Pavement Club Meeting
January 5th, 2010

Update on Department of Civil Engineering

- In 2009-2010 lost 8 faculty out of 36
  - Two hires away
  - One denied tenure
  - Five retirements
  - Only 3 cross disciplinary positions back
- Also lost 3 support staff in the main office
- ~380 Undergraduate Students
- ~180 Graduate Students
  - 70 Ph. D.
  - 110 M.S.

Pavements Mechanics and Materials

- Part of Transportation group
- Two full-time faculty
  - Lev Kazanovich – “concrete” research
  - Mihai Marasteanu – “asphalt” research
- One full-time asphalt laboratory manager
- Seventeen current graduate students
  - 6 Ph.D. + 4 MS (concrete)
  - 4 Ph.D. + 3 MS (asphalt)

Asphalt Materials

- Since 2000 graduated:
  - 4 Ph.D. students: academia, FHWA, consulting
  - 7 MS students: MnDOT, consulting
- Attracted consistent funding over the years
  - ✓ Average of ~ $200k per year to support graduate students, laboratory operations, laboratory manager, PI time
- Main funding sources:
  - ✓ MnDOT, LRRB
  - ✓ FHWA
  - ✓ NCHRP and NCHRP Idea

The University main role is to EDUCATE and TRAIN

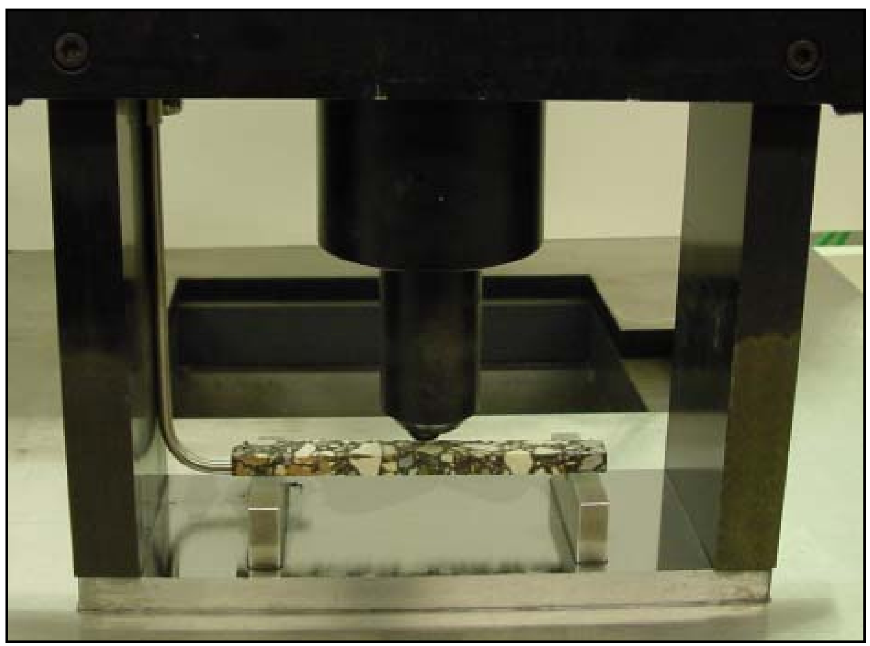
students and not to

“do research for the sake of research”

Asphalt Pavements

- Research in asphalt pavements combines fundamental research with practical engineering solutions
- Main efforts in
  - Low temperature cracking
    - Development of new test methods and analyses for better material selection
  - Use of Reclaimed Asphalt Pavements (RAP) and roofing shingles
  - Maintenance and rehabilitation

Development of a Simple Test to Determine the Low Temperature Creep Compliance of Asphalt Mixtures NCHRP-IDEA 133



Introduction

- Superpave mix design is based on volumetric analysis and limited testing for moisture susceptibility
- Unlike other Civil Engineering materials, mechanical testing has been rarely performed on asphalt mixtures, except for research projects
  - Expensive testing equipment
  - Time consuming sample preparation and testing
- Only recently, significant effort to implement the simple performance test (E*) as part of AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG)

Introduction

- E* testing does not consider low temperature cracking, the critical distress in cold regions pavements
- Current AASHTO specifications for thermal cracking
  - **Creep** and **strength** tests with Indirect Tension Test (IDT)
    - ✓ IDT equipment over $100k
    - ✓ Use of expensive extensometers
    - ✓ Large test specimens that do not allow evaluating aging effects or properties of asphalt lifts smaller than 2″
  - The result: very few laboratories are capable of performing IDT testing

Idea Behind this Research Effort

- Can a simpler test device and method be developed to "replace" IDT ?
- The Bending Beam Rheometer (BBR) used to test asphalt binders appeared to be the "ideal" candidate
  - Relatively cheap: ~$20k
  - No need of expensive strain gauges
  - Excellent repeatability
  - Use of small specimens
  - Biggest advantage: **most laboratories have BBR** equipment and trained personnel to use it

IDT vs. BBR

Main Challenges

- Test specimens preparation
  - Thin beams with thickness = ¼"

- Increased loading capacity to deform mixture specimens
  - ~ 10 times stiffer than binder specimens

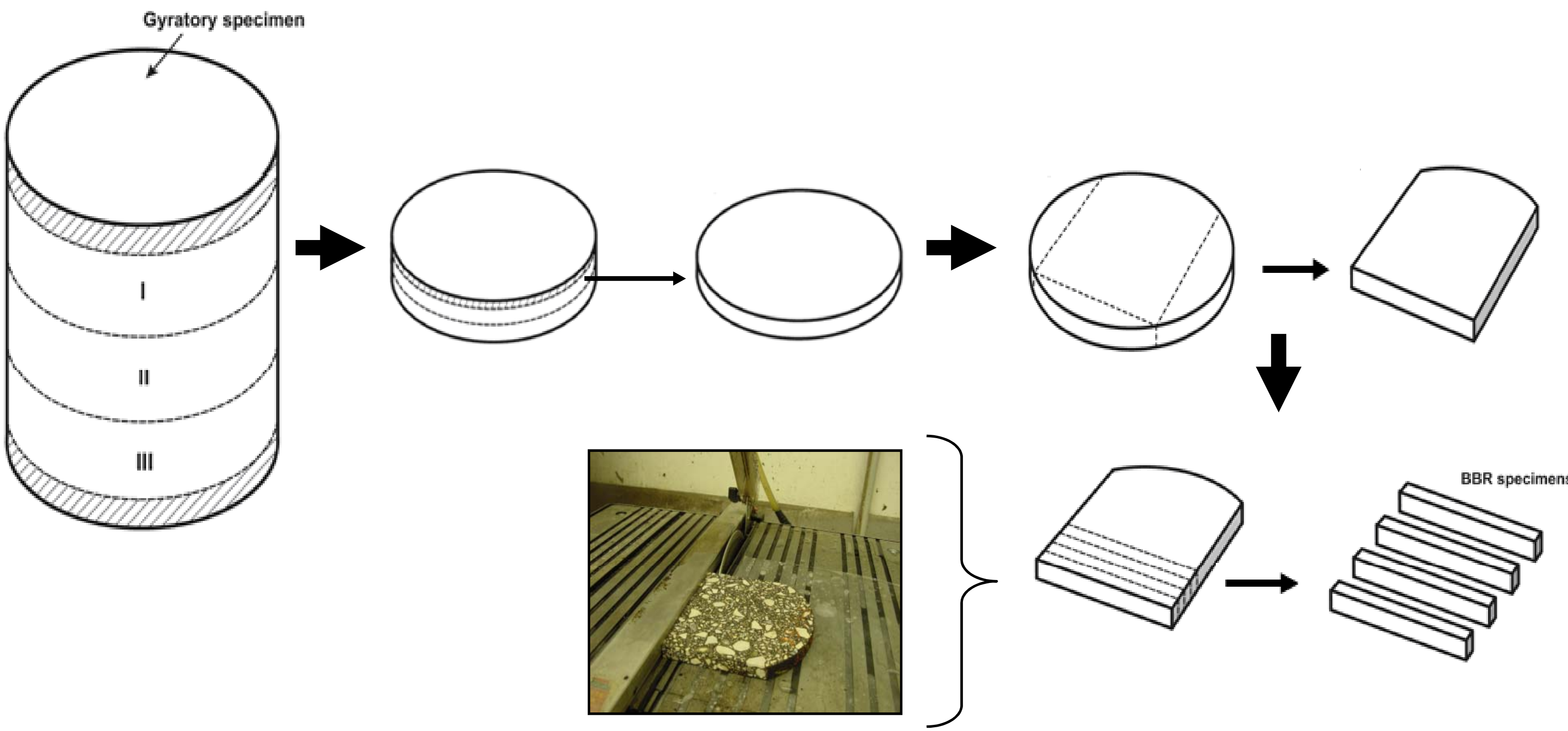
- **Biggest challenge**: how can small specimens be representative of asphalt mixtures containing aggregates larger than ¼" ???

Main Reasons for "Why it Works"

1. Unlike other distresses, low temperature cracking is mainly an environmental distress
   - Restrained pavement contracts as temperature drops
   - Critical stress is **tensile stress**
   - Tensile stress controlled by asphalt mastic (binder)
     - ✓ Very little contribution from larger aggregates
2. At low temperatures, mismatch between mastic (binder) properties and aggregate properties significantly reduced
   - Not true for intermediate and high service temperatures

What Was Accomplished

- **Developed detailed sample preparation procedure** for tall and normal gyratory compacted cylinders and field cores

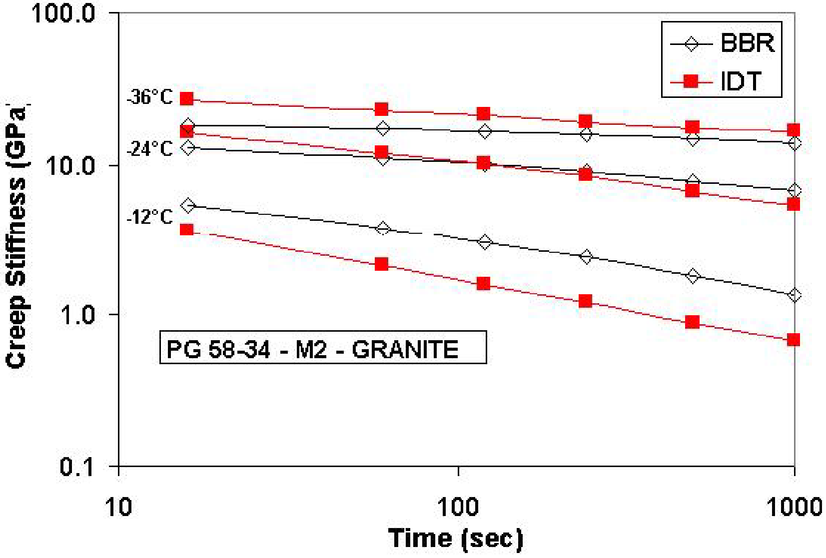


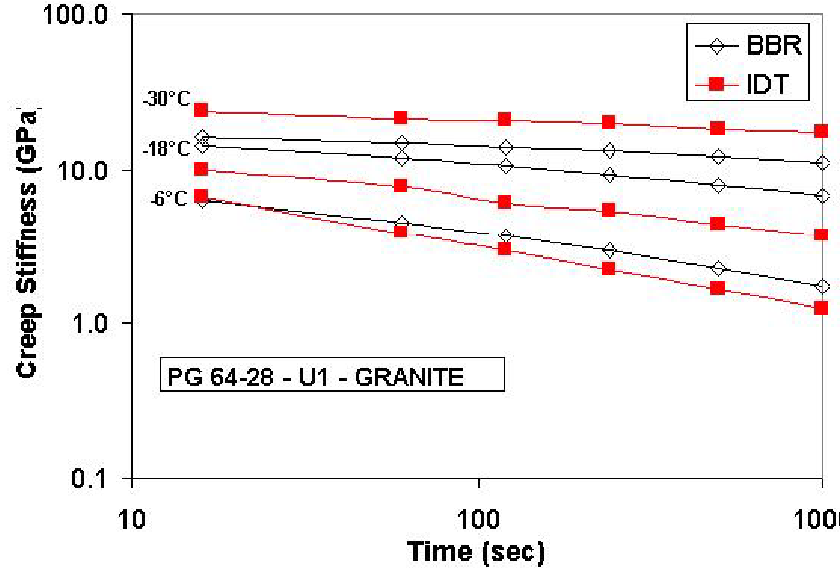
Accomplishments

- **Developed detailed loading procedure** that allows testing mixture beams with minimal software modifications and no changes to current BBR equipment for testing at temperatures above the PG critical low temperature
  - Below PG critical temperature, predict creep compliance using time-temperature superposition
- *Note that a heavier loading frame was received from Cannon Instrument that allows testing below the PG critical temperature and, with additional modification, will allow fracture of the beams*

Accomplishments

- **Compared IDT and BBR** creep compliance results
  - Slightly different creep compliance curves
  - Relative ratio between BBR and IDT results varies with time and temperature





Accomplishments

- **Investigated the *Representative Volume Element* (RVE)** of asphalt mixtures with respect to low temperature creep stiffness
  - Main criticism of the proposed method: Volume of material tested in BBR is not representative of asphalt mixtures containing aggregates sizes larger than the smallest size of the beam (6.25mm)

Representative Volume Element

- Very few studies available in literature for RVE of asphalt mixtures (for intermediate and high temperature)
  - Weissman *et al.* (1999): FE simulations for triaxial loading and simple shear at room temperatures
    - ✓ Suggest that at low temperatures, where moduli mismatch between aggregate and mastic diminishes, smaller RVE compared to RVE at intermediate and high temperatures
  - Romero & Masad (2001): x-ray imaging and shear tests at intermediate temperatures
    - ✓ They also suggest that the stiffer binder diminishes the aggregate size influence on variability of the response

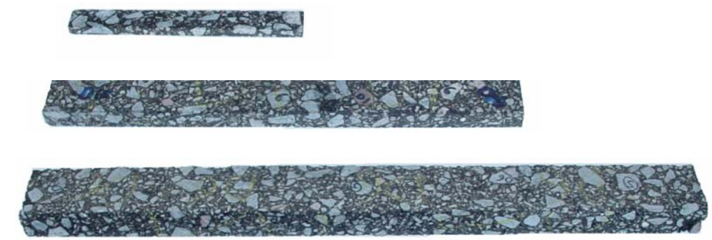
Testing Procedure

- Low temperature 3-point bending creep tests on specimens with three different sizes:

6.25mm × 12.5mm × 100mm (1x) →

12.5mm × 25mm × 200mm (2x) →

18.75mm × 37.5mm × 300mm (3x) →



- Effect of temperature studied by performing tests at three temperatures:

  -High temperature (HT) level (PG low limit + 22˚C)

  -Intermediate temperature (IT) level (PG low limit + 10˚C)

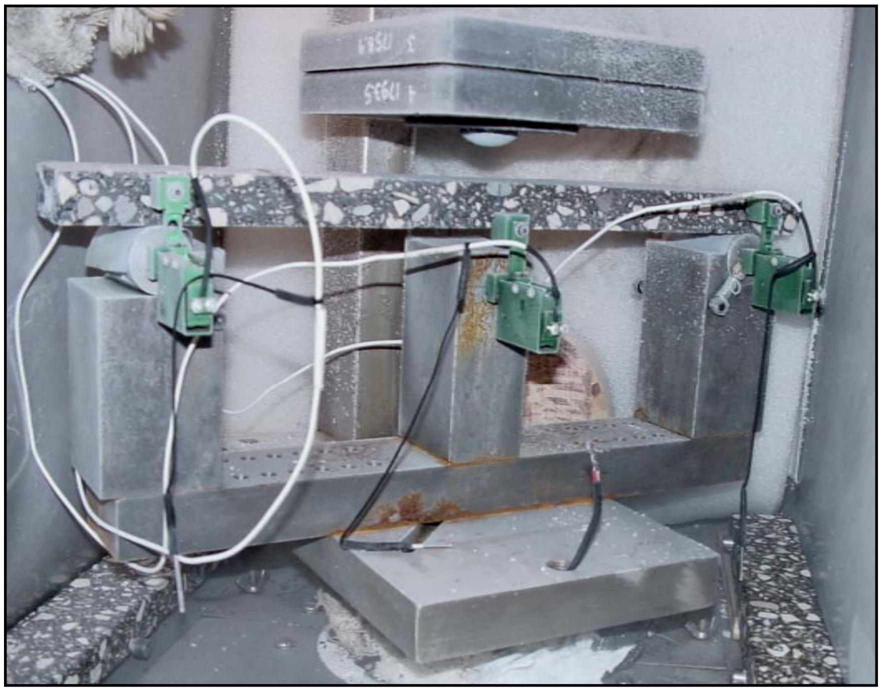
  -Low temperature (LT) level (PG low limit - 2˚C)

Testing Procedure

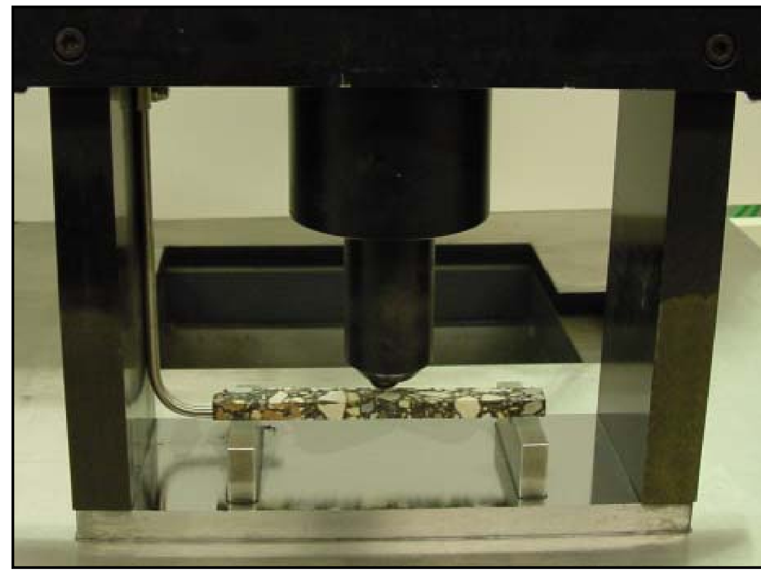
1. Slab compacted mixtures were cut into six 3X beams
   - Three replicates tested at HT and LT and six replicates tested at IT
2. 3X beams were cut into 2X beams using typical laboratory saw
   - Three replicates tested at HT and LT and six replicates tested at IT
3. 2X beams were cut into 1X beams (size of BBR specimens) and tested in BBR device
   - Ten replicates tested at each temperature level

Note: 3X and 2X beams tested using MTS 810 servo hydraulic machine; 1X beams tested using typical Cannon Industries BBR

Testing Procedure



MTS 810

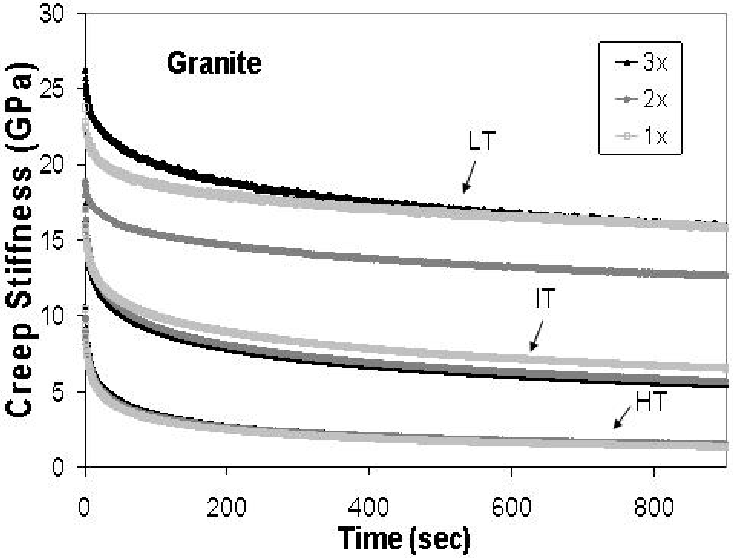


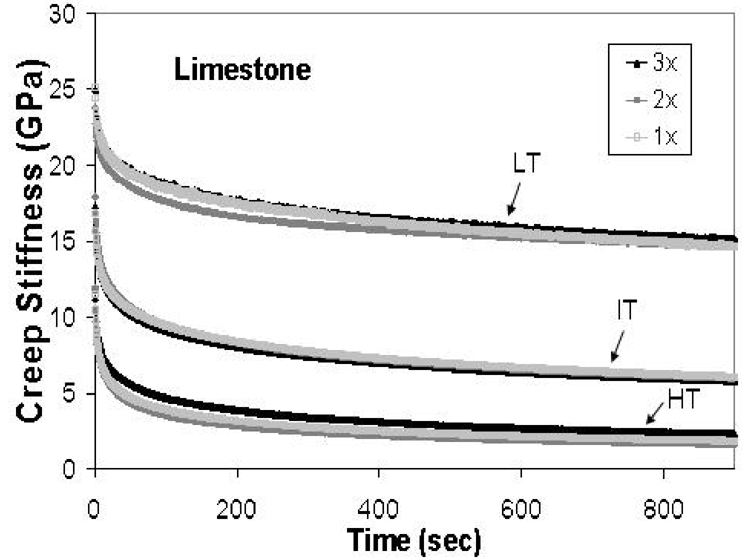
BBR

Results

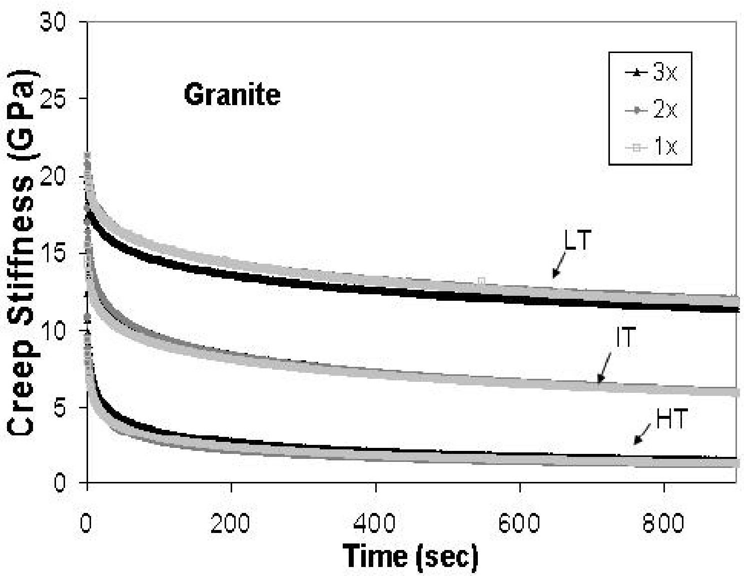
- 360 tests on 3 different size beams at 3 temperatures
- Creep stiffness calculated using Bernoulli - Euler beam theory and correspondence principle
- 2X and 3X beams: deflection measured = deflection due to mid span test load + deflection due to uniformly distributed load equivalent to beam weight
- 1X beams: weight of beam counter balanced by buoyancy forces in BBR ethanol bath

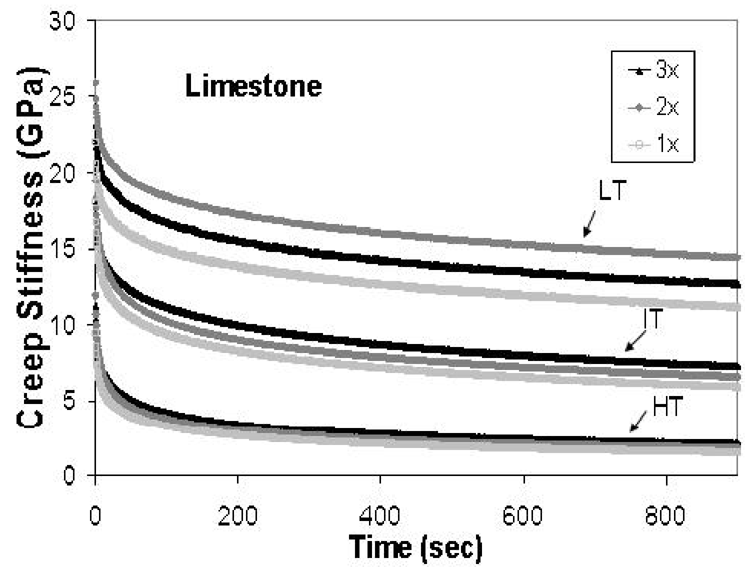
Results





PG 58-34





PG 58-28

Statistical Analysis

- Correlation matrices calculated and analyses of variance (ANOVA) performed
  - Creep stiffness = response variable
  - Size, time, temperature, binder type, and aggregate = independent parameters
- Linear relation assumed between response variable and predictors
- Only creep stiffness values at 8, 15, 30, 60, 120 and 240 seconds used in calculation

Statistical Analysis

Variable	Type / Description
Binder PG	Factors (dummy): PG 58-34, PG 58-28, PG 64-34, PG 64-28
Binder modification	0 – unmodified; 1 – modified
Aggregate Type	0 – granite; 1 – limestone
Beam size	1 - 1x beams; 2 - 2x beams; 3 - 3x beams
Time	8, 15, 30, 60, 120 and 240 sec

Statistical Analysis: All Temperatures

	Creep Stiffness
Aggregate	-0.044
Modification	-0.011
Size	0.042
Size*Aggregate	-0.022

	Creep Stiffness
Size*Time	**-0.214**
Temperature	**-0.853**
Time	**-0.259**

Variable	Estimate	Std. Error	t-value	p-value
Constant	1642.10	324.93	5.05	**0**
Size	517.81	113.16	4.58	**0**
Size*Aggregate	-100.32	124.03	-0.81	0.4187
Size*Time	-0.97	0.74	-1.31	0.1913
Binder[58-28]	-386.72	222.88	-1.74	0.0829
Binder[64-34]	1300.94	152.69	8.52	**0**
Binder[64-28]	907.03	158.26	5.73	**0**
Modification	88.59	98.22	0.90	0.3672
Aggregate	-3120.94	287.30	-10.86	**0**
Temperature	-561.55	5.53	-101.52	**0**
Time	-16.48	1.59	-10.36	**0**

Statistical Analysis: HT Level

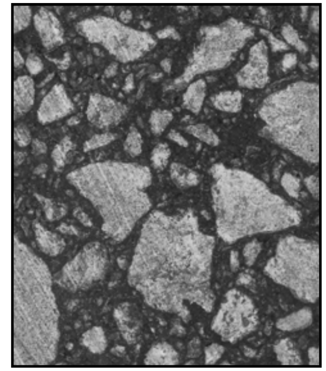
	Creep Stiffness
Aggregate	**0.158**
Modification	-0.081
Size	**0.163**

	Creep Stiffness
Size*Aggregate	**0.235**
Size*Time	**-0.523**
Time	**-0.649**

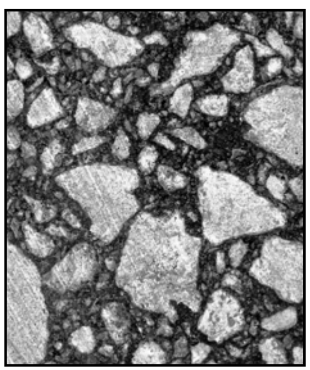
Variable	Estimate	Std. Error	t-value	p-value
Constant	4753.42	252.50	18.83	**0**
Aggregate	-292.34	268.46	-1.09	0.2767
Modification	-2198.67	164.57	-13.36	**0**
Size	311.09	107.88	2.88	**0.0041**
Size*Aggregate	478.97	124.90	3.84	**0.0001**
Size*Time	-1.31	0.77	-1.71	0.0880
Binder[64-28]	1084.92	162.06	6.70	**0**
Binder[58-34]	2562.60	229.04	11.19	**0**
Binder[64-34]	3317.50	227.47	14.58	**0**
Time	-13.08	1.65	-7.92	**0**

Digital Image Processing

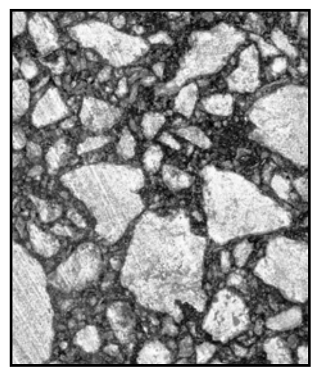
720 dpi RGB image, detection of aggregates larger than 75 μm



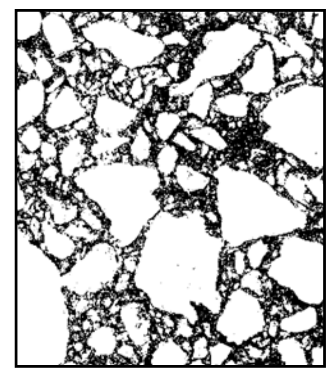
original RGB image converted to gray scale



enhance contrast between two phases by histogram equalization

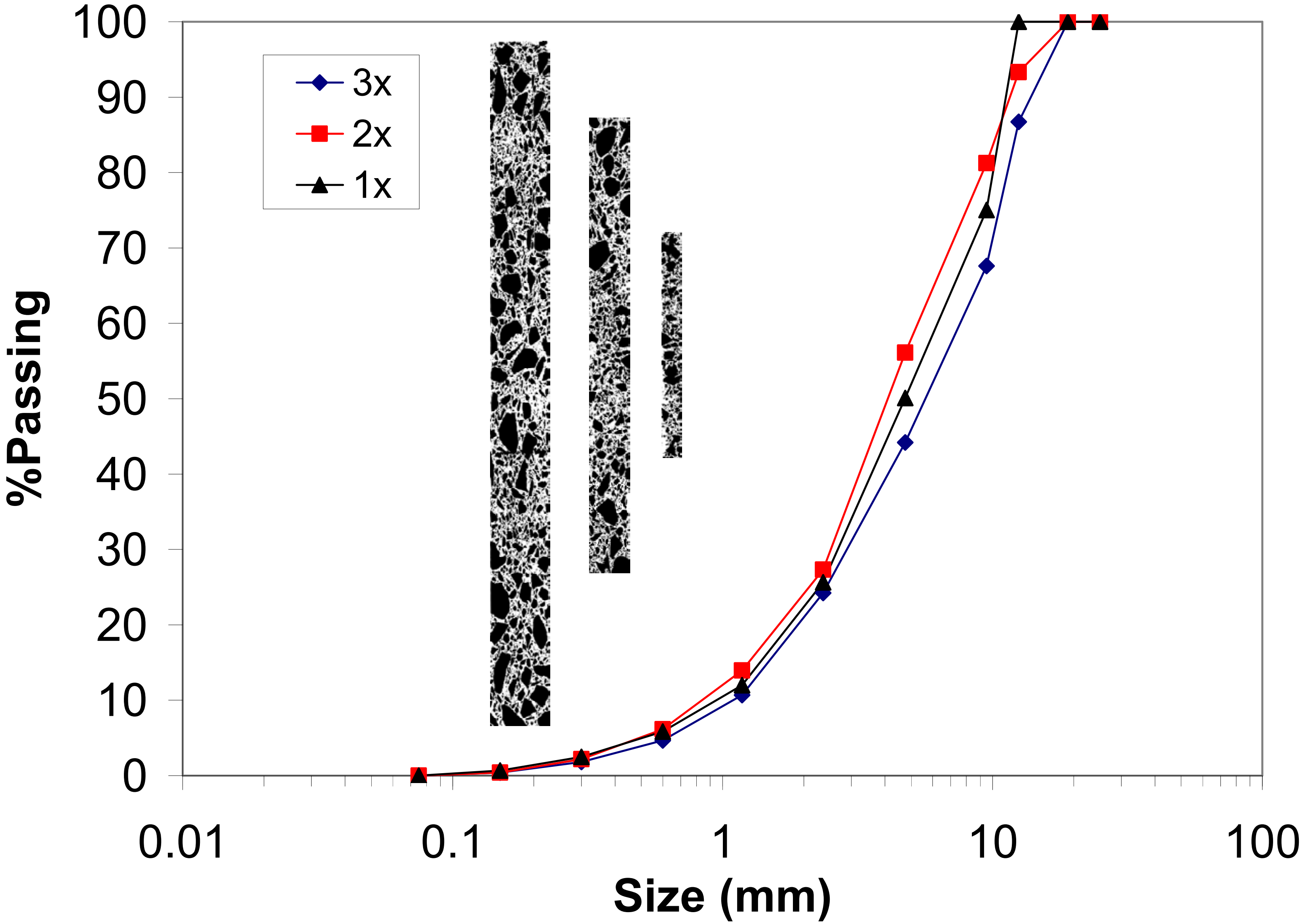


noise present in large aggregates reduced by applying spatial filter

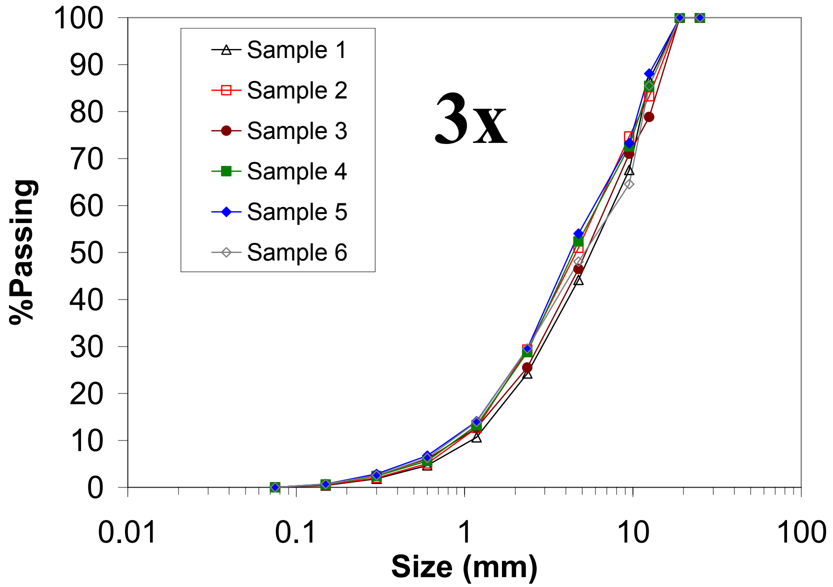


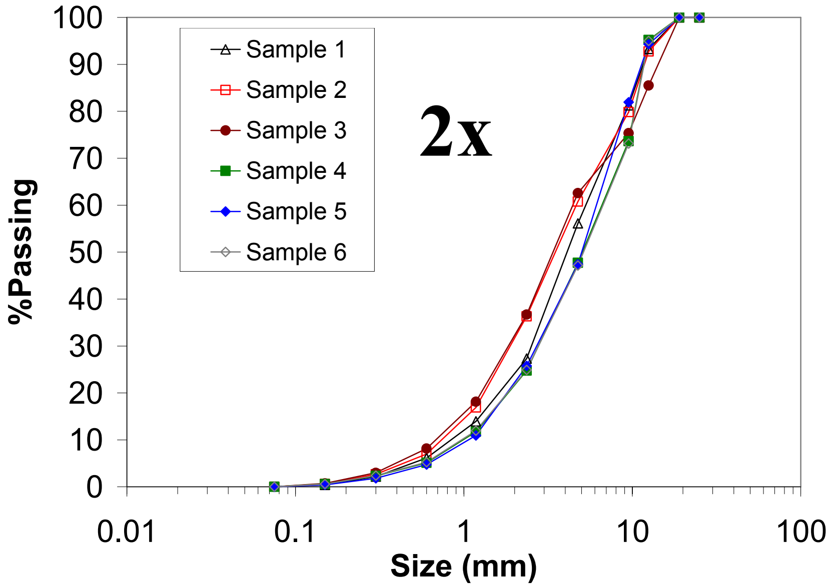
gray scale image converted to binary image (threshold= 0.35)

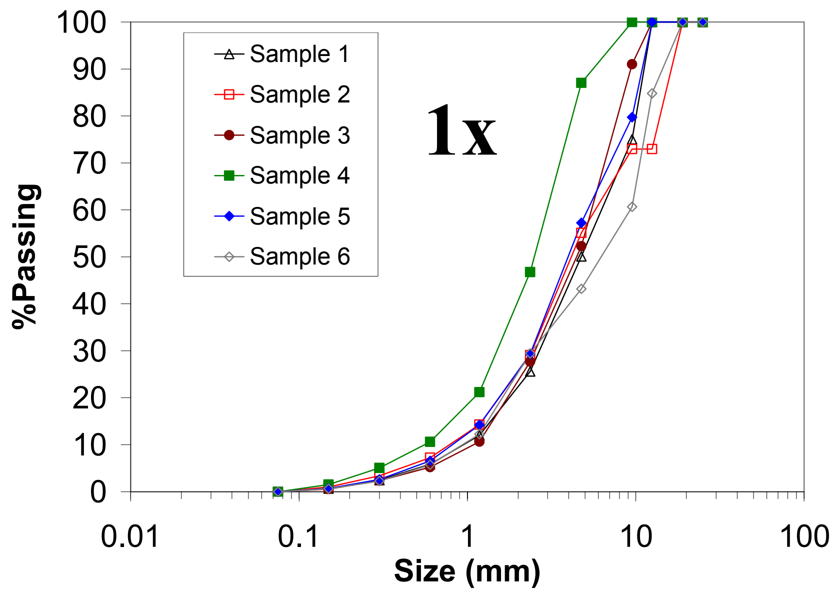
Size Distribution and RVE



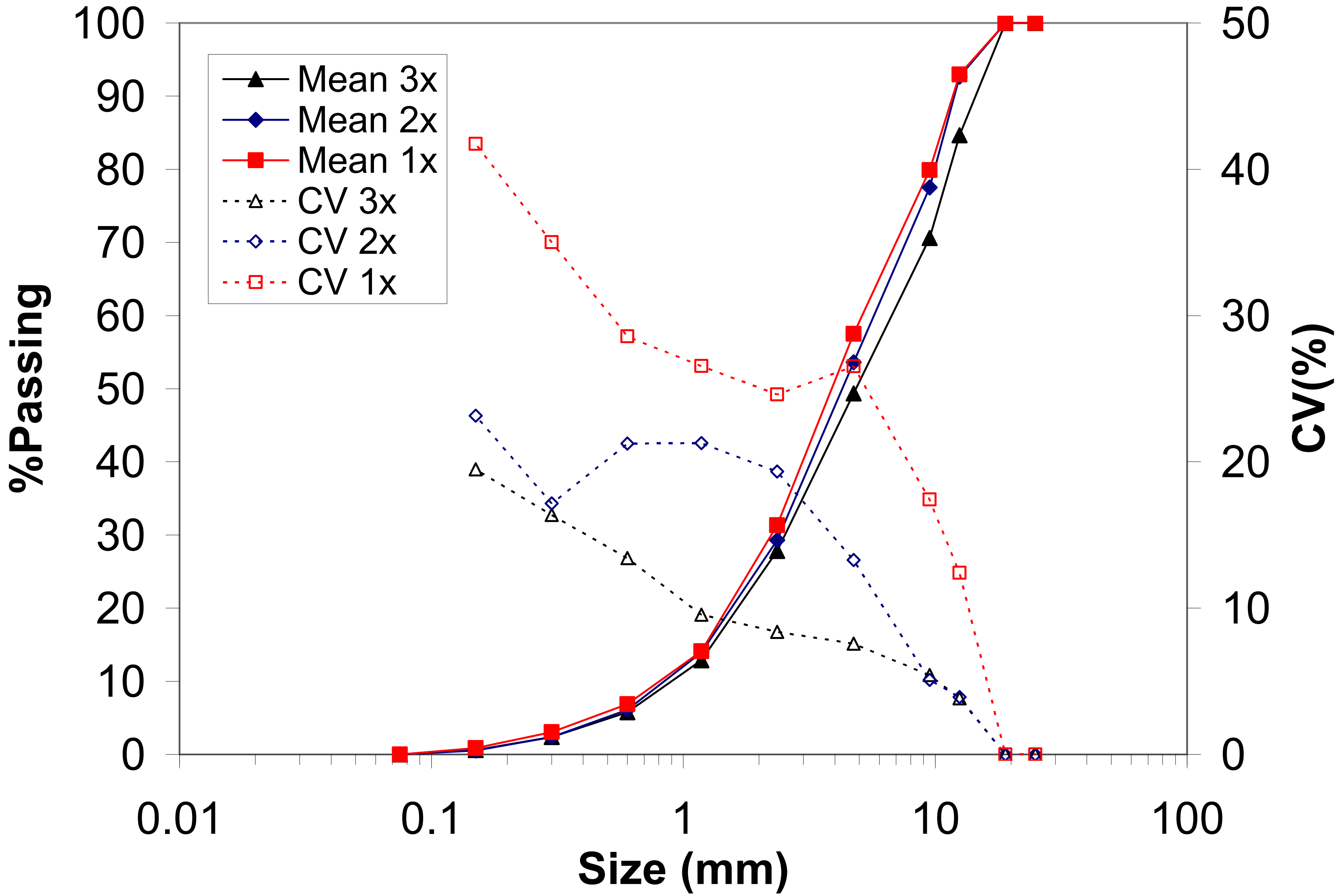
Size Distribution and RVE



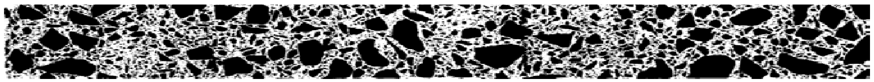




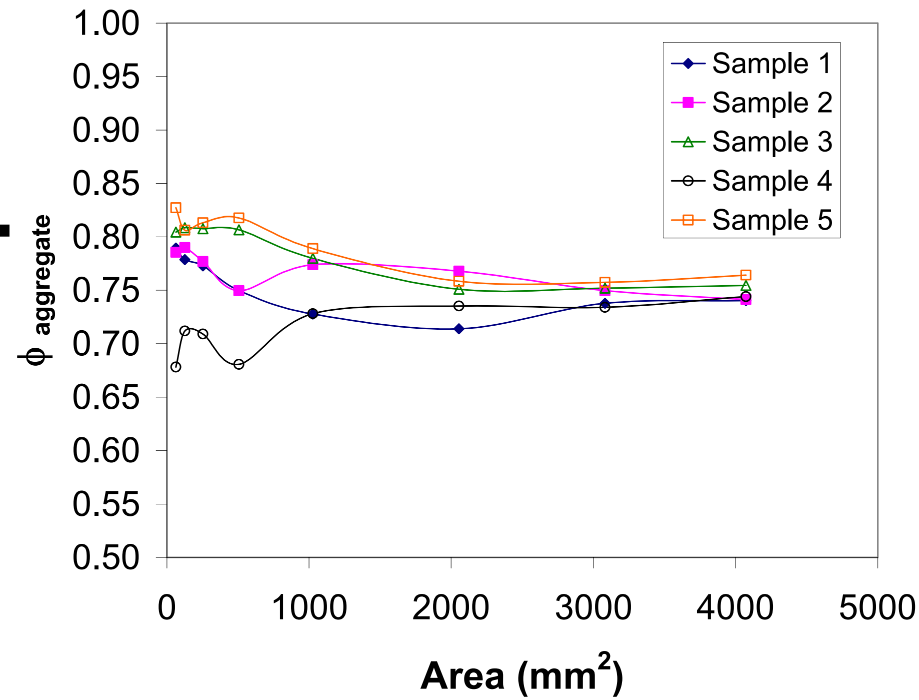
Size Distribution and RVE

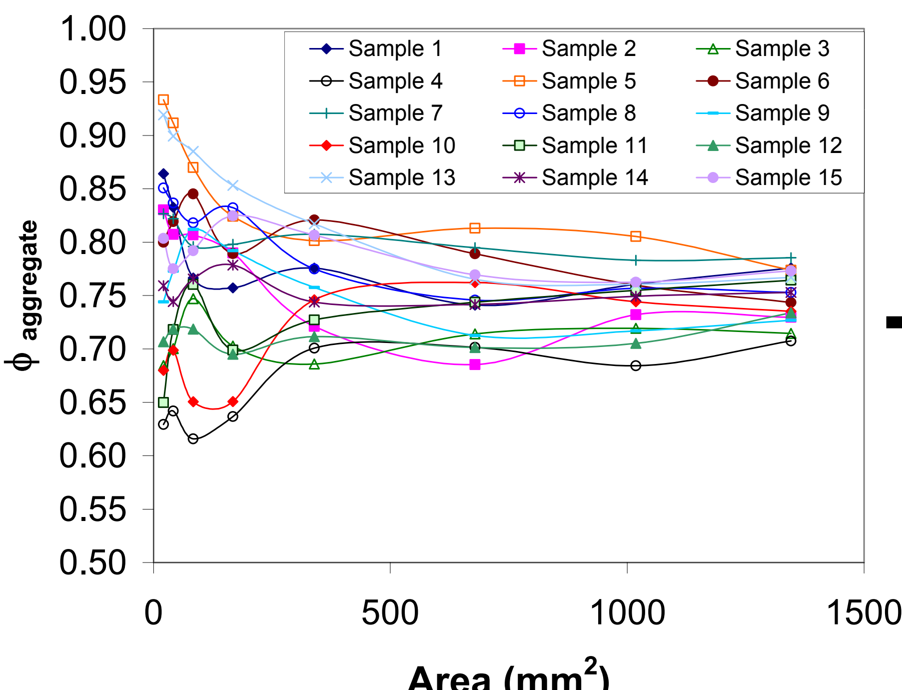


Volumetric Fraction and RVE



3x





1x

Conclusions

- Creep stiffness of asphalt mixtures at low pavement service temperatures can be obtained by testing small (BBR) beams
  - Stiffness mismatch between aggregates and mastic (binder) reduces at low temperatures
  - Mixture creep stiffness becomes less dependent of size and distribution of larger aggregate particles

Conclusions

- Similar size distribution curves observed from 2D digital images analysis of 1X, 2X and 3X beams
  - Supports the idea that BBR mixture beams (1X) may be representative
- Major fluctuations on volumetric fraction of aggregates (fundamental mixture parameter) are reduced for samples larger or equal than 1X

Future Work: BBR Fracture Testing

- Why needed?
  - Creep compliance provides only one of the parameters necessary for predicting low temperature performance
  - Strength is the other parameter needed in the MEPDG low temperature algorithm (TC Model)
- Main challenges
  - Requires heavier loading frame
  - Requires constant loading rate from zero to failure
    - ✓ Current frame only capable of instantaneous loading

BBR Fracture Testing – Preliminary Results

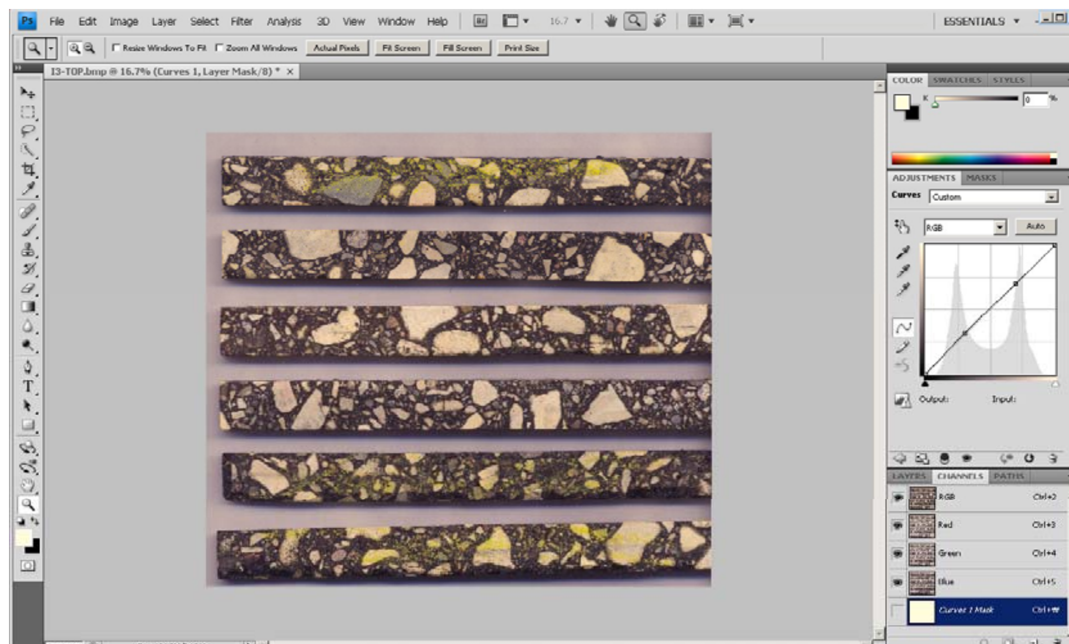
- Heavier load frame received from Cannon
  - Capable of applying 10kgf (compared to 1kgf)
- Improvised device using water flow at constant rate allowed preliminary fracture testing of thin mixture beams with reasonable results

BBR Fracture Testing – Preliminary Results

- Cannon Industries recently delivered to University of Minnesota a test frame with proportional valve control that allows loading at constant loading rate
  - Air flow rate in the air bearing system controlled by modified software
  - No other changes to current BBR equipment
- New system will be capable of performing both creep and strength tests on thin mixture beams

Microstructure Evaluation – Prelim. Results

- Encouraging results obtained using a typical scanner, to scan thin beams, and commercially available digital imaging processing software
  - Images processed in Photoshop and then analyzed in MATLAB



Microstructure Evaluation – Prelim. Results

- Analysis of a limited number of beams resulted in average VMA values of 34.15% for a mixture with known volumetric properties and VMA = 16.3%
  - Error due to presence of fines (<75μm) that cannot be detected by scanners
  - Can be corrected if information about proportions of fines can be reasonably estimated

VMA uncorrected (%)	VMA Corrected (%)		
	Volume Ratio = 3	Volume Ratio = 7	Volume Ratio = 19
34.15	12.20	24.74	30.68

  - Needs to be further investigated

Potential Applications

- Can provide a relatively simple tool to investigate particle size distribution and volumetric fraction
  - Obtain reasonably accurate aggregate gradation
  - Obtain distribution of aggregates within the mixture volume
    - ✓ Critical information for determining asphalt mixture Representative Volume Element (RVE)
    - ✓ **May provide information about distribution of RAP particles in new mixtures and improve RAP processing**
  - Potential to become a simple “fingerprint” tool for quality control


Thank you!