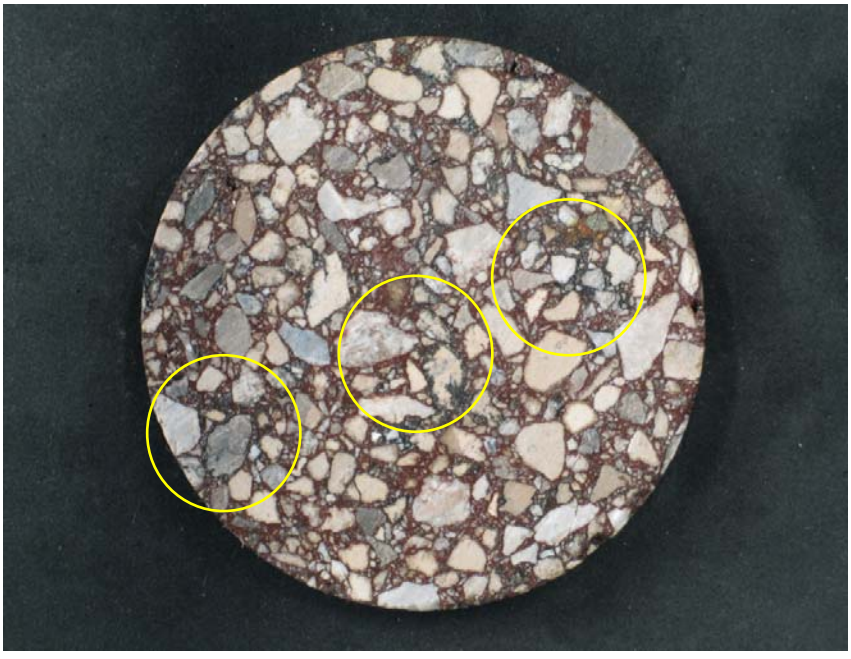
Visual assessment for segregation

Large RAP Mixture – 4 minutes mixing time

NTEC

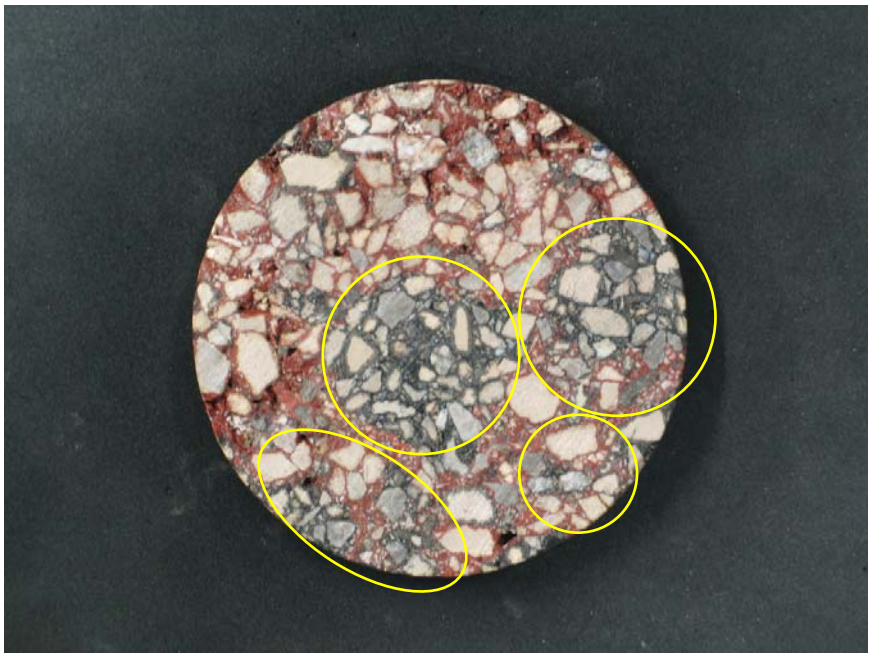
Visual assessment for segregation



Large RAP Mixture – 8 minutes mixing time

NTEC

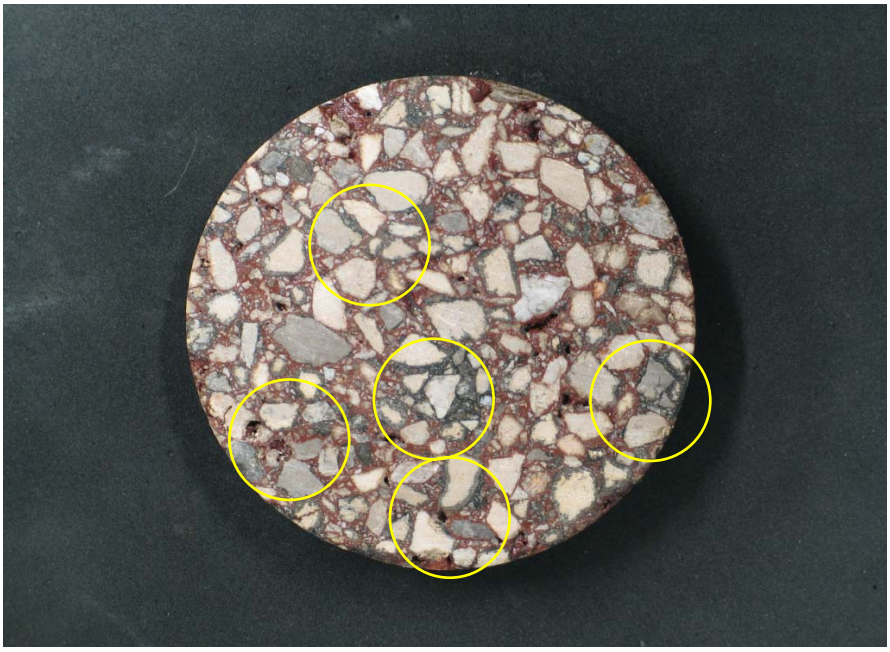
Visual assessment for segregation



Small RAP Mixture – 1 minutes mixing time

NTEC

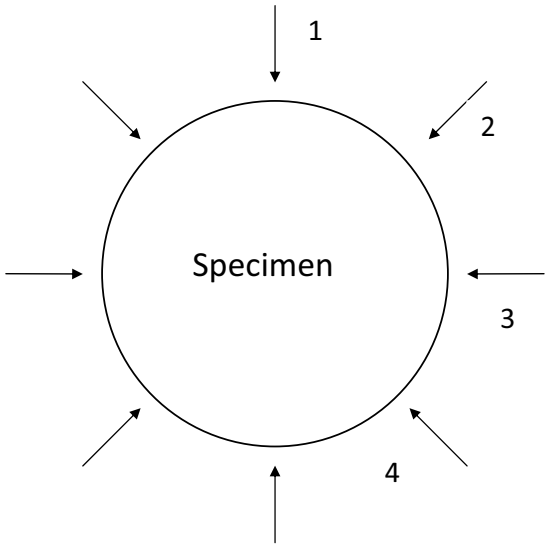
Visual assessment for segregation



Small RAP Mixture – 8 minutes mixing time

NTEC

Mechanical assessment



Stiffness measurement scheme

NTEC

Table 30: Stiffness versus different RAP/superheated virgin aggregate mixing duration

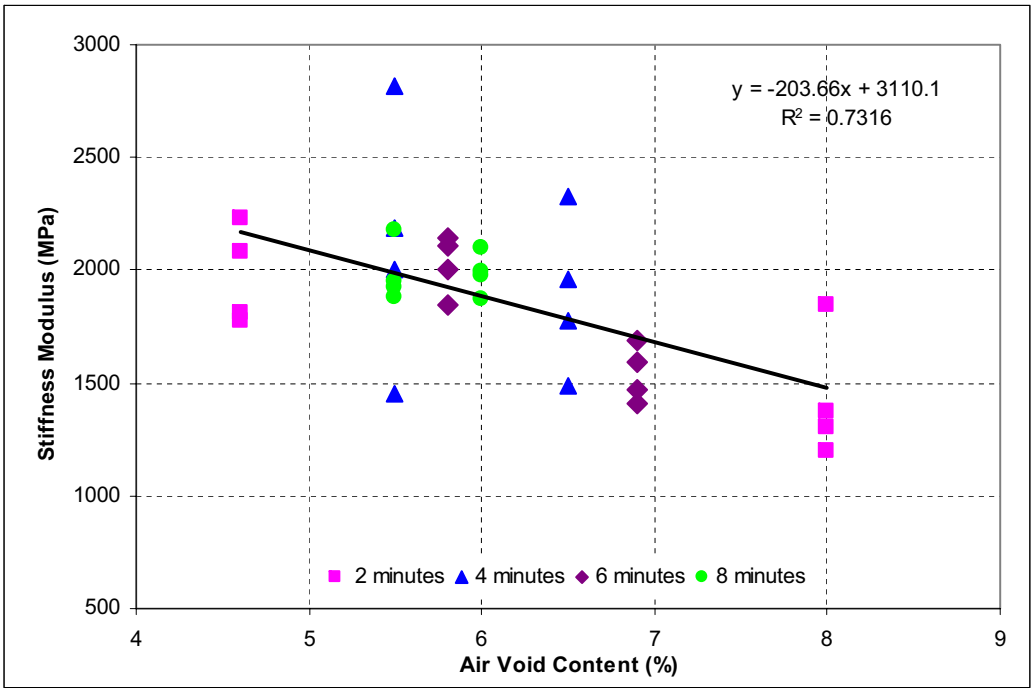
Mechanical assessment

Mixing Time (mins)	Samples	Air void Content %	Stiffness in Different Directions (Mpa) 1	2	3	4	Mean Stiffness (MPa)	COV (%)
2	1	4.6	1813	2232	1778	2078	1975	11
	2	8	1306	1197	1374	1844	1430	20
4	1	5.5	1452	2816	2004	2183	2114	27
	2	6.5	2324	1959	1774	1491	1887	18
6	1	6.9	1690	1591	1408	1472	1540	8
	2	5.8	2147	2106	2002	1850	2026	7
8	1	6	1977	2098	1999	1873	1987	5
	2	5.5	1924	1950	1881	2175	1983	7

Stiffness versus different RAP/superheated virgin aggregate mixing duration

NTEC

Mechanical assessment



Stiffness modulus versus air void content

NTEC

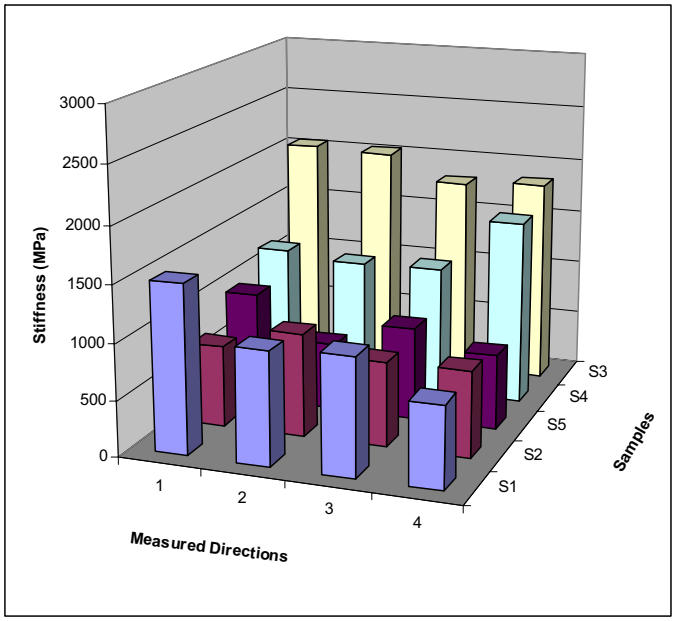
Mechanical Assessment

Mixing time (minutes)	Mean Stiffness (MPa)	Standard Deviation	Coefficient of Variation (%)
2	1702	374	22
4	2000	449	22
6	1783	286	16
8	1984	105	5

Mean stiffness versus RAP/superheated virgin aggregate mixing duration

NTEC

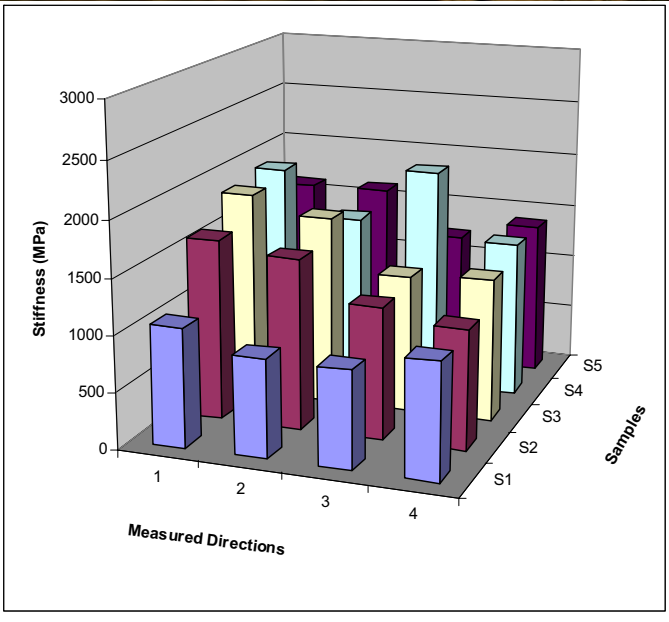
Mechanical Assessment



Stiffness versus core location and measuring direction of LR FS-2 mixture

NTEC

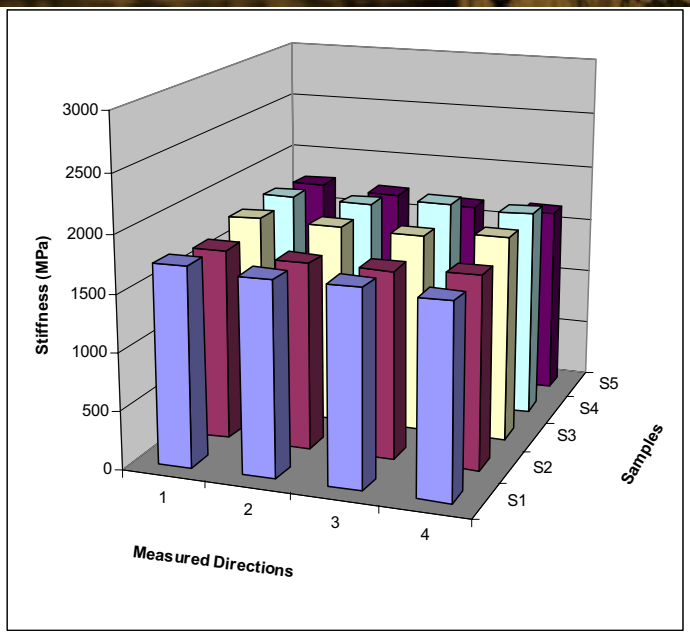
Mechanical Assessment



Stiffness versus core location and measuring direction of LR FS-4 mixture

NTEC

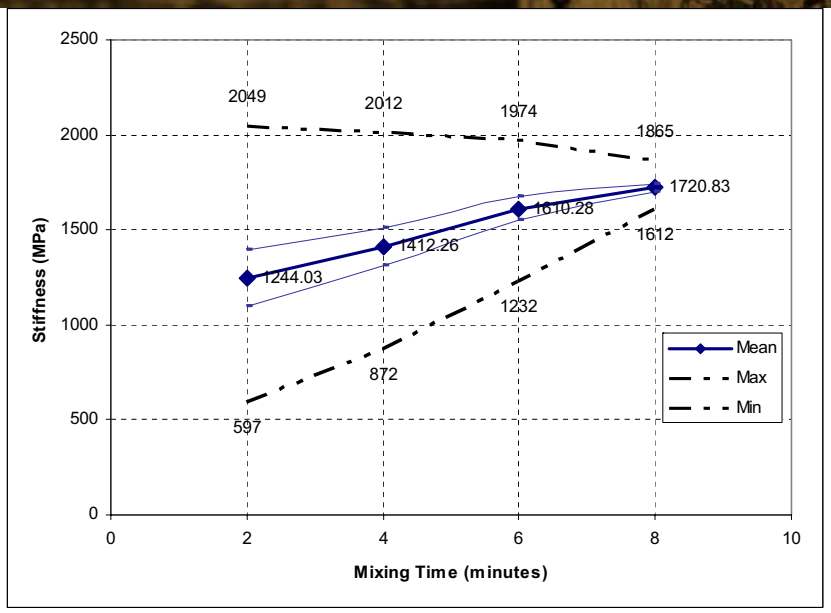
Mechanical Assessment



Stiffness versus core location and measuring direction of LR FS-8 mixture

NTEC

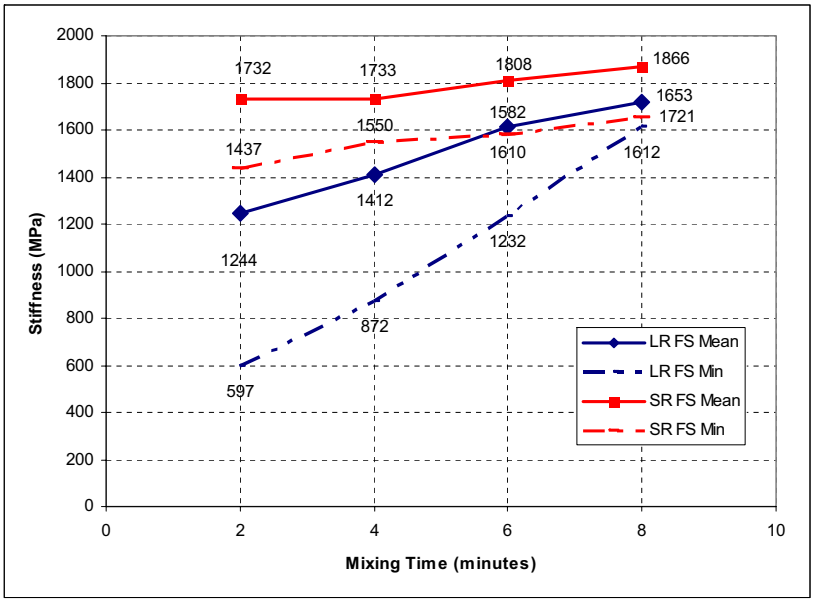
Mechanical Assessment



Stiffness versus mixing time of Large RAP Field Simulated Mixtures

NTEC

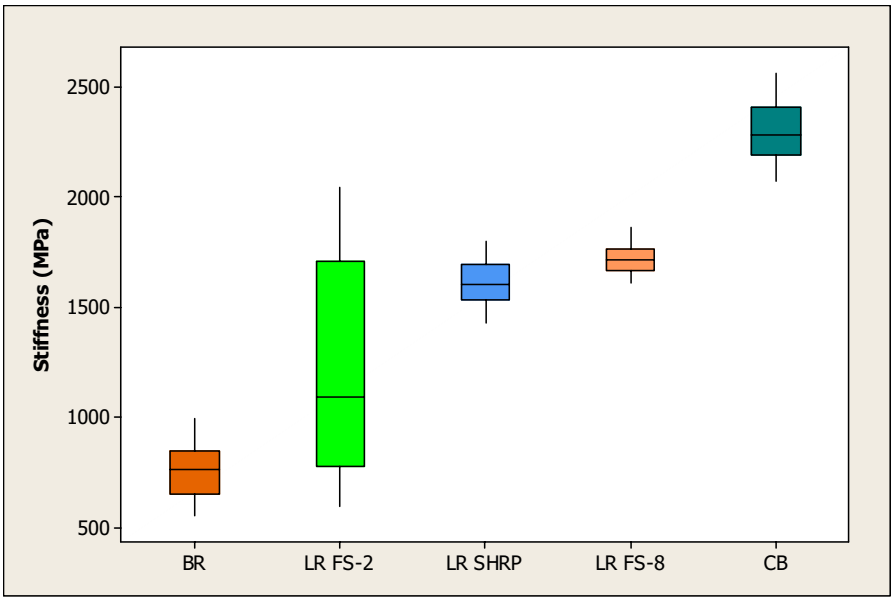
Mechanical Assessment



Stiffness ranges versus mixing time of both Large and Small RAP mixtures manufactured by Field Simulated Methods

NTEC

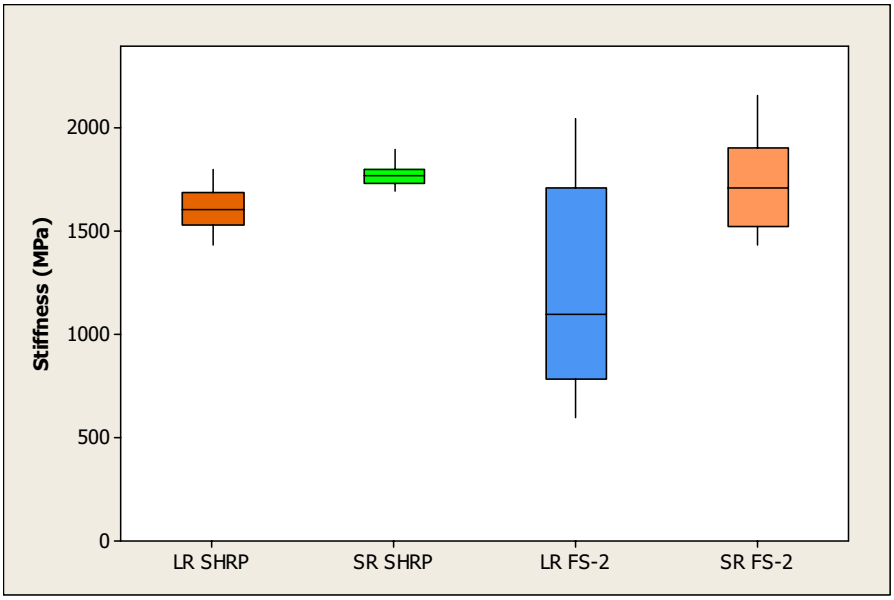
Mechanical Assessment



Inter-quartile stiffness ranges of control and LR Mixtures manufactured by different methods

NTEC

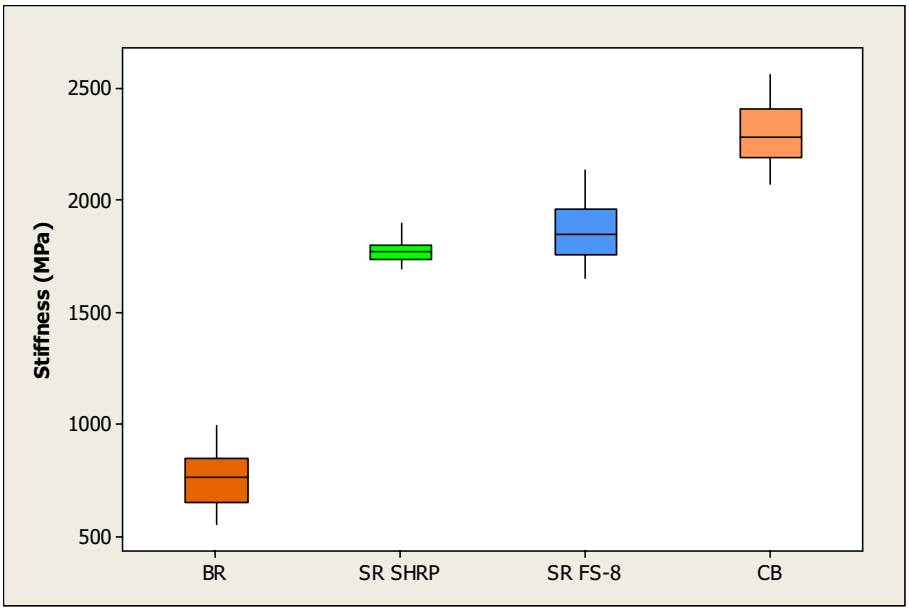
Mechanical Assessment



Inter-quartile stiffness ranges of SHRP mixtures and FS-2 mixtures

NTEC

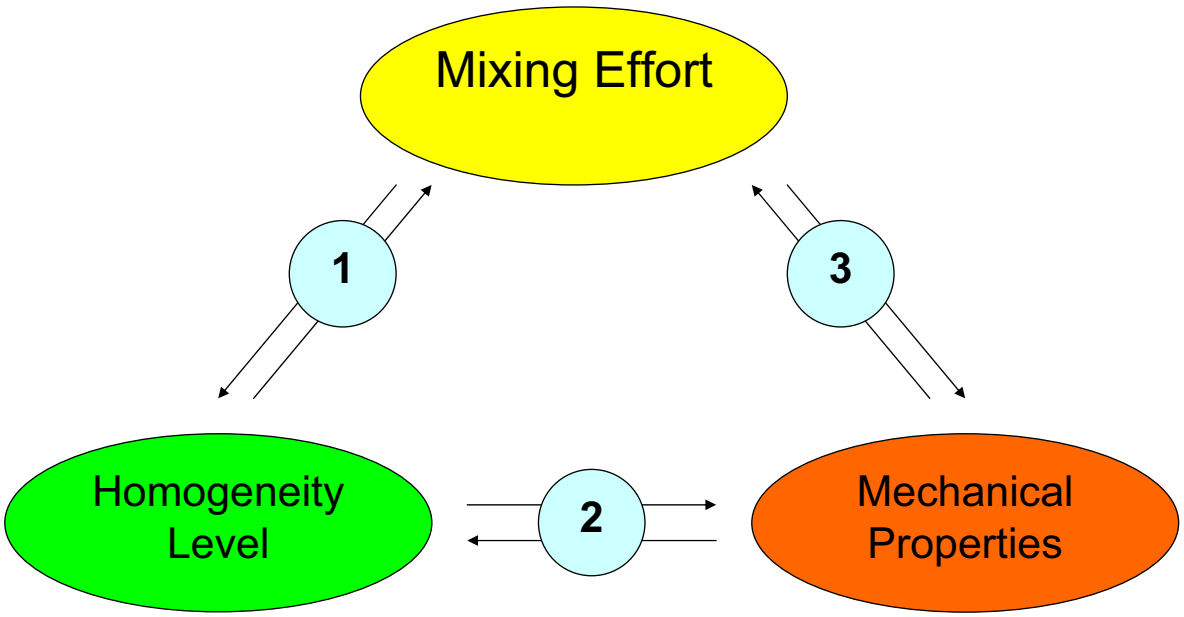
Mechanical Assessment



Inter-quartile stiffness ranges of control and SR Mixtures manufactured by different methods

NTEC

Parameter relationship



Relation between mixing effort, homogeneity and mechanical properties of recycled asphalt

NTEC

Thank you

very much!

NTEC

Literature Review

- Design
  - Viscosity of blend (RAP and virgin binder) estimation
  - Assumption: complete (100%) blending between RAP and virgin binder
  - How to estimate: by viscosity mixing equations
  - Accuracy: approximately 30% difference

NTEC

Viscosity Mixing Equations

Arrhenius (1887)

$$\ln(\eta_{mix}) = x_1 \ln(\eta_1) + x_2 \ln(\eta_2)$$

Nissan & Grunberg (1949)

$$\ln(\eta_{mix}) = x_1 \ln(\eta_1) + x_2 \ln(\eta_2) + x_1 x_2 G_{12}$$

Epp (1977)

$$\ln(\ln(\eta_{mix})) = x_1 \ln(\ln(\eta_1)) + x_2 \ln(\ln(\eta_2))$$

- η_{mix} Viscosity of the blend
- η_1 η_2 Viscosity of RAP and virgin binder
- x_1 x_2 Volume percentages of two liquids
- G_{12} The material parameter

NTEC

Laboratory Evaluation of Mix Properties

Specimen Preparation

- RAP size less than 20 mm and completely dried
- RAP is preheated at 110°C for 2 hours
- RAP is then mixed with virgin materials (binder and aggregate) at mixing temperature for 2 minutes
- The mix is then compacted

Testing

- Fatigue
- Permanent Deformation
- Stiffness
- Moisture sensitive test

NTEC

Recycled Hot Mix Asphalt Production

Production Equipment

- Drum Mixer
- Batch Plant Facility

Material

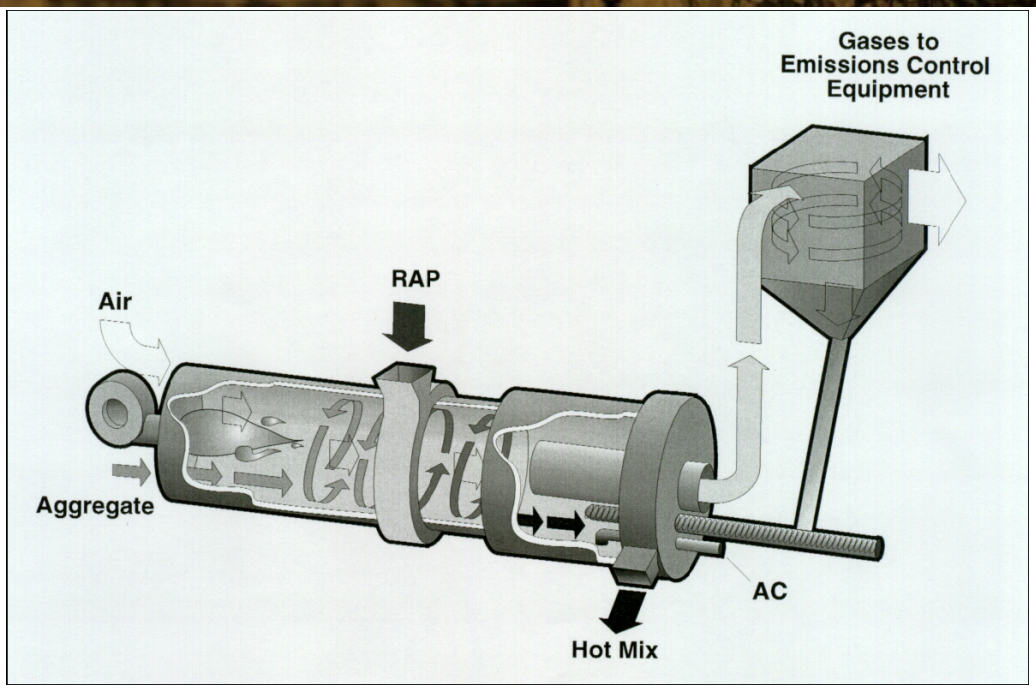
- Wide Variety of RAP size
- Moisture contents vary from 3 to 8%

Production Mechanism

- RAP (ambient temperature) is mixed with superheated virgin aggregate for 2 minutes
- The Superheat temperature is estimated based on the percentage of RAP
- The blend is mixed with virgin binder for maximum 1 minute

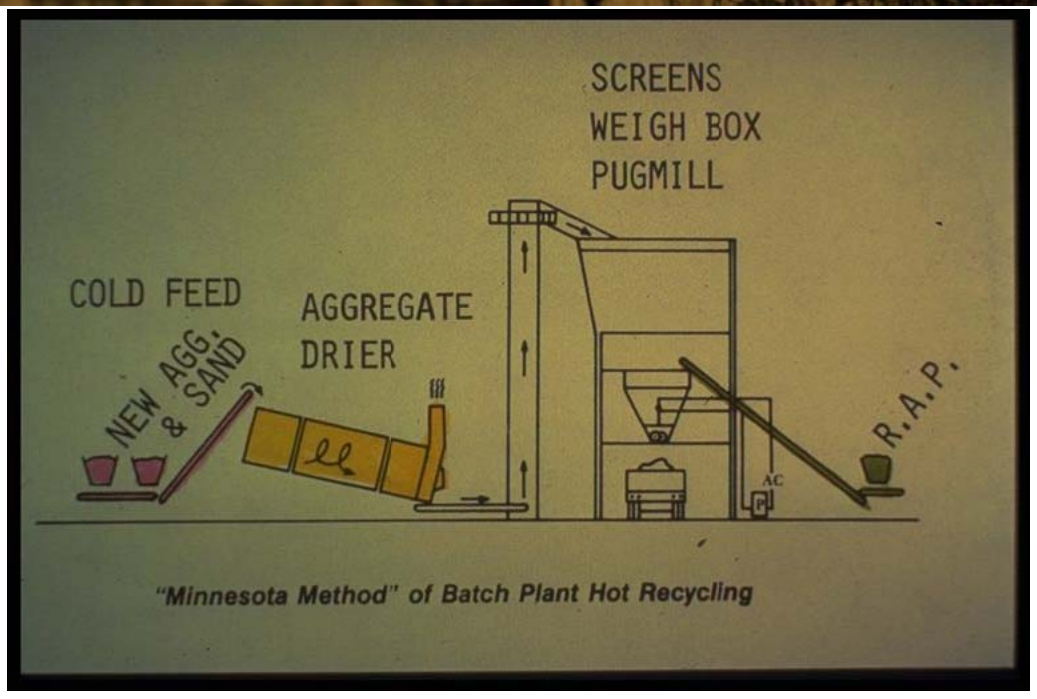
NTEC

Drum Mixer



NTEC

Batch Plant Facility



NTEC

RAP sizes

State	Max. RAP % – Batch Plants			Max. RAP % – Drum Plants			Top Size for RAP
	Base	Binder	Surface	Base	Binder	Surface	
Alabama	40	40	15	50	50	15	2 in
Alaska	–	–	–	–	–	–	–
Arizona	30	30	30	30	30	30	1.5 in
Arkansas	70	70	70	70	70	70	3 in
California	50	50	50	50	50	50	2 in
Colorado	15	15	15	15	15	15	1.5
Connecticut	40	40	40	40	40	40	2 in
Delaware	35	35	25	50	50	30	2 in
Florida	60	50	None	60	50	None	Specs
Georgia	25	25	25	40	40	40	2 in
Hawaii	30	None	None	40	None	None	1.5 in
Idaho	Open	Open	Open	Open	Open	Open	2 in
Illinois	50	25	15	50	25	15	Specs
Indiana	50	50	20	50	50	20	2 in
Iowa	Open	Open	Open	Open	Open	Open	1.5 in
Kansas	50	50	50	50	50	50	2 in
Kentucky	30	30	30	30	30	30	Specs
Louisiana	30	30	None	30	30	None	2 in
Maine	40	40	None	40	40	None	1 in
Maryland	Open	Open	Limit	Open	Open	Limit	Specs
Massachusetts	20	20	10	40	40	10	.75 in
Michigan	50	50	50	50	50	50	Specs
Minnesota	59	50	30	50	50	30	3 in
Mississippi	30	30	15	30	30	15	2 in
Missouri	50	50	50	50	50	50	1.5 in
Montana	50	50	10	50	50	10	2 in
Nebraska	Not Used	Not Used	Not Used	Open	Open	Open	2 in
Nevada	50	50	15	50	50	15	1.5 in
New	35	35	15	50	50	15	Specs
Hampshire	25	25	10	25	25	10	2 in
New Jersey							

NTEC

Superheat Temperature for Virgin Aggregate

Theory

- The amount of heat (Cutnell and Johnson, 2004) required to raise the temperature of a mass is

$$Q = mc(T_2 - T_1)$$

- The amount of heat required to raise the RAP at ambient temperature to the mixing temperature is equal to the amount of heat dispersed from virgin aggregate so the temperature drops from superheated to mixing value

RAP Content (%)	RAP Moisture Content (%)	Superheat Required (°F)			
		240°F Mix	260°F Mix	280°F Mix	300°F Mix
10	0	269	291	313	335
	1	274	296	318	340
	2	279	301	323	345
	3	284	306	328	350
	4	289	311	333	355
	5	294	316	338	360
20	0	292	317	342	367
	1	303	328	353	378
	2	314	339	364	389
	3	325	350	375	400
	4	336	361	386	411
	5	347	372	397	422
30	0	324	352	330	408
	1	343	371	599	427
	2	362	390	418	446
	3	381	409	437	465
	4	400	428	456	484
	5	419	447	475	503
40	0	366	397	430	463
	1	424	426	459	492
	2	453	455	488	521
	3	482	484	517	550
	4	511	513	546	579
	5	540	542	575	608
50	0	420	460	500	540
	1	464	504	544	588
	2	508	548	588	628
	3	552	592	632	672
	4	596	636	676	716
	5	640	680	720	760

NOTE: Calculations assume 10°F loss from dryer to pugmill and 70°F outside air temperature.

RAP preheating temperature required in Drum Mixer (Brock and Richmond, 2005)

NTEC

Specimen Preparation Procedure

Modified Method

- Virgin Aggregate is superheated at 215^{o}C for at least 8 hours
- RAP (at ambient temperature) is mixed with superheated virgin aggregate for 2, 4, 6, 8 minutes
- The blend is mixed with virgin binder in mixer conditioned at 135^{o}C for 2 minutes

SHRP method

- Virgin aggregate is heated at 150^{o}C for at least 8 hours
- RAP is heated at 110^{o}C for 2 hours
- Conditioned RAP, virgin aggregate and binder are mixed in the mixer conditioned at 135^{o}C for 2 minutes

NTEC