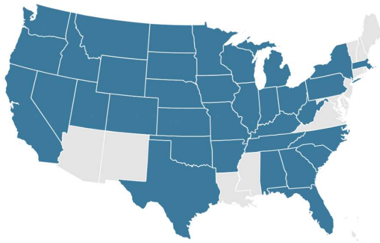


Performance Engineered Mix - Michigan

Michigan Department of Transportation

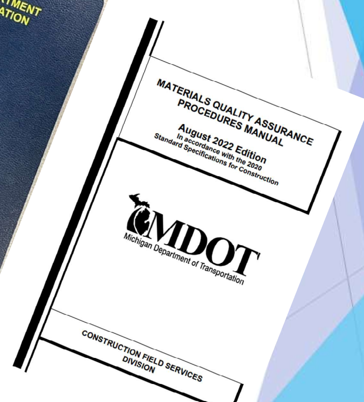
What does PEM mean for MDOT?

- Creating long-life durable mixes
- Methods for accepting mix design
- Construction practices
- Test methods for validation

- Michigan Clear Roads Policy:
  - Safety!!!!
  - Exposing roads and structures to harsh deicing agents
- Need concrete resistant to deicing agents!!

Michigan Department of Transportation Specifications:

- MDOT's 2020 Standard Specifications for Construction:
  - Division 10
- MDOT's Materials Quality Assurance Procedures (MQAP):
  - Section 3.09 for Optimized Aggregate Gradation
  - Section 5.15 for Admixture for Concrete (QPL)



MICHIGAN DEPARTMENT
OF TRANSPORTATION

2020
STANDARD
SPECIFICATIONS
FOR CONSTRUCTION

MDOT
Michigan Department of Transportation

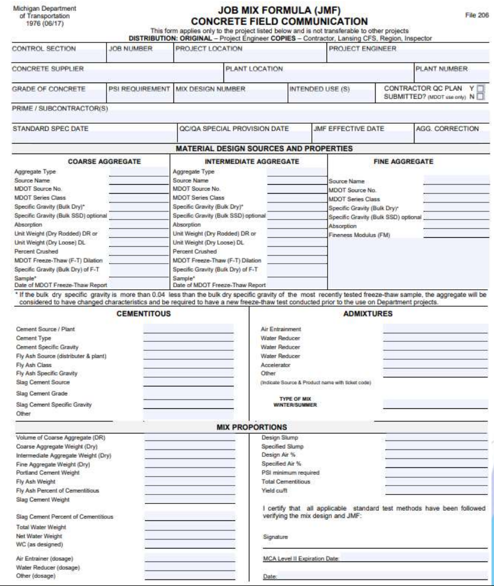
Division 10 - Concrete Mixtures

QA and QC:

- Quality Control (QC)
  - Administered by the Contractor
  - Monitor, assess, and adjust production and placement processes
  - Ensure final product meets specifications
- Quality Assurance (QA)
  - Administered by the Department
  - Deals with acceptance of the product:
    - Materials selection
    - Sampling and testing
    - Construction inspection
    - Review of Contractor QC documentation

Job Mix Formula (JMF):

- Contractor Provided Mixes:
  - 4 methods of verification:
    - Trial Batches
    - Same Mix
    - Similar Mix
    - Annual Verification
  - Benefits:
    - Allows for more ingenuity
  - Difficulties:
    - Learning curve for both Department and Contractor personnel



Michigan Department of Transportation 1976 (06/17)

JOB MIX FORMULA (JMF)
CONCRETE FIELD COMMUNICATION

File 206

This form applies only to the project listed below and is not transferable to other projects
DISTRIBUTION: ORIGINAL – Project Engineer **COPIES** – Contractor, Lansing CFS, Region, Inspector

CONTROL SECTION | JOB NUMBER | PROJECT LOCATION | PROJECT ENGINEER
CONCRETE SUPPLIER | PLANT LOCATION | PLANT NUMBER
GRADE OF CONCRETE | PSI REQUIREMENT | MIX DESIGN NUMBER | INTENDED USE (S) | CONTRACTOR QC PLAN SUBMITTED? (MDOT use only) Y ☐ N ☐
PRIME / SUBCONTRACTOR(S)
STANDARD SPEC DATE | QC/QA SPECIAL PROVISION DATE | JMF EFFECTIVE DATE | AGG. CORRECTION

MATERIAL DESIGN SOURCES AND PROPERTIES

COARSE AGGREGATE
Aggregate Type
Source Name
MDOT Source No.
MDOT Series Class
Specific Gravity (Bulk Dry)*
Specific Gravity (Bulk SSD) optional
Absorption
Unit Weight (Dry Rodded) DR or
Unit Weight (Dry Loose) DL
Percent Crushed
MDOT Freeze-Thaw (F-T) Dilation
Specific Gravity (Bulk Dry) of F-T Sample*
Date of MDOT Freeze-Thaw Report

INTERMEDIATE AGGREGATE
Aggregate Type
Source Name
MDOT Source No.
MDOT Series Class
Specific Gravity (Bulk Dry)*
Specific Gravity (Bulk SSD) optional
Absorption
Unit Weight (Dry Rodded) DR or
Unit Weight (Dry Loose) DL
Percent Crushed
MDOT Freeze-Thaw (F-T) Dilation
Specific Gravity (Bulk Dry) of F-T Sample*
Date of MDOT Freeze-Thaw Report

FINE AGGREGATE
Source Name
MDOT Source No.
MDOT Series Class
Specific Gravity (Bulk Dry)*
Specific Gravity (Bulk SSD) optional
Absorption
Fineness Modulus (FM)

* If the bulk dry specific gravity is more than 0.04 less than the bulk dry specific gravity of the most recently tested freeze-thaw sample, the aggregate will be considered to have changed characteristics and be required to have a new freeze-thaw test conducted prior to the use on Department projects.

CEMENTITOUS
Cement Source / Plant
Cement Type
Cement Specific Gravity
Fly Ash Source (distributer & plant)
Fly Ash Class
Fly Ash Specific Gravity
Slag Cement Source
Slag Cement Grade
Slag Cement Specific Gravity
Other

ADMIXTURES
Air Entrainment
Water Reducer
Water Reducer
Water Reducer
Accelerator
Other
(Indicate Source & Product name with ticket code)
TYPE OF MIX WINTER/SUMMER

MIX PROPORTIONS
Volume of Coarse Aggregate (DR)
Coarse Aggregate Weight (Dry)
Intermediate Aggregate Weight (Dry)
Fine Aggregate Weight (Dry)
Portland Cement Weight
Fly Ash Weight
Fly Ash Percent of Cementitious
Slag Cement Weight
Slag Cement Percent of Cementitious
Total Water Weight
Net Water Weight
WC (as designed)
Air Entrainer (dosage)
Water Reducer (dosage)
Other (dosage)

Design Slump
Specified Slump
Design Air %
Specified Air %
PSI minimum required
Total Cementitious
Yield cu/ft

I certify that all applicable standard test methods have been followed verifying the mix design and JMF:

Signature
MCA Level II Expiration Date:
Date:

Mix Design Requirements:

Table 1004-1:
Concrete Mixtures

		Concrete Grade								
		3000	**3500**	**3500HP(a),(b)**	**4000**	**4000HP(a),(b)**	**4500**	**4500HP(a),(b)**	**M**	**X**
Compressive strength (psi)	7 day	2200	2600	2600	3000	3000	3200	3200	Commercial-grade concrete containing 517 lb/cyd. Portland cement may be replaced with an SCM.	Unless otherwise specified, Grade X concrete contains 282 lb/cyd of cement.
	28 day	3000	3500	3500	4000	4000	4500	4500		
	70%	2100	2450	2450	2800	2800	3150	3150		
Flexural strength (psi)	7 day	500	550	550	600	600	625	625		
	28 day	600	650	650	700	700	750	750		
	70%	420	455	455	490	490	525	525		
Slump (inch)		(c)–(f)	(c)–(k)	(c)–(k)	(l)–(n)	(l)–(n)	(d)–(f)	(e)–(f)		
Cementitious material content (lb/cyd)		489–517	517–611(o)	470–564(o)	517–611	517–611	517–658	517–658		
Class of coarse aggregate		(p)–(r)								
Maximum w/cm ratio		0.45								
Air content range		5.5 – 8.5%								
Section reference		402, 403, 602, 803, 804, 806, 808, 810, 813, 814, 819	401, 602, 603, 705, 706, 712, 713, 718, 801, 802, 803, 810, 819	401, 602, 603, 706, 712, 713, 718, 801, 802, 803, 810, 819	705, 922	705, 922	706, 711, 712	706, 711, 712	N/A	N/A

Maximum Cement Content:

- Pavements: 564 lbs. (6 sack)
- Bridge Decks: 611 lbs. (6.5 sack)
- Benefits:
  - Reduced paste content
  - Reduced costs associated with cement
- Difficulties:
  - Initial concerns about strength development
    - No problems

Table 1004-1:
Concrete Mixtures

		Concrete Grade								
		3000	3500	3500HP[(a),(b)]	4000	4000HP[(a),(b)]	4500	4500HP[(a),(b)]	M	X
Compressive strength (psi)	7 day	2200	2600	2600	3000	3000	3200	3200	Commercial-grade concrete containing 517 lb/cyd. Portland cement may be replaced with an SCM.	Unless otherwise specified, Grade X concrete contains 282 lb/cyd of cement.
	28 day	3000	3500	3500	4000	4000	4500	4500		
	70%	2100	2450	2450	2800	2800	3150	3150		
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	28 day	600	650	650	700	700	750	750		
	70%	420	455	455	490	490	525	525		
Slump (inch)		(c)–(f)	(c)–(k)	(c)–(k)	(l)–(n)	(l)–(n)	(d)–(f)	(e)–(f)		
Cementitious material content (lb/cyd)		489–517	517–611[(o)]	470–564[(o)]	517–611	517–611	517–658	517–658		
Class of coarse aggregate		(p)–(r)								
Maximum w/cm ratio		0.45								
Air content range		5.5 – 8.5%								
Section reference		402, 403, 602, 803, 804, 806, 808, 810, 813, 814, 819	401, 602, 603, 705, 706, 712, 713, 718, 801, 802, 803, 810, 819	401, 602, 603, 706, 712, 713, 718, 801, 802, 803, 810, 819	705, 922	705, 922	706, 711, 712	706, 711, 712	N/A	N/A

Maximum W/C Ratio:

- Maximum W/C Ratio:
  - 0.45
- Benefits:
  - Densifying the paste
  - Lowers permeability
  - Helps protect from chemical attack
  - Reduces scaling potential
- Difficulties:
  - Dependent on Water Reducing Admixtures

Table 1004-1:
Concrete Mixtures

		Concrete Grade								
		3000	3500	3500HP[(a),(b)]	4000	4000HP[(a),(b)]	4500	4500HP[(a),(b)]	M	X
Compressive strength (psi)	7 day	2200	2600	2600	3000	3000	3200	3200	Commercial-grade concrete containing 517 lb/cyd. Portland cement may be replaced with an SCM.	Unless otherwise specified, Grade X concrete contains 282 lb/cyd of cement.
	28 day	3000	3500	3500	4000	4000	4500	4500		
	70%	2100	2450	2450	2800	2800	3150	3150		
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	28 day	600	650	650	700	700	750	750		
	70%	420	455	455	490	490	525	525		
Slump (inch)		(c)–(f)	(c)–(k)	(c)–(k)	(l)–(n)	(l)–(n)	(d)–(f)	(e)–(f)		
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Admixtures:

- Air entraining:
  - ASTM C260
  - Local cement testing
- Chemical (water-reducers, retarders and accelerators)
  - ASTM C494
  - Local cement testing
  - Type MR

Summary Sheet

LOCAL CEMENT ADMIXTURE TESTING

Air Entrainment

	CONTROL MIXTURES				TEST MIXTURES				ASTM : C260 Air Entrainer
Batch: Date:				Control Avg				Test Avg	
Admixture Name oz/cwt									
Water, pcy W/C lb/lb Relative water content, %									
Slump, in Air Content, %									control avg. +/- 1 control avg. +/- 0.5
Concrete Temp, F Ambient Temp, F									
COMPRESSIVE STRENGTH 3 day, psi 7 day, psi 28 day, psi									
3 day, % reference 7 day, % reference 28 day, % reference									90% min 90% min 90% min

I hereby certify that the above information submitted is actual physical laboratory test data obtained according to the requirements specified in the Qualification Procedure and Testing Procedure for the product.

Person Responsible For Testing: ______________________ (Signature)

______________________ (Print Name)

Laboratory Name and Address: ______________________

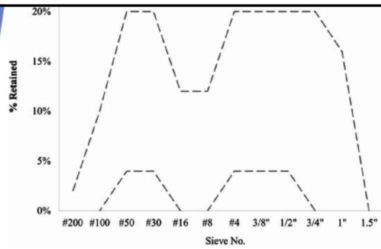
Date Tests Were Conducted: ______________________

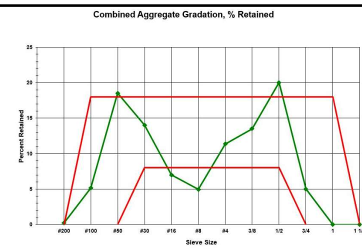
Telephone Number: ______________________

Supplementary Cementitious Materials:

- Replacement rates:
  - 25%-40% replacement of Portland cement
    - Replacement amount is determined by the Contractor
  - 40% total replacement

- Improvements:
  - Permeability
  - Resistance to Freeze-thaw damage
  - Consistency
- Difficulties:
  - Can cause air issues
  - Slower initial strength gains





Optimized Aggregate Gradation

3.09 of the Materials Quality Assurance Procedure Manual

Why Optimized Aggregates?

- Weather:
  - Freeze and thawing
  - Saturated state

- Concrete performance increased!

Coarse/Intermediate Aggregates:

- Freeze-thaw program:
  - All coarse and intermediate aggregates tested
  - Vacuum saturation method
  - Maximum dilation of 0.040
- Maximum absorption:
  - 24-hour soak
  - 2.5%

Coarse/Intermediate Aggregates:

- Loss by Wash:
  - Crushed 2% all other 1%
- LA Abrasion:
  - 40% max
- Flat and elongation, quarried carbonate, deleterious, etc.

Fine Aggregates:

- Organic Impurities
- Mechanical Analysis
  - Loss by Washing
  - Gradation
  - Fineness Modulus

Optimized Aggregates:

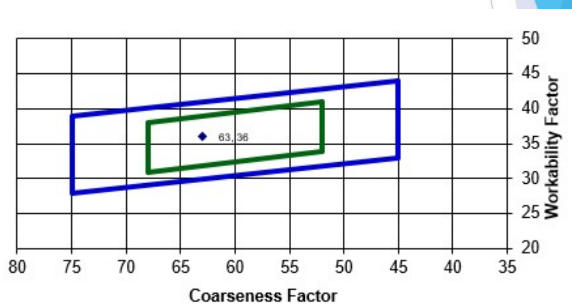
- Based off the Shilstone Method
- Combining aggregate gradations
  - “Well” Graded

Optimized Aggregate Gradation

Aggregate Classification →	Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Theoretical Combined Gradation %Passing	Theoretical Combined Gradation %Retained
Relative Percent →	48.77	11.48	39.75		
Actual Batch Weight (lbs) (SSD) →	1550.0	365.0	1240.0		
Specific Gravity →	2.69	2.69	2.64		
Sieve Size	Percent Passing				
2 inch	100	100	100	100.0	0.0
1½ inch	100	100	100	100.0	0.0
1 inch	100	100	100	100.0	0.0
¾ inch	83.6	100	100	92.0	8.0
½ inch	40.2	99.6	100	70.8	21.2
⅜ inch	20.6	89.7	100	60.1	10.7
No. 4	4.2	26.1	99.8	44.7	15.4
No. 8	2.4	7.7	86.4	36.4	8.3
No. 16	2.2	3.1	64.9	27.2	9.2
No. 30	2	2.1	43.7	18.6	8.6
No. 50	1.9	1.8	21.2	9.6	9.0
No. 100	1.8	1.7	4.5	2.9	6.7

Optimized Aggregates:

- Determination of optimized aggregate proportions:
  - Coarseness Factor
  - Workability Factor
  - CF vs. WF Chart
- Additional aggregate proportion checks:
  - JMFs and QC



		Key	
Identify Aggregate with a Freeze/ Thaw Dilation > 0.040%	None	Enter Data →	
Identify Aggregate from a Quarried Carbonate Source:	Coarse/ Intermediate	Calculated Data →	
Identify the Application:	Structural	Spec Passed →	
(4.13.03.C.1) Maximum Sieve Size (Sieve Size: 2.0 or 1.5)	1.5	Spec Failed →	
Calculate>>	Calculate		
(4.13.04.D.1.a.1) (4.13.04.D.1.a.2) Max Theo. Retention> ⅜ Sieve	Pass		
(4.13.04.D.1.a.3) Sum of Adjacent Sieves> 10%	Pass		
(4.13.04.D.1.a.4) Aggregate Retained>= Min. Req.	Pass		
(4.13.03.A.1) Carbonate Source Agg. Passed No. 4 Sieve <= 15%	Pass		
(4.13.03.A.2) F-T Agg. (>.040%) Retained on ½" Sieve <= 5%	Pass		
Coarseness Factor (CF):	63		
Workability Factor (WF):	36		

Optimized Aggregates:

- Improvements:
  - Slump/Consistency
  - Reduced permeability
  - Additional aggregates gradation used
- Difficulties:
  - Department and Contractor understanding
    - [MDOT Optimized Aggregate Spreadsheet]()
  - Ready Mix with limited bins
    - Preblended aggregates
    - 2 aggregate gradation blends

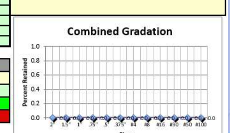
Optimized Aggregate Gradation

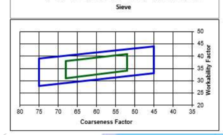
Aggregate Classification →	Coarse Aggregate	Intermediate Aggregate	Fine Aggregate	Theoretical Combined Gradation %Passing	Theoretical Combined Gradation %Retained
Relative Percent →					
Actual Batch Weight (lbs) (SSD) →					
Specific Gravity →					
Sieve Size	Percent Passing				
2 inch	100	100	100		
1½ inch	100	100	100		
1 inch	100	100	100		
¾ inch	100	100	100		
½ inch	100	100	100		
⅜ inch	100	100	100		
No. 4	100	100	100		
No. 8	100	100	100		
No. 16	100	100	100		
No. 30	100	100	100		
No. 50	100	100	100		
No. 100	100	100	100		

Project Information

Control Section		Job Number	
Location		Date	
Mix Design Type		JMF Number	
Conc. Producer		Plant Location	
Pounds of Cement:		564	
Comments			

		Key	
Identify Aggregate with a Freeze/ Thaw Dilation > 0.040%	None	Enter Data →	
Identify Aggregate from a Quarried Carbonate Source:	Coarse/ Intermediate	Calculated Data →	
Identify the Application:	Pavement (Thickness > 6")	Spec Passed →	
(3.13.03.C.1) Maximum Sieve Size (Sieve Size: 2.0 or 1.5)		Spec Failed →	
Calculate>>	Calculate		
(3.13.04.D.1.a.1) (3.13.04.D.1.a.2) Max Theo. Retention> ⅜ Sieve	Pass		
(3.13.04.D.1.a.3) Sum of Adjacent Sieves> 10%	Fail		
(3.13.04.D.1.a.4) Aggregate Retained>= Min. Req.	Fail		
(3.13.03.A.1) Carbonate Source Agg. Passed No. 4 Sieve <= 15%	Pass		
(3.13.03.A.2) F-T Agg. (>.040%) Retained on ½" Sieve <= 5%	Pass		
Coarseness Factor (CF):			
Workability Factor (WF):			





Alkali Silica Reactivity SP:

- Testing Requirements:
  - Valid for 2 years
  - Current test methods:
    - ASTM C 1293 (Concrete Prism Test)
    - ASTM C 1567 (Mortar Bar Test)
      - 25% to 40% SCM replacement
    - ASTM C 1260 (Mortar Bar Test)

Concrete Pavements Curing SP:

- Places a priority on curing
  - Timing
  - Adequate curing compound
    - White like a sheet of paper
  - Creates a pay item for curing

20SP-602E-01

MICHIGAN
DEPARTMENT OF TRANSPORTATION

SPECIAL PROVISION
FOR
CURING CONCRETE PAVEMENT SURFACES

CFS:JFS 1 of 3 APPR:ARB:TES:04-02-20
FHWA:APPR:04-03-20

a. Description. This work sets forth requirements for curing horizontal and vertical surfaces of the concrete pavement. All work will be in accordance with the standard specifications, except as modified herein.

Curing requirements for temporary concrete pavements are not covered by this special provision and will be in accordance with the standard specifications.

Concrete Bridge Deck Curing SP:

- Currently piloting:
  - Increases safety
    - Less night work
  - Maintaining adequate curing
  - Hybrid between wet curing and curing compound

Saw Cutting Comments:

- Sawing at the right time
- Sawing to an adequate depth
  - At least 1/3 thickness of pavement
- Clean joint of slurry whenever possible

PEM Testing:

- V-Kelly Ball (V-Kelly)
- Box Test
- Formation Factor
- Surface Resistivity
- Bulk Resistivity
- Sequential Air Metric Apparatus/Super Air Meter (SAM)

PEM Testing:

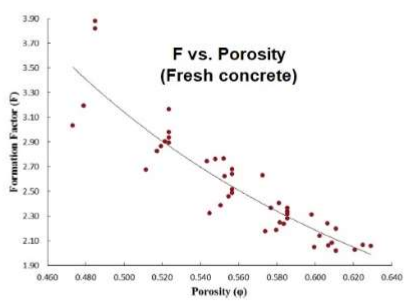
- V-Kelly Ball (V-Kelly):
  - **QC Test**

PEM Testing:

- Box Test:
  - **QC Test**

PEM Testing:

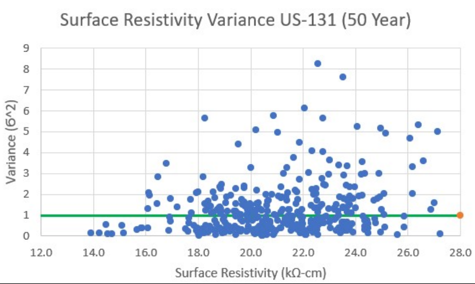
- Formation Factor:
  - MDOT has not used the formation factor



Source: Sallehi et al. (2018)

PEM Testing:

- Surface Resistivity:
  - Not in use
  - Currently MDOT has transitioned to Bulk Resistivity



PEM Testing:

- Bulk Resistivity:
  - MDOT's experience:
    - Simpler test than surface resistivity
    - Consistent results
    - Ensure the sponges remain wet
    - Keep away from metal
    - Correlates with surface resistivity
    - Correlated well with RCP in recent research project
  - Currently MDOT is collecting data
  - Perhaps require its use for trial batches in the future

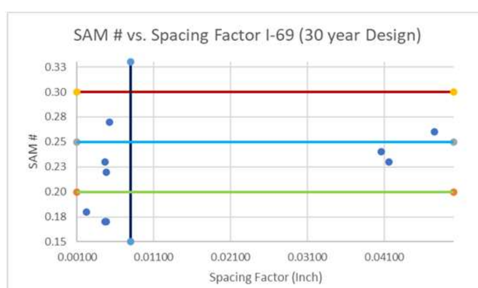
PEM Testing:

- Super Air Meter (SAM):
  - Pilot field Testing/Shadow SP:
    - 12CF601
    - Requires testing for information only:
      - Mainline Pavement
      - Structures
      - Barrier
    - One test per sublot
      - Typically 5 tests per day for mainline paving
  - Michigan Concrete Association's has a SAM certification Class

PEM Testing:

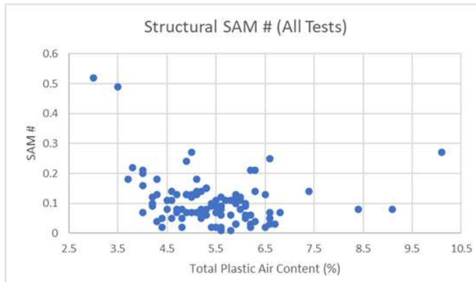
- Super Air Meter (SAM):
  - MDOT's Experience:
    - Introduce the SAM gauge
    - Inspectors experience ↑

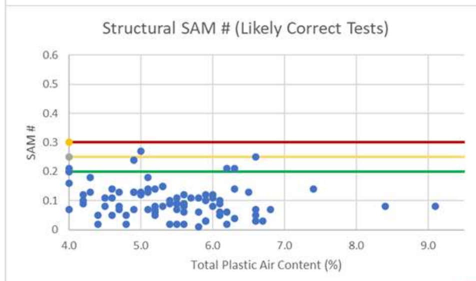
      Time to run the test ↓↓
    - Do not store wet gauges in cases
    - Do not leave the gauges in the air-conditioned cab prior to testing
    - Always have spare batteries
    - Have a backup gauge
    - Use the Shotgun
    - Follow the gauge's directions



PEM Testing:

- Super Air Meter (SAM):
  - OSU's "Likely ran correctly tool"
    - Likely ran correctly >90%
    - Removed outliers
  - SAM # > 0.3
    - 98%
  - SAM # > 0.2
    - ~90%





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Michigan Department of Transportation