0-6444: Treatments for Clays in Aggregates Used to Produce Cement Concrete, Bituminous Materials, and Chip Seals

P1 Deliverable: Training Materials for Testing and Mitigation Techniques

TEXAS A&M UNIVERSITY

Texas A&M Transportation Institute

RESEARCH TEAM

1. Texas A&M Transportation Institute, Texas A&M University

Materials and Pavement

A. Rigid Pavement

- ***Anol Mukhopadhyay (Research Supervisor) – Associate Research Scientist / Ad. Graduate Faculty***
- ***Brandon Pitre – Graduate Research Assistant (GRA)***

B. Flexible Pavement

- ***Cindy Estakhri – Program Manager***
- ***Edith Arambula – Associate Research Scientist***

2. Soil Science, Texas A&M University

- ***Andrew Russell – GRA***
- ***Youjun Deng – Assistant Professor***

POTENTIAL TEST METHODS

- **The project has identified the Modified Methylene Blue (MMB) method as the most promising field method to detect the presence of harmful clay minerals in aggregate fines**

- **X-Ray Diffraction (XRD) method, an advance research tool, was used to establish the MMB method**
  - **XRD is the best research tool to identify and quantify clay minerals with reasonably good accuracy**
  - **XRD is not a field method**

- **The training materials for the MMB test method are provided next**

Modified Methylene Blue Test (MMBT): Test Approach

- New rapid and reliable method to detect the presence of swelling clay minerals in aggregate fines
- A sample of aggregate fine is combined with a methylene blue solution and mixed for a prescribed period of time
- The resulting mixture of aggregate fine and MB solution is filtered and diluted
- A colorimeter is used to determine the absorbance of the final solution, which is correlated with the concentration of methylene blue prior to dilution
- The change in concentration in methylene blue prior to dilution is converted to a methylene blue value (MBV) and reported

Detailed MMB Test Procedure

SCOPE

- This test method intends to provide a rapid test to determine the amount of methylene blue adsorbed by a sample of aggregate fines for both the laboratory and field.
- The result is reported as a methylene blue value (MBV). The MBV is a function of the amount and activity of clay minerals present in an aggregate fine sample. In general, the higher the MBV the higher the clay (swelling) content is.
- This test method differentiates between (i) clay and non-clay minerals and (ii) swelling and non-swelling clay minerals, in fines containing clay size particles (i.e., < 2 µm).
- In general, a high methylene blue value is undesirable for construction applications as it is an indicator of poor aggregate performance in asphalt, concrete and other construction applications (e.g., flexible base materials).

DEFINITION

Aggregate fines **– Aggregate passing the 4.75-mm (No. 4) sieve.**

- *Aggregate fine containing up to 100% passing the 425-µm (No. 40) or 75-µm (No. 200) sieve can also be measured in this test, including limestone filler and other mineral filler.*
- *The fine materials of the above sizes collected from different construction materials (e.g., coarse and fine aggregates used in portland cement concrete and hot mix asphalt, soil and flexible base materials) can be tested by this method.*

- **The unit of MBV is milligrams of methylene blue per gram of dry sample of fine materials of the above size(s).**

- ***Threshold MBV*** **- A maximum MBV may be specified to limit the permissible quantity and activity of clay in an aggregate fine sample.**

APPARATUS

4.75 mm (No. 4) sieve with 4.75 mm openings conforming to ASTM E11.

Mass balance capable of measuring to the nearest 0.1 g.

Micropipette capable of measuring to the nearest 1 µL.

Colorimeter capable of reading absorbance of a sample at 610 ± 1 nm at operating conditions of at least 0 to 50ºC. The colorimeter shall also be able to read absorbance between zero and the absorbance associated with a 0.144% wt concentration of methylene blue solution.

- **A Hach DR 850 colorimeter has been found to be suitable for this test. This colorimeter accommodates 16 mm diameter vials and is capable of reading absorbance between 0 and 2 A.**

MMB TEST: MAIN APPARATUS

ADDITIONAL APPARATUS

- **Disposable items (per test): two plastic 45-mL test tubes, one plastic 1-mL vial, one 3-mL syringe with Luer-Lok adapter, one 0.2-μm syringe filter, one colorimeterglass cuvette, one micropipette tip, and three transfer pipettes.**
- **Additional disposable items for confirming methylene blue starting concentration: plastic 45-mL test tube, plastic 1-mL vial, colorimeter glass cuvette, micropipette tip, and two transfer pipettes.**
- **Additional disposable items for calibrating colorimeter: plastic 45-mL test tube, plastic 1- mL vial, colorimeter glass cuvette, micropipette tip, and two transfer pipettes.**
- **Weigh dish – is a pour boat to hold a minimum of 20 grams of sample.**
- **Eyedropper with a capacity of 7.50 mL.**
- **Disposable Latex Gloves – strong enough to protect hands.**
- **Blow drier to dry sample in the field.**

REAGENTS AND MATERIALS

- **Methylene blue** ($C_{16}H_{18}N_3SCl$) test solution at a weight concentration of 0.5% trihydrate methylene blue. Methylene blue is commercially available in both anhydrous and trihydrate form.

- **Purity of reagent** – Reagent grade chemicals shall be used in all tests. Other grades may be used, provided it is ascertained that the reagent is of sufficiently high purity to permit its use without compromising the accuracy of the results.

- **Purity of water** – unless otherwise indicated, references to water shall be understood to mean potable water.

SAMPLE PREPERATION

1.Sampling of aggregate fine should be done in accordance to TEX-XXX-E (Practice D75).

2.Thoroughly mix the sample and reduce it as necessary using the applicable procedures in TEX-XXX-E (Practice C702).

3.Obtain at least 30 g of material passing the 4.75-mm sieve in the following manner:

3.1 Separate the sample on the 4.75-mm (No. 4) by sieving.

3.2 Break down any lumps of material in the coarse fraction to pass the 4.75-mm (No. 4) sieve. Use a mortar and rubber-covered pestle or any other means that will not cause appreciable degradation of the aggregate.

3.3 Remove any coatings of fines adhering to the coarse aggregate. These fines may be removed by surface-drying the coarse aggregate, then rubbing between the hands over a flat pan.

3.4 Add the material passing the sieve obtained in steps 3.2 and 3.3 to the separated fine portion of the sample (step 3.1).

SAMPLE PREPERATION: Contd.

4. Dry the test specimen to constant weight at 110 ± 5°C and cool to room temperature before testing.

5. To obtain additional test specimens, repeat the procedures in steps 3 and 4.

Testing

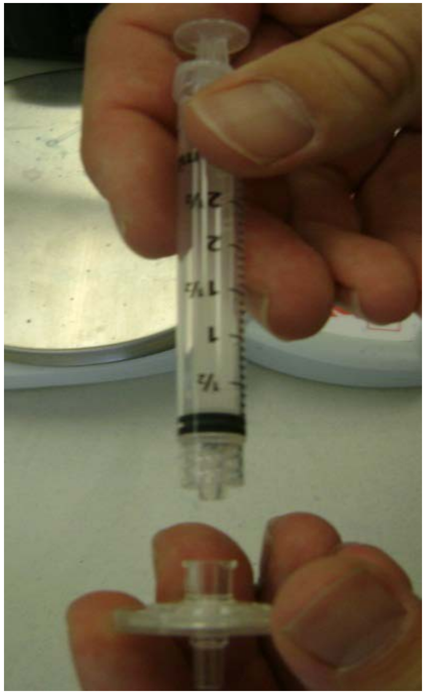
1. **Weigh 20 grams of dry sample for testing.**
2. **Weigh 30 grams of methylene blue test solution (0.5% wt%) in a 45 mL test tube.**

Testing (Contd.)

3. Carefully add the 20 g of sample to the 30 g of methylene blue solution.
4. Shake the sample tube for 1 minute and allow it to rest for 3 minutes. After the 3-minute rest period, shake the sample tube for an additional 1 minute.

Testing (Contd.)

5. Remove the plunger from the 3 mL syringe and place a filter on the luer-lok fitting.
6. Using a transfer pipette, add approximately 2 mL of the test solution to the syringe and replace the plunger.
7. Slowly filter 0.5-1.0 mL of the test solution into a new clean 1 mL plastic tube.

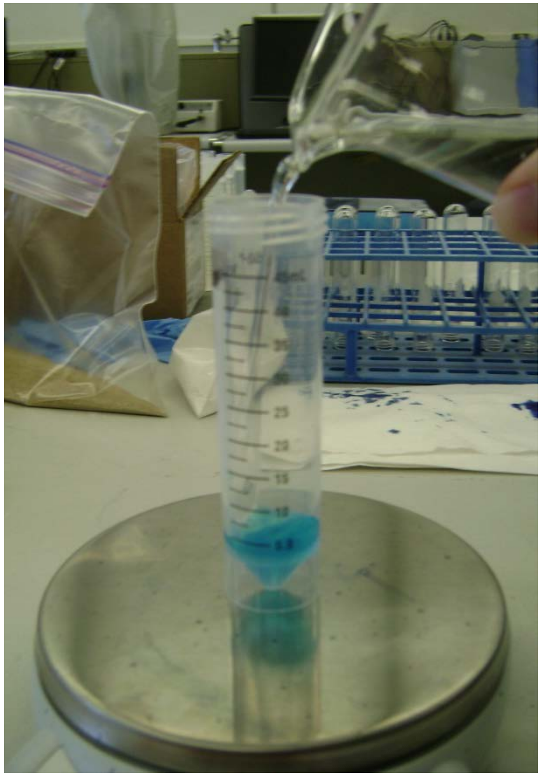


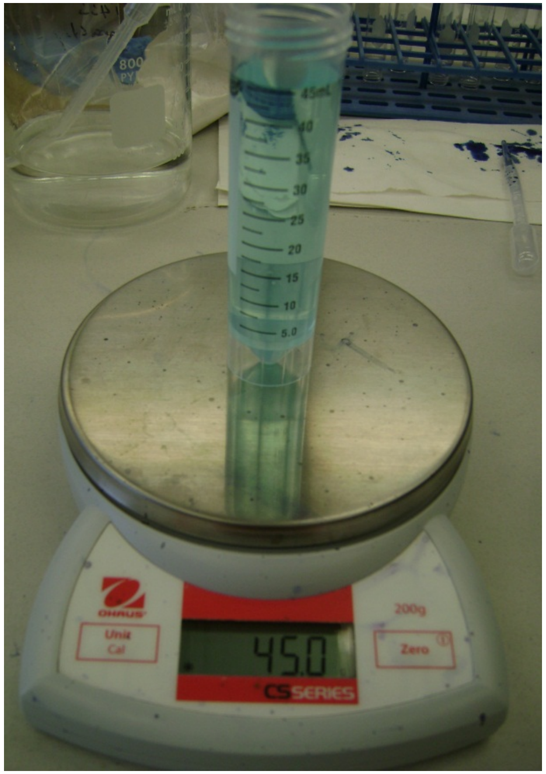
Testing (Contd.)

8. Tare a new clean 45 mL sample tube on the balance.
9. Using the adjustable micro-pipette, transfer 130 µL of the filtered solution into the sample tube.

Testing (Contd.)

10. Dilute the 130 µL aliquot with water to accurately make a total of 45 grams.
11. Cap the tube and mix the sample by gently shaking the tube.
12. Transfer the diluted solution to the glass test tube.



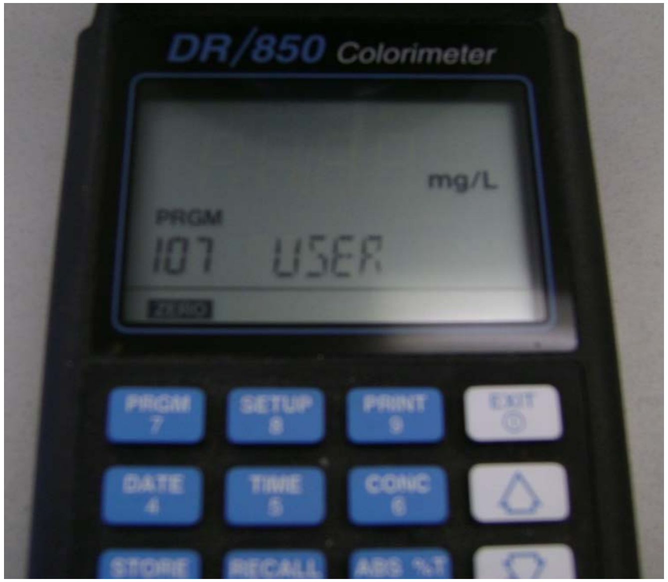


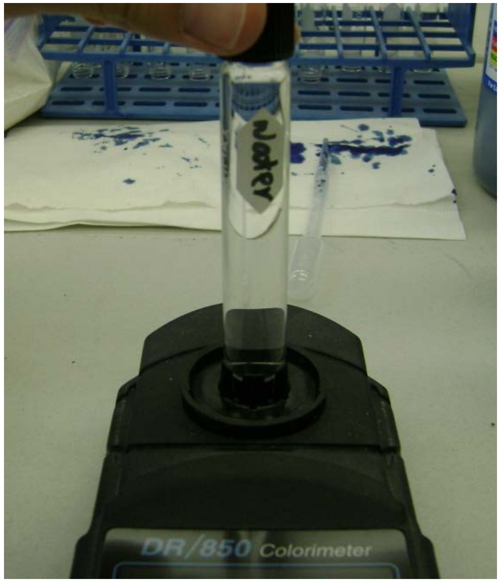
Testing (Contd.): Colorimeter Operation

1. **Remove the instrument cover. Insert the 16 mm test tube adapter into the cell compartment and rotate until it drops into the alignment slots, gently pushing adapter until it snaps into place. Turn on the power to the colorimeter.**

Testing (Contd.)

2. **Press the PRGM button and the display will read "PRGM?". Type in "107" then hit the ENTER key.**
3. **Place a glass test tube filled with water into the tube adapter and place cover over the tube. Press the ZERO key.**
4. **The instrument will display a value of 7.50, which indicates normal operation.**





Testing (Contd.)

5. Replace the water-containing tube with the test sample glass tube.
6. The value displayed by the colorimeter is the methylene blue value (MBV). Please note the instrument has been calibrated to read in mg/g even though the units display as mg/L.

Confirmation of Correct Starting Methylene Blue Concentration and Related Correction in MBV

- **The Grace test procedure is based on a starting methylene blue concentration of 0.50 wt. % (percent by weight based on anhydrous methylene blue).**

- **Because of the variation in different sources of methylene blue, the actual methylene blue solution concentration must be determined using method 106 on the colorimeter.**

- **Should the solution concentration be different than 0.50 wt. %, the correction factor described next must be applied to obtain the correct MBV result.**

Procedure to Determine the Actual MB Concentration

1. Use the micropipette to transfer a 130 µL aliquot of the starting methylene blue solution to a 45 mL test tube.

2. Dilute the aliquot to 45 g with water and gently mix the contents.

3. Transfer to the glass tube and cap.

4. Press the PRGM button on the Hach DR 850 colorimeter and the display will read “PRGM?”. Type in “106” then press ENTER.

5. Insert a glass tube filled with water and press “ZERO” on the colorimeter. Water should be potable; deionized or distilled water can be used but is not required.

6. Insert the glass tube with the diluted methylene blue solution.

7. Press “READ.” Program 106 reports the concentration of the diluted methylene blue solution in ppm. A reading of 14.44 ppm corresponds to a concentration of 0.50 wt. %.

Procedure to Determine the Actual MB Concentration (contd.)

8. Convert the concentration in step 7 ($C_{method\ 106,\ ppm}$) to the concentration of the starting methylene blue solution ($C_{initial\text{-}actual}$) by using the following equation:

$$C_{initial-actual} = (C_{Method\ 106,\ ppm})\frac{45ml}{(130\mu l)(1000)}$$

For example, if the result of Program 106 is 14.2 ppm, the actual concentration of the starting methylene blue solution is calculated as follows:

$$C_{initial-actual} = (C_{Method\ 106,\ ppm})\frac{45ml}{(130\mu l)(1000)}$$

$$= (14.2\ ppm)\frac{45ml}{(130\mu l)(1000)} = 0.0049$$

9. Repeat this test three times and calculate the average.

Correction of Methylene Blue Value

The following equation can be used to calculate the corrected methylene blue value if the wrong methylene blue concentration is used:

$$MBV_{corrected} = \frac{\left(C_{initial-actual} - C_{initial-theoretical} + \frac{MBV_{measured}(20g)}{(30ml)(1000)}\right)(30ml)}{20g} \text{ x } 1000$$

Where: $MBV_{corrected}$ = corrected methylene blue value, mg/g

$C_{initial\text{-}theoretical}$ = theoretical concentration (0.5%)

$MBV_{measured}$ = measured methylene blue value with wrong starting solution concentration

Determination of Correction Factor

For example, using the value of $C_{initial\text{-}actual}$ of 0.0049 as given earlier, and a measured MBV of 2.40 mg/g, the corrected MBV would be calculated by the equation below

$$MBV_{corrected} = \frac{\left(0.0049 - 0.0050 + \frac{(2.40mg/g)(20g)}{(30ml)(1000)}\right)(30ml)}{20g} x1000 = 2.25\ mg/g$$

$C_{factor} = MBV_{Corrected} – MBV_{measured}$

C_{factor} (for the above example) = 2.25 – 2.40 = -0.15 (0.15 needs to be deducted from the measured MBV)

Determine the correction factor for each new bottle of methylene blue by the above procedure and report the corrected MBV

The Degree of Sample Dilution to Get a Representative MBV

- **The maximum value that the colorimeter can measure is 7.5.**

- **In the case of sample with high clay contents, the highest MBV around 7.5 is measured with 20 gm of sample. It is recommended to report MBV of > 7.5 in this case.**

- **If the measured MBV is maxed out at 7.5 with 20 gm of sample, it is advisable to reduce the sample size from 20 g to 10 g and determine the MBV using 10 g of sample and 10 g of inert filler (i.e., clean silica sand with zero MBV). When using this 10-10 dilution method, the measured MBV needs to be doubled to get the real MBV for the sample.**

- **If the MBV is maxed out at 15.00 with 10-10 dilution, the MBV is outside of the range of the instrument's tolerance.**

Summary of Research Findings: PCC

- **A strong positive correlation between expansive clay content and MBV was evident, indicating that the MMB test is the most reliable and rapid test method to detect clay minerals in aggregate fines.**
- **MBV shows a good correlation with both percent reduction in strength and increase in shrinkage of the PCC mixtures with clay contamination (both pure clays as well as clay contaminated stockpiled materials).**
- **The relationship between MBV and flexural strength was used to assign a threshold MBV of 4.5 for materials passing # 4 sieve size.**

Summary of Research Findings: PCC

- **Although the bar linear shrinkage (Tex-107-E) and sand equivalent (SE) tests (Tex-203-F) give good repeatability in the results, these tests fail to provide consistent and accurate indications of clay minerals present in aggregate fines.**

- **The SE test fails to distinguish between clay-sized particles and actual clay minerals. Furthermore, the SE test is not effective to differentiate between expansive (e.g., smectite) and non-expansive clay minerals (e.g., kaolinite).**

Summary of Research Findings: HMA

- The pass/fail situation based on the HWTT was inconsistent with the specification limit of 45 percent minimum SE.
- The same is true for the results of the Bar Linear Shrinkage test.
- The Methylene Blue Test is sensitive to clays, which contribute to stripping in HMA and could be used to eliminate problematic field sand sources.
- Based on the pass/fail HWTT results, a preliminary threshold MBV of 7.0 mg/g with corresponding SE threshold value of 55 percent are proposed.
- It appears that HMA is more robust and can tolerate higher amounts of clay contamination than PCC, mainly because water is not present in HMA.

Categorization of Aggregate Fines Based on MBV (- # 4 Sieve)

- **A maximum MBV may be specified to limit the permissible quantity and activity of clay in a aggregate fines.**
- **A correlation between MBV and concrete/HMA performance testing became the basis to assign a threshold MBV and categorize aggregate fines.**

Portland Cement Concrete	
MBV (passing # 4 Sieve)	Performance Category
≤ 4.5	Normal
4.5–6.5	Poor
≥ 6.5	Very poor

Hot Mix Asphalt	
MBV (passing # 4 Sieve)	Performance Category
< 7.0	Normal
7.0–10.0	Poor
> 10.0	Very poor

Determination of MBV Using Passing #40 Size Materials

- **Grace recommends MB testing using a sand-sized sample, i.e., passing the No. 4 sieve.**

- **However, MB testing at the P40 (passing No. 40 sieve) size was also conducted in this project since that is the same size used for the Plasticity Index (PI) and bar linear shrinkage tests.**

- **MBV increases with decreasing sample particle size (e.g., from − #4 sieve to − #40 sieve) – possibly due to enrichment of clay minerals in the finer fractions during sieving.**

Categorization of Aggregate Fines Based on MBV (- # 40 Sieve)

Portland Cement Concrete	
MBV (passing # 40 Sieve)	Performance Category
≤ 11	Normal
11–14	Poor
≥ 14	Very poor

The relationship between MBV and flexural strength was used to assign a threshold MBV of 11.0 for materials passing # 40 sieve size.

MBB Test: Summary

- The ranges are arbitrary in nature at this time as these are based on the MBV of limited stockpiled materials. A large number of aggregate stockpiled materials need to be tested for their MBV in both passing # 4 and # 40 sizes along with corresponding PCC/HMA performance testing in order to assign more accurate MBV ranges.

- A high MBV (i.e., above the threshold ranges) indicate increased potential for diminished aggregate performance in asphalt, concrete, and other construction applications.

- MBV of both − #4 and − #40 sizes can be used to categorize aggregate fines from stockpiled materials.

MBB Test: Summary (Contd.)

- **Rapid** – no sieving or tedious titration required. The entire test can be completed in less than 10 minutes
- **Portable** – fits into a small toolbox
- **Comprehensive** – measures the entire size fraction of aggregate, rather than just the < 75 µm or < 2 mm fraction
- **Simple** – no advance training required
- **Accurate and repeatable**
  - Results correlated to AASHTO T 330 and EN 933
  - COV mostly within 6% with − #4 size
  - COV mostly within 3% with − #40 size
- **A good correlation between % swelling clay (e.g., smectite) and MBV** – MBV is a very effective method to detect the presence of swelling clay in aggregate fines
- This test method provides a **rapid and reliable field method** for determining changes in the quality of aggregates during production or placement

Current Practice of Mitigation to Remove Aggregate Fines

- **It is currently a standard procedure to have aggregates go through a series of washing during production before they are placed in stockpiles in order to remove any deleterious matter that may have been incorporated at the quarry site.**

- **In many cases, this technique is quite effective at removing this deleterious matter from the aggregates, but depending on the nature and degree of the clay contamination, sometimes this method fails to remove the harmful clay minerals that can be contained within the fines.**

- **The deleterious matter and clay minerals may be either contained within the aggregate source or collected from the ground during stockpiling operations.**

- **Therefore, improved techniques are needed.**

Proposed Mitigation Techniques

- **Surfactants can be added during concrete mixing or dispersants can be used during washing in aggregate producing plant.**

- **The approach of using dispersants may be helpful if simply washing with water is not effective enough to provide a clean, high-quality aggregate suitable to be used in concrete.**

Use of Cationic Surfactants to Mitigate the harmful Effects of Clay Minerals in Aggregate fines

- **The use of cationic surfactants and their effectiveness to combat the harmful effects induced by swelling clay was explored in this study**

- **Two cationic surfactants were found to be useful to make expansive clay in aggregate fines effectively non expansive or less expansive with respect to PCC performance**
  - **Arquad T-50 (viscous liquid)-AkzoNobel**
  - **Hexadecyltrimethylammonium (HDTMA, powder)-VWR**

- **The procedure for dosage calculation, addition of surfactant to the concrete, cost estimation and performance evaluation is provided next**

Surfactant Dosage Calculation

Step 1: **Conduct MMB test of the aggregate fines (both − 4 and − 40 sizes) from stockpile materials and determine the MBVs. If the MBVs are higher than the threshold values then proceed to Step 2.**

Step 2: **Estimate % smectite from the measured MBV by using the relationship between smectite content vs. MBV that was developed in this project.**

Step 3: **Calculate the dosage of the selected surfactant with different levels of charge balance (i.e., 40, 60, and 100%) using the attached Excel spread sheet. The required inputs for the spread sheet are % smectite (determined in Step 2), sample size (lb of coarse or fine aggregate per yard of concrete depending on whether the swelling clays are introduced through coarse or fine aggregates).**

Instructions for the Use of Spreadsheet

- Enter % smectite in the yellow boxes
- Enter sample size in the green box
  - Coarse aggregate weight in lb if coarse aggregate is the source of contamination
  - Fine aggregate weight in lb if fine aggregate is the source of contamination
- Enter the cost of the surfactant in the blue boxes
- Depending on the type of clay minerals, change the CEC value in the red box

Surfactant Dosage Calculation

Step 4: **Develop some mixtures of aggregate fines (both − 4 and − 40 size materials of around 80 g) and surfactant (dosages correspond to 40, 60, and 80% charge balance calculated in Step 3) and water (quantity needed to make the mixture with sufficient wetability, similar to shrinkage test) and keep it under typical lab conditions (23°C and ~60% RH) for 2–3 hours followed by under oven (60°C) overnight. Run the MMB test of all the mixtures next day and determine which dosage is sufficient to reduce the MBV below the threshold value (i.e., 4.5 for − 4 size and 11 for − 40 size).**

The dosage correspond to 40% charge balance is found to be a standard practical dosage for concrete. However, it is recommended to do the MMB testing (as in Step 4) whenever new stockpile material is tested for MBV.

Adding Surfactant to PCC During Mixing

Step 5: Add the surfactant of required dosage (determined in Steps 3 and 4) during concrete mixing. The time of addition, mechanisms, and effectiveness are provided in the next slide.

- Based on experiments with pure clay (e.g., 1.5% bentonite), a dosage equivalent to 60% charge balance was required for Option 1 whereas it was a dosage corresponds to 40% charge balance for Option 2 to maintain a constant workability (i.e., 1 inch slump).
- With each method of addition, the *w/c* was effectively reduced from 0.49 to 0.46, while giving adequate workability and slump of over 1 inch.
- It seems Option 2 is more effective than Option 1 in this situation. Additionally, Option 2 should be the recommended choice if fine aggregate is contaminated with clay minerals.

It is necessary to verify the applicability of both these options in the context of typical concrete batch plant operation. The option that goes well with the existing operation of a batch plant (without any special requirement) will be the most preferable option to use surfactant.

Time of Addition of Surfactant with Possible Mechanisms and Effectiveness

	Option 1	Option 2
Time of addition of surfactant	Adding raw surfactant directly to coarse aggregate and 20-30% water (first stage of a conventional mixing sequence)	Adding raw surfactant during the final stage of a conventional mixing (e.g., after adding all the concrete ingredients)
Mechanisms	Surfactant reacts with expansive clay present in coarse aggregate fines before the addition of other concrete ingredients (e.g., cement, fine aggregate, admixtures)	(i) Clay in fines consumes some water and causes mix less workable at the beginning, (ii) Surfactant interact with the water filled clays subsequently and expel the consumed water and makes the mix workable with the normal range of w/c
Effectiveness	Should be good provided coarse aggregate does not absorb surfactant (remote possibility)	The interaction (if any?) between surfactant and fly ash/cement/AEA may reduce the effectiveness of the main reaction between surfactant and clay minerals (need further investigation)

Performance Verification

Step 6: Conduct testing to determine fresh concrete properties (e.g., measure slump and water demand). Considerable reduction of water demand should be achieved in comparison with the control mix without any surfactant.

Step 7: Conduct testing to determine hardened concrete properties (e.g., strength and shrinkage testing). Considerable increase of strength and reduction of shrinkage should be achieved in comparison with the control mix without any surfactant in order to justify the use of surfactants.

More research is needed (steps 1–7) using problematic stockpiled materials to verify the effectiveness of different surfactants and other effective chemicals.

It is recommended to do the work under Steps 5, 6, and 7 in the field lab before applying the surfactant in the batch plant for large scale production to make sure that surfactant is providing the expected beneficial effects.

Use of Dispersant in Aggregate Producing Plant

- It is also recommended to explore the possibility of adding dispersant with the water during washing (if any) in the aggregate producing plant. The presence of dispersant with washing water may be useful to remove clay minerals effectively. No investigation has been done in this aspect.

- If significant removal of clay minerals by washing with water plus dispersant is achieved during aggregate production then the use of surfactant during concrete mixing in the batch plant may not be required.

Guidelines on Controlling Aggregate Fines Based on MBV and Total Fine Contents and Recommended Treatment

The guidelines (presented in detailed in the next 3 slides) for PCC are summarized below:

- **Conduct the MBB testing of the stockpiled materials and determine the performance category based on MBV ranges**
- **Assess the pass/fail situation based on a comparative assessment between MBV and the current practice**
- **Determine the total allowable fine contents with respect to − #4, − #40 sieve sizes**
- **Determine the effective treatment – type and dosage of surfactant or other effective chemicals; use the Excel spreadsheet**
- **Cost benefit analysis – use the attached Excel spread sheet to calculate the cost of adding surfactant per yard of concrete**

Guidelines for PCC

MBV (−4) / (−40)	Current Specifications (e.g., content of −200 sieve)	Total Permissible Fine (−4 or −200) Contents	Treatment Recom-mendation	Remarks
≤ 4.5 or ≤ 11 PASS	Within the permissible limit (PL) PASS	Total fine content can be increased	No treatment	Flexibility in controlling the fine contents
≤ 4.5 or ≤ 11 PASS	Above the PL FAIL	-More than the limits specified by the current methods and / or -Higher than the upper limits of the current specified gradation ▲	No treatment	Allowing a material which is unnecessarily failed by current specifications - sustainable approach, save money ♣

♣ICAR research shows that addition of non-clay fines (manufactured fines, e.g., limestone fines) more than the recommended limit do not cause any harmful effects

▲ Further investigation is needed to assign the effective limits

Guidelines for PCC

MBV (−4) / (−40)	Current Methods (e.g., content of −200 sieve)	Total Permissible Fine (−4 or −200) Contents	Treatment Recommen-dation	Remarks
4.5 - 6.5 or 11.0-14.0 MARGINAL	Within the PL PASS	≤ Upper limit of the current specified gradation ▲	Low surfactant dosage (e.g., T50, HDTMA with dosage correspond to 40% charge balance) ♥	Not allowing a material that is passed by the current methods without any treatment – good control to make durable concrete
≥ 6.5 or ≥ 14 FAIL	Within the PL PASS	≤ Lower limit of the current specified gradation ▲	High surfactant dosage (e.g., dosage correspond to 60% charge balance) ♥	

▲ Further investigation is needed to assign the effective limits

♥ Use of suitable dispersant should also be evaluated

Guidelines for PCC

MBV (−4) / (−40)	Current Methods (e.g., content of −200 sieve)	Total Permissible Fine (−4 or −200) Contents	Treatment Recommendation	Remarks
≥ 6.5 or ≥ 14 FAIL	Above the PL FAIL	≤ lower limit of the current gradation ▲ or Controlled use of fines of specific sizes ▲	-High surfactant dosage during concrete mixing ♥ and / or - Treatment in the aggregate Plant - add dispersant with washing water ♥	A bad material can still be used with proper treatment – sustainable approach

▲ Further investigation is needed to assign the effective limits
♥ Use of both surfactant and dispersant needs to be explored in order to identify an effective and economic treatment method

Guidelines for HMA

Current procedure on controlling fine content – SE, Shrinkage, decantation

Conduct MMB Test for the stockpiled materials and determine the performance category		Treatment (e.g., Use of cationic surfactants) Cost of Lime: $125/ton		
MBV (−4)	**Performance Category**			
		Dosage	**Type**	**Cost**
≤ 7.0	Normal	No	Lime Or Liquid	0.0
7.0–10.00	Poor	Minimum dosage based on MBV (~40% charge balance)		TBD
≥ 10	Very poor	Higher dosage than determined by MBV		TBD

Pass/Fail Situation for HMA: Current vs. Proposed Methods

Current Methods	Proposed method Based on MMBT	Treatment recommendation
Pass (SE/shrinkage values are within the permissible limits)	Fail MBV ≥ 10	Treatment needed
Fail (SE is lower or shrinkage is higher than the permissible limits)	Pass MBV is ≤ 7.0	No treatment

Implications

- **Based on MMB test, materials that are failed by the current specifications (e.g., aggregate fines with clay size non-clay mineral particles) can be allowed, which promotes sustainability and saves money.**
- **MMB test has the ability to consistently identify the problematic materials that need remedial measures.**
- **Establishing criteria based on type and concentration of clay minerals present in aggregate fines, and total permissible fine content will be the effective way to avoid durability issues.**
- **The MMB test could allow the design of an optimum quantity and type of anti-stripping additive for a particular HMA (instead of common practice, i.e., 1 % lime).**