER TIME FOLLOWING PRODUCTION



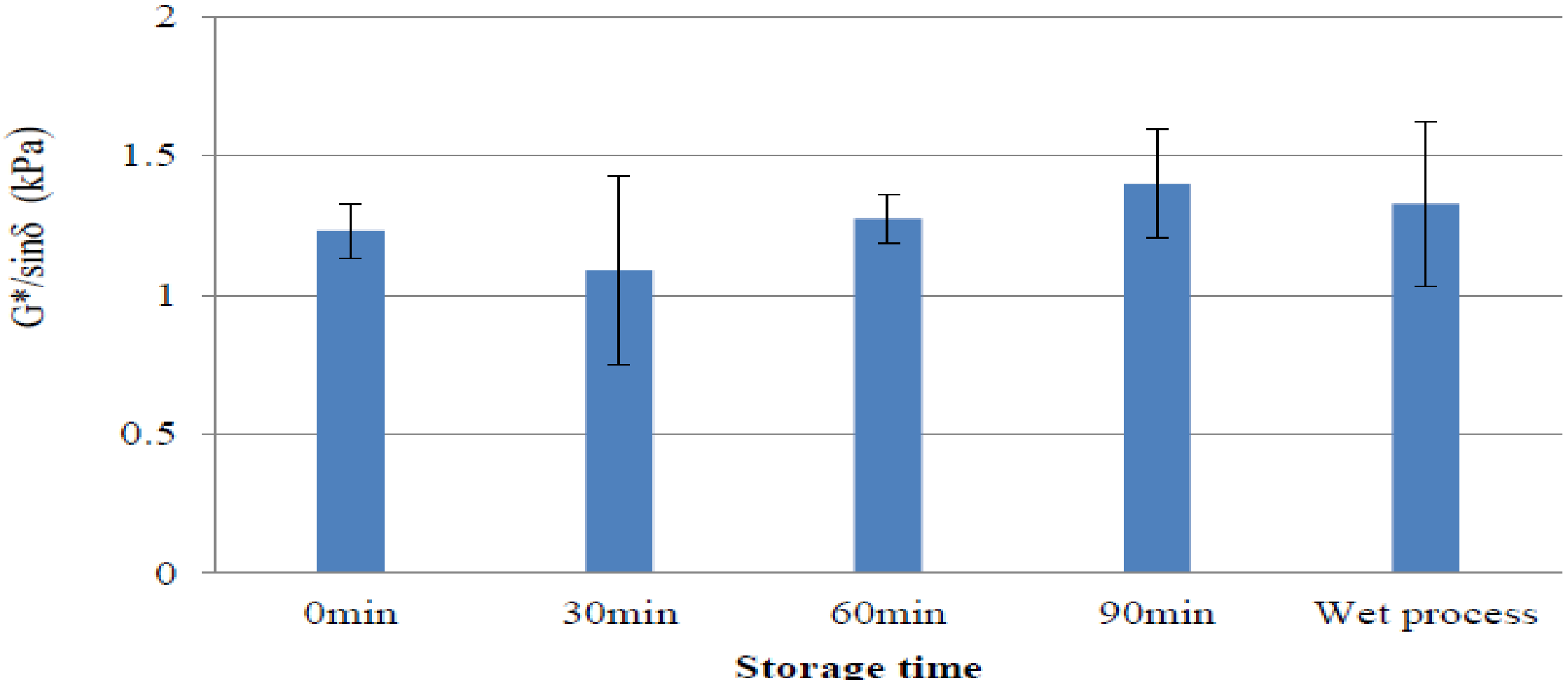
SMA-EXTRACTED BINDERS: PHASE ANGLE EVOLUTION OVER TIME FOLLOWING PRODUCTION



DRY PROCESS PEM RUTTING RESISTANCE OVER TIME FOLLOWING PRODUCTION



DRY PROCESS SMA RUTTING RESISTANCE OVER TIME FOLLOWING PRODUCTION



RUBBER-BINDER INTERACTION SUMMARY

- RECENT LITERATURE SUGGESTS THAT THE TIME REQUIRED TO EFFECT MOST (>90%) RUBBER SWELLING DEPENDS ON RUBBER PHYSICAL CONDITION AND BINDER PROPERTIES
- THE TIME REQUIRED FOR OPTIMUM SWELLING RANGES FROM 30 TO 90 MINUTES
- VARIABILITY IS SMALL AFTER AN HOUR
- PLANT MIXING SHORTENS THE TIME FOR DRAW-UP
- PROCESS SLOWS WITH DROPS IN TEMPERATURE
- PROCESS STOPS UPON COMPACTION

LAB TESTING SUMMARY

- IT IS POSSIBLE TO PRODUCE DRY PROCESS MODIFIED BINDERS THAT WILL PERFORM COMPARABLY TO WET PROCESS RUBBERIZED BINDERS
- IT IS POSSIBLE TO PRODUCE DRY PROCESS MIXES THAT PERFORM COMPARABLY TO WET PROCESS RUBBERIZED MIXES
- BOTH FORMS OF RUBBERIZED ASPHALT PERFORM COMPARABLY TO PMA IN A RANGE OF LAB TESTS
- BUT THE LAB ISN’T THE FIELD…

COLD WEATHER TESTING, PLACEMENT

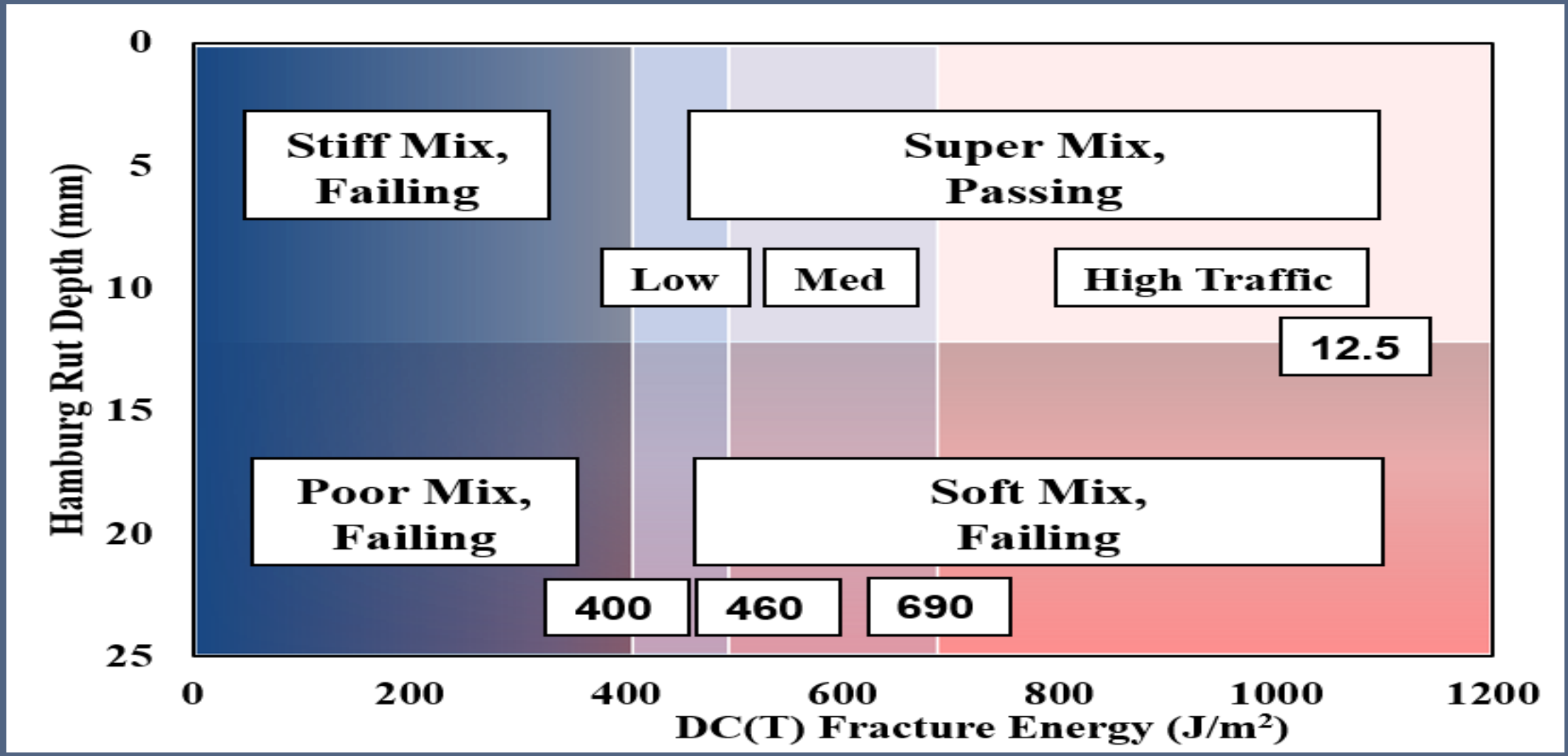
I-88 MAIN LINE AND SHOULDER DRY PROCESS MODIFIED SMA PAVING

2015 Condition Ratings and Remaining Service Life (RSL) of Core Locations & Contract Sections

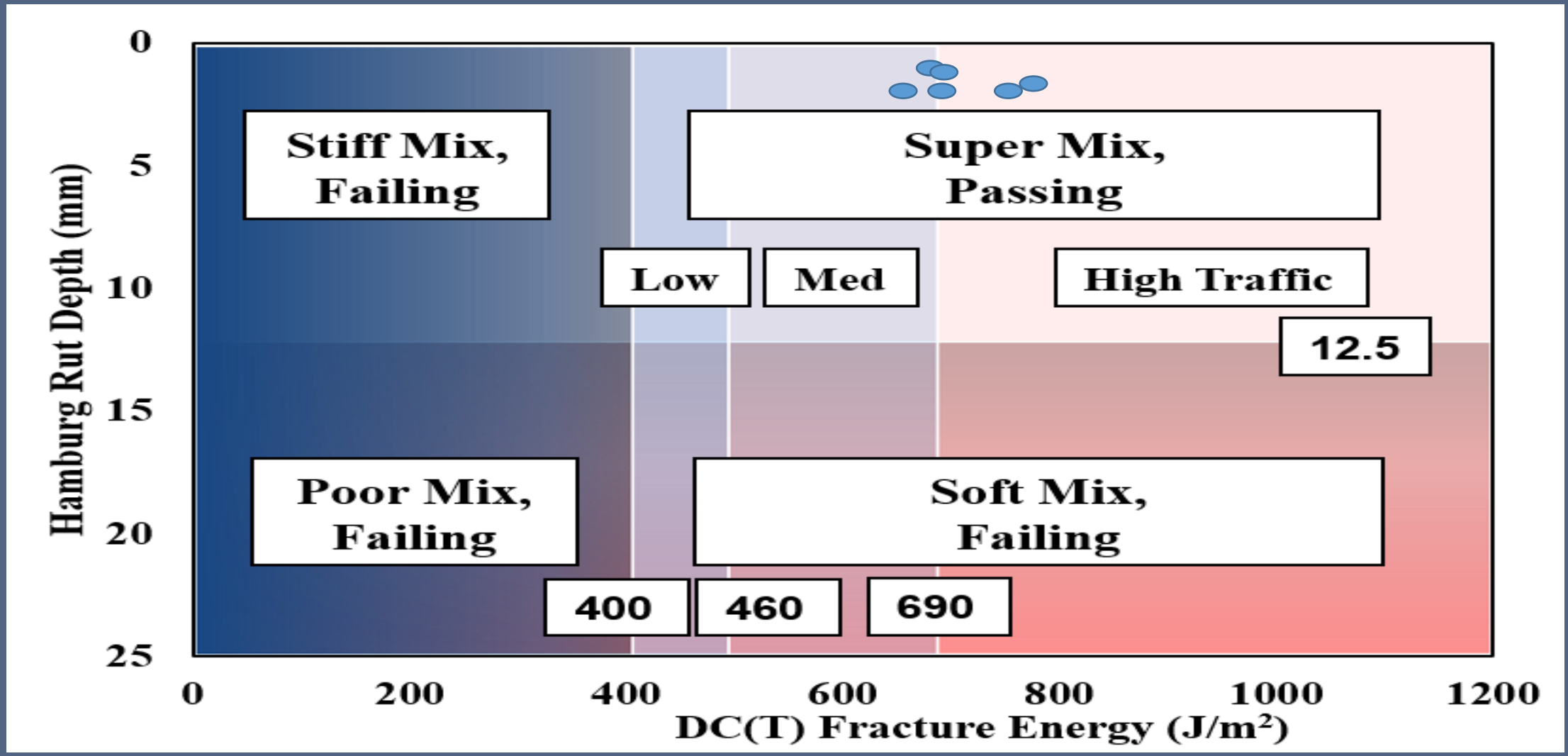
Mix Location	Year Placed	ABR %	CRS for Contract Section	CRS at Core Location	RSL at Core Location (Years), Total life
A. I-90 WB near Rockford	2009	14	8.0	8.1	15, 21
B. I-90 EB near Rockford	2008	16	7.9	7.8	12, 19
C. I-90 EB near Newberg	2009	36*	8.1	7.7	11, 17
D. I-90 WB near Rt. 25 / Elgin	2011	33*	N.A.	7.2 in 2014	N.A.
E. I-88 EB East of Dekalb	2012	37*	7.8	7.5	7, 10
F. I-355 NB at 63rd St.	2009	0	7.3	7.1	10, 16
G. I-294 NB, N. of Cermak	2012	31*	6.9	6.5	5, 8

* With RAS

HAMBURG/DCT MIX DESIGN PLOT



HAMBURG/DCT PLOT: SYSTEM RUBBER PROJECTS



DRY PROCESS ASPHALT IN LOW TEMPERATURE ENVIRONMENTS

- APPROACHING UP TO FOURTEEN YEARS OF SERVICE
- NO HISTORY OF THERMAL CRACKING
- TYPICAL PROFILE FOR SMA, 12.5 MM SURFACE MIXES
  - 70, -22 EQUIVALENT
  - HLWT: 2.5
  - DCT: 600-675
  - IN 14TH YEAR OF SERVICE FOR OLDEST PROJECTS

MULTIPLE RESEARCHERS AND STATES HAVE CONCLUDED THAT THE DRY PROCESS DOESN'T WORK

- WHY?
  - BAD DATA
  - BAD HISTORY
  - COMPLEX CONTROLS
- OUR APPROACH: BETTER LAB, PROCESS CONTROL

ENGINEERED DRY PROCESS: POINTS OF CONTROL

PROBLEM	CONTROL POINTS
• LAB PROCEDURES NOT WELL UNDERSTOOD	• ENHANCED LAB TRAINING AND EQUIPMENT
• RUBBER/BINDER INTERACTION NOT WELL UNDERSTOOD	• OPERATIONAL GUIDELINES TO MANAGE INTERACTION
• BINDER VARIABILITY	• OPERATIONAL GUIDELINES
• BINDER TEMPERATURE	• OPERATIONAL GUIDELINES
• TYPE OF RUBBER: CRYO/AMBIENT	• SINGLE TYPE IN USE
• RUBBER PSD	• QC CONTROL OF PSD
• RUBBER APPLICATION CONTROL	• ENGINEERED DELIVERY SYSTEM
• CURING OR DIGESTION TIME	• OPERATIONAL GUIDELINES
• FIELD ISSUES	• FIELD ISSUES
• WORKABILITY	• ENGINEERED CR
• COMPACTION PROCESS	• ENGINEERED CR

DOES PROCESS CONTROL WORK IN GA?

Dense Graded Mixes						
Contractor	Project #	Plant#	Mix Type	Tonnage	Route	County
ER Snell	CSSTP-M00-00(821)	80	12.5mm SP	22,419	SR140	Gwinnett
ER Snell	CSSTP-M00-00(832)	80	12.5mm SP	26,220	SR9	Gwinnett
ER Snell	CSSTP-008-00(578)	80	12.5mm SP	18,629	SR124	Gwinnett
The Lions Group	CSSTP-M003-00(754)	53	12.5mm SP	17,293	SR8	DeKalb
Reeves/Tugalo	CSNHS-M003-00(900)	91	12.5mm SP	10,744	SR17	Habersham
Reeves	CSSTP-M003-00(936)	37	12.5mm SP	7,212	SR26	Laurens
Reeves	CSSTP-M003-00(494)	46	12.5mm SP	14,736	SR28	Richmond
Reeves	M004173	15	12.5mm SP	20,000	SR10	Richmond
Reeves	CSNHS-M003-00(932)		12.5mm SP	17,293	SR27	Sumter
Reeves	CSSTP-M003-00(765)	4	12.5mm SP	10,971	US441	Baldwin
Reeves	CSSTP-M003-00(765)	4	19mm SP	1,071	US441	Baldwin
Reeves			12.5mm SP	2,000	SR26	Houston
Reeves/Baker	CSSTP-M003-00(910)		12.5mm SP	8,000	SR307	Chatham
Reeves/Baker	MLP00-0307-00(008)		12.5mm SP	6,000		Chatham
Reeves/Baker			19mm SP	6,200		Chatham
Reeves	M004271/72		12.5mm SP	22,000	SR247	Bibb
Baldwin	Various			50,000		
Southern	Various			1,000		
Reeves/Baker	M004590		12.5mm SP	14,000	US341	Wayne

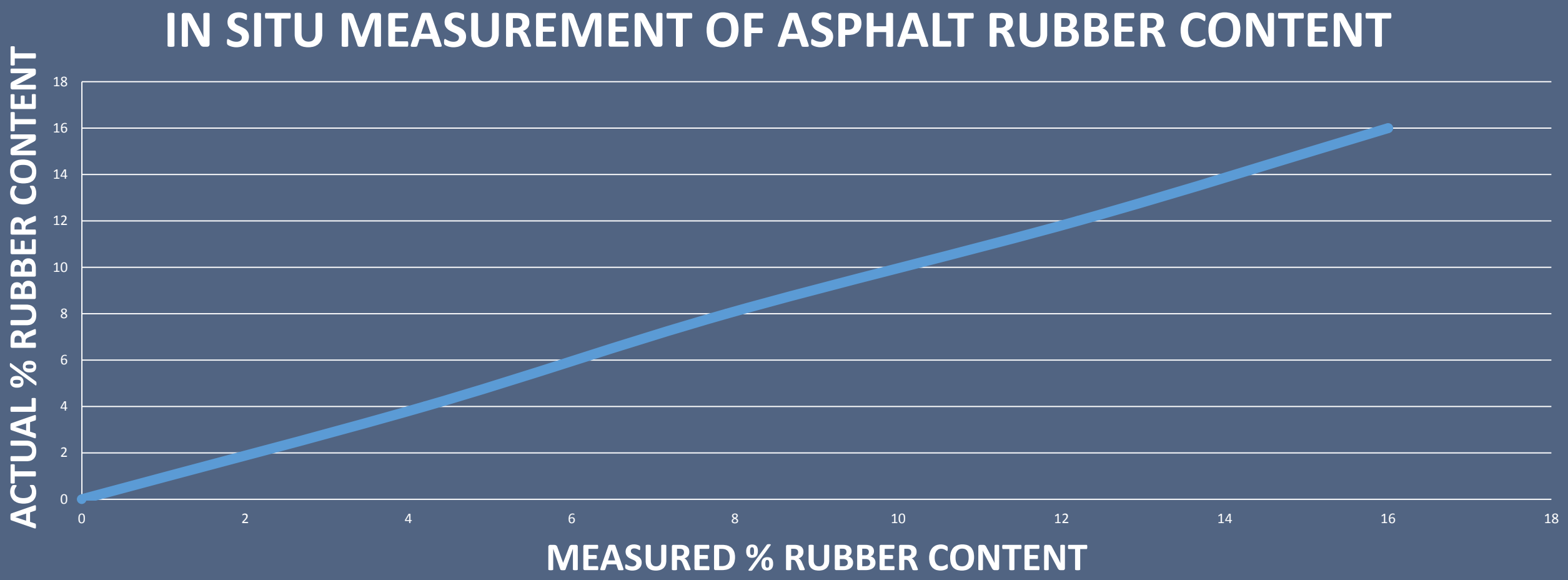
Open Graded Mixes

Contractor	Project #	Plant#	Mix Type	Tonnage	Route	County
Scruggs	CSNHS-M003-00(998)		PEM	28,049	I-75	Lowndes
Reeves	NH-IM-520-1(15)01		PEM	19,000	I-20/I-520	Richmond
Reeves	M004271/72		OGFC	3,000	SR247	Bibb
Reeves	CSNHS-M003-00(890)		OGFC	10,000	SR319	Tift
Reeves	CSNHS-M003-00(560)		OGFC	562	I-75	Houston/Peach
Reeves	NHIMO-0075-02(211)		PEM	10,900	I-75	Bibb
Reeves	0010868		PEM	22,415	I-75	Turner
Reeves	NH000-0520-01(017)		PEM	7592	I-520	Richmond
Reeves	M004317		PEM	15525	I-520	Richmond

SMA Mixes

Contractor	Project #	Plant#	Mix Type	Tonnage	Route	County
Reeves	NH-IM-520-1(15)01	15	SMA	10,744	I-20/I-520	Richmond
Reeves	City Of Tifton		SMA	300		Tift
Reeves	NHIMO-0075-02(211)		SMA	26,500	I-75	Bibb
Reeves	NH000-0520-01(017)		SMA	13,652	I-520	Richmond
Reeves	M004317		SMA	23,400	I-520	Richmond

FIELD VERIFICATION OF ASPHALT CONTENT



WHY DRY PROCESS MIX DESIGNS?

- DOTS
  - QUALITY PAVEMENT
  - RELIABLE DELIVERY SYSTEM
  - VERIFICATION
  - SUSTAINABILITY
- CONTRACTORS
  - EASE OF USE
  - TRUE COST SAVINGS
- WET, DRY AND PMA: PERFORMANCE EQUIVALENCE

THANK YOU