Properties of Pavement Geomaterials Stabilized with Fly Ash

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ABSTRACT

This paper describes an evaluation of the mechanical performance of fly ash stabilized materials. Soft clay soil, asphaltic recycled pavement material (RPM), and road-surface gravel (RSG) were stabilized using Class C and off-specification fly ashes to create working platforms or stabilized base course for construction of flexible and rigid pavements at six sites in Wisconsin and Minnesota. California bearing ratio (CBR) and resilient modulus (M_r) tests were conducted on the subgrade soil, RPM, and RSG alone and on mixtures prepared in the field and the laboratory to evaluate improvements in bearing resistance and stiffness. Fly ash stabilization improved the stiffness and strength of the materials significantly. After 7 d of curing, CBR of the stabilized materials (10 to 150) was two to ten times the CBR of the materials alone (1 to 50). The M_r of the stabilized materials ranged between 20-200 MPa after 14 d of curing, whereas the M_r of the materials alone was 10~120 MPa. Lower CBR and M_r were obtained for stabilized materials mixed in the field relative to the stabilized materials mixed in the laboratory.

INTRODUCTION

Fly ash is an byproduct of coal combustion that traditionally has been disposed in landfills. However, the self-cementing properties characteristic of some fly ashes can be used beneficially to improve the mechanical properties of soil and other unbound pavement materials. In subgrade applications, fly ash is used to stabilize a soft soil to provide a stable working platform for highway construction equipment that is strong and stiff. In base applications, fly ash is used to increase the stiffness of the base course material and to enhance the structural capacity of the pavement (Edil et al., 2002; Bin-Shafique et al., 2004; Trzebiatowski et al., 2004).

Recycled pavement material (RPM) is created in-place by pulverizing and blending the existing hot-mix asphalt, base, and subgrade associated with a deteriorated roadway.

The RPM can be used in situ to form a base course that is overlain with new hot-mix asphalt (HMA). However, residual asphalt and fines from the underlying subgrade may result in RPM having lower strength and stiffness compared to compacted virgin base material. Fly ash stabilization of RPM is one of method to improve the strength and stiffness of RPM (Li et al. 2006). Fly ash has also been used to stabilize existing road-surface gravel (RSG) when upgrading gravel roads to paved roads (Hatipoglu et al. 2006). The existing RSG is blended with fly ash and compacted to form a base course for the HMA surface. Wisconsin, Minnesota, and Kansas ave reported considerable success using fly ash for stabilization to promote sustainable construction and improve the pavement structure. However, documented field evaluations are limited.

This paper describes mechanical properties of fly ash stabilized materials (FASM) at six sites in Wisconsin and Minnesota (Table 1). At these sites, soft clay subgrade soil, RPM, and RSG were stabilized using Class C or off-specification fly ashes to create working platforms or base course for flexible and rigid pavements . A similar construction process was used at all sites, Fly ash was spread uniformly on the surface of the subgrade, RPM, or RSG using truck-mounted lay-down equipment (Edil et al. 2002) and then mixed in using a road reclaimer. When needed, water was added during mixing using a water truck. The mixture was compacted within 1-2 h of blending using a tamping foot compactor followed by a vibratory steel drum compactor. The stabilized pavement materials (FASM) was cured for 7 d and then overlain with base/surface materials.

Table 1. Pavement Structure and Materials

Sites	Scenic Edge	STH 60	STH 32	USH 12	Waseca	Chisago
Location	City street in Cross Plains, WI	State highway, WI	State highway, WI	US highway, WI	City street in Waseca, MN	Highway CR 53, MN
Project length	700 m	305 m	370 m	1200 m	500 m	3500 m
Surface material	100 mm-HMA	125 mm-HMA	230 mm-PCC	200 mm-PCC	75 mm-HMA	89 mm-HMA
Base material	175 mm-CA	225 mm-CA	200 mm-CA	150 mm-CA	150 mm-SRPM	254 mm-SRSG
Subbase material	300 mm-FASM	300 mm-FASM	300 mm-FASM	300 mm-FASM	N/A	N/A
Fly ash content[a]	10%	12%	10%	12%	10%	10%[b]

STH = State Trunk Highway, HMA = Hot Mixed Asphalt, PCC = Porland Cement Concrete, CA = Crushed aggregate, FASM = fly ash stabilized material, RPM = recycled pavement material, RSG = road-surface gravel, [a]Class C fly ash in dry weight, [b]mixing of Class C and Off-Specification fly ash.

MATERIALS

Disturbed samples of subgrade soil, RPM, and RSG (≈ 20 kg each) were collected during construction at each site. Tests were conducted on each sample to determine index properties, soil classification, water content, dry unit weight, compaction characteristics, and CBR. Samples of fly ash were also collected.

Subgrade

A summary of the properties of the subgrade at Scenic Edge, STH 60, STH 32, and USH 12 sites is shown in Table 2. The subgrade soils are fine-grained soils (CL, CL-ML, CH) and coarse-grained soils (SM, SC, GC) according to the Unified Soil Classification System. According to the AASHTO Soil Classification System, subgrade soils are fine-grained silt-clay materials (A-4, A-6, A-7-6) or coarse-grained soils that classify as A-2-6 (one station in STH 32 site, and 3 stations in USH 12 site). CBR of the subgrade soils ranges from 2 to 15 (mean = 5), indicating that the existing subgrade is soft at each site.

Table 2. Physical properties and classifications of subgrade soils.

Station	LL	PI	% Fines	Classification		w_N (%)	w_{opt} (%)
				USCS	AASHTO		
Scenic Edge	44	20	90	CL	A-7-6	27.0	20.0
STH 60	39	15	95	CL-ML	A-6	25.0	19.0
STH 32							
615+50	23	13	53	CL	A-4	10	9.8
614+50	23	14	46	SC	A-4	8.1	11
613+50	23	14	43	SC	A-4	9.9	10.6
612+50	34	16	66	CL	A-6	11.5	13.6
611+50	28	14	35	GC	A-2-6	7.6	9.8
USH 12							
580+00	46	29	71	CL	A-7-6	NA	15.0
586+00	40	27	43	SC	A-6	7.8	9.0
590+00	31	17	35	SM	A-2-6	14.7	10.0
594+00	65	49	65	CH	A-7-6	7.8	15.0
598+00	38	21	50	SC	A-6	10.8	9.0
602+00	42	23	56	CL	A-7-6	NA	15.0
606+00	41	24	57	CL	A-7-6	12.2	15.0
610+00	27	15	35	SM	A-2-6	6.7	10.0
612+00	27	12	44	SC	A-6	14.3	9.0
614+00	26	11	34	SM	A-2-6	8.1	10.0

LL = liquid limit, PI = plasticity index, USCS = Unified Soil Classification System, AASHTO = American Association of State Highway and Transportation Officials, w_N = *in situ* water content, w_{opt} = optimum water content.

Recycled Pavement Material (RPM) and Road Surface Gravel (RSG)

Particle size distribution curves for the RPM and RSG are shown in Fig. 1. The blending during production of RPM and RSG results in a material that is spatially uniform in particle size distribution, compaction characteristics, and water content. The particle size distribution curves fall in a relatively narrow band. Most of the RPM consists of sand and gravel-size particles (> 75 μm), which reflects the presence of the pulverized asphalt and the original base course. The RSG samples consist of well-graded gravelly sand. The sand content is consistently around 60% and the gravel content is about 25%. Because of the uniform nature of the RSG along the alignment at the Chisago site, a single composite sample was prepared for laboratory testing. is the composite sample classified as gravelly clayey sand according to USCS.

Fly Ash

Fly ash from Columbia Power Station in Portage, WI was used for stabilization of subgrade at the STH 60, Scenic Edge, and USH 12 sites. Fly ash from the Pleasant Prairie (PP) Power Station in Pleasant Prairie, WI was used for stabilization of subgrade at the STH 32 site. Fly ash from Riverside Power Station in St. Paul, MN was used for stabilization of RPM at the Waseca site and RSG at the Chisago site. Physical and compositional properties of fly ashes are summarized in Table 3. The Columbia, PP, and Riverside 7 fly ashes are Class C fly ashes following ASTM C 618, whereas the Riverside 8 fly ash is referred to as “off-specification” fly ash because it does not meet the Class C or Class F criteria in ASTM C 618.

Table 3. Chemical Composition and Index Properties of Fly Ashes

Parameters	Percent of Composition			
	Columbia fly ash	Pleasant Prairie fly ash	Riverside 7 fly ash	Riverside 8 fly ash
Fly ash source	Portage, WI	Pleasant Prairie, WI	St. Paul, MN	
$SiO_2 + Al_2O_3 + Fe_2O_3$, %	55.5	64	57	39
CaO, %	23.1	21	24	9
SO_3, %	3.7	2	2	5.4
Loss on ignition (%)	0.7	0.6	0.9	16.4
Classification (ASTM C 618)	C	C	C	off-Specification
Site location	Scenic Edge, STH 60, USH 12	STH 32	Waseca and Chisago, MN	Chisago, MN

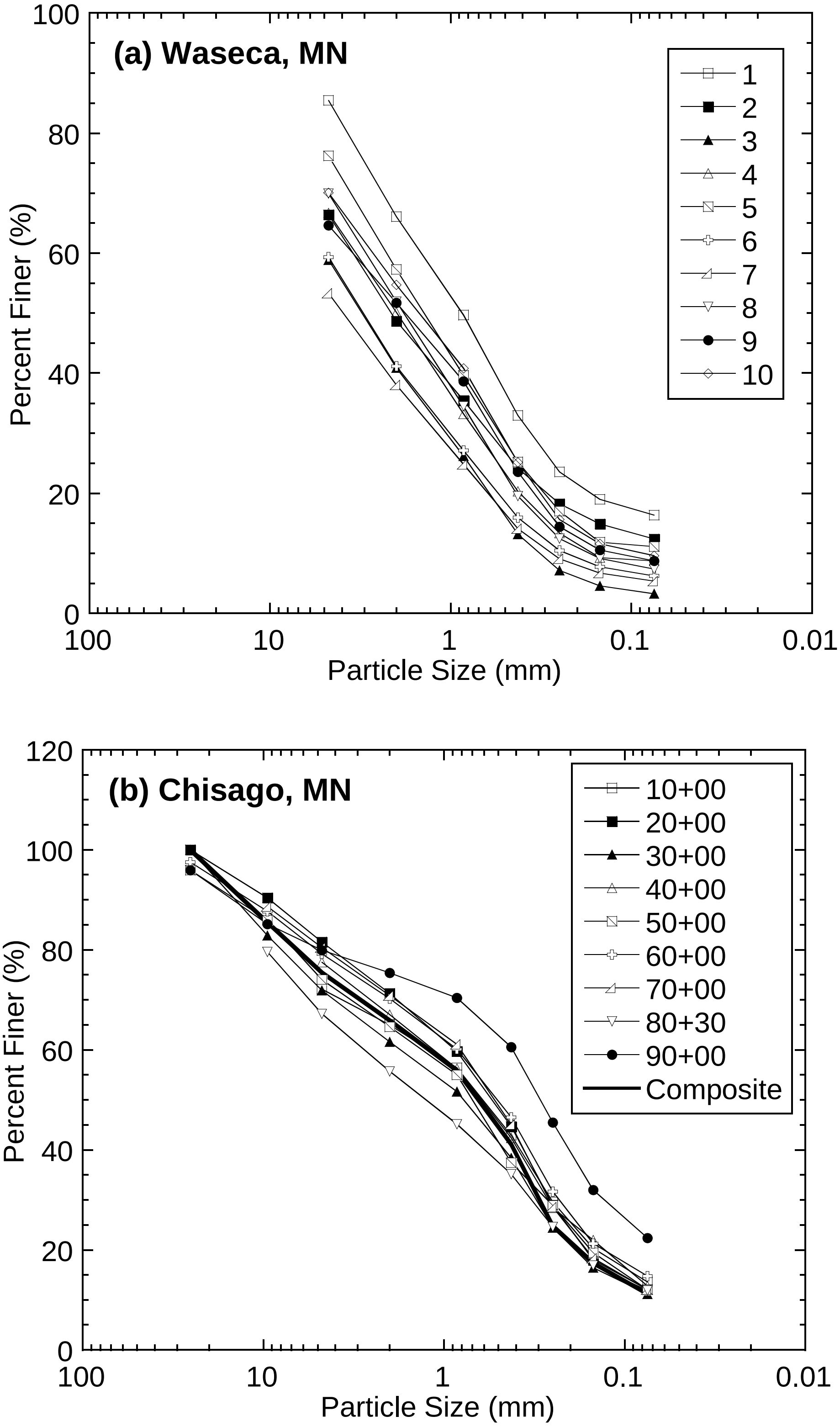

Fig. 1. **Particle size distributions of the RPM (a) and RSG (b).**

METHODS

Field-Mix and Laboratory-Mix Specimens

Water content and unit weight of the compacted FASM at each site was measured at each station using a nuclear density gage (ASTM D 2922) immediately after compaction was completed. Grab samples (≈ 20 kg) of FASM were also collected at these locations and were immediately compacted into a CBR mold (114 mm inside diameter x 152 mm height) and a resilient modulus mold (102 mm inside diameter x 203 mm height) to the unit weight measured with the nuclear density gage. Three lifts were used for the CBR specimens and six lifts were used for the M_r specimens. After compaction, the specimens were sealed in plastic and stored at 100% humidity for curing (7 d for CBR specimens, 14 d for M_r specimens). These test specimens are referred to henceforth as 'field-mix' specimens.

Specimens of FASM were also prepared in the laboratory using separate samples of the pavement materials and fly ash collected during construction. These specimens, referred to henceforth as 'laboratory-mix' specimens, were prepared at the field water content and dry unit weight. The laboratory-mix specimens were compacted and cured using the same procedures employed for the field-mix specimens.

California Bearing Ratio (CBR) Tests

The CBR tests were conducted in accordance with ASTM D 1883 after 7 d of curing (field-mix or laboratory-mix FASM) or immediately after compaction (pavement materials). The specimens were not soaked and were tested at a strain rate of 1.3 mm/min. The 7-d curing period and the absence of soaking are intended to represent the competency of the surface pavement material (HMA or PCC) is placed (Bin-Shafique et al., 2004).

Resilient Modulus (M_r) Tests

Resilient modulus tests on the FASM and pavement materials were conducted following the methods described in AASHTO T292 after 14 d of curing (FASM) and immediately after compaction (materials). The 14-d curing period is intended to reflect the condition when hydration is nearly complete (Edil et al., 2006). The loading sequence for cohesive soils was used for the FASM as recommended by Bin-Shafique et al. (2004) and Trzebiatowski et al. (2004) for soil-fly ash mixtures. RPM and RSG were tested using the loading sequence for cohesionless soils.

RESULTS

CBR

CBR of the RSG, field-mix SRSG, and laboratory-mix SRSG at the Chisago site is shown in Fig. 2a. There is no systematic variation in CBR of the SRSG along the alignment, suggesting that the variability in the CBR is more likely due to heterogeneity in the material rather than systematic variation in site conditions or construction methods.

The CBR of the RSG is 24, the laboratory-mix SRSG has CBR of 154, and the field-mix SRSG has CBR between 16 and 90 (mean = 60). Thus, adding fly ash to the RSG increased the CBR appreciably, although the CBR in the field was 61% lower, on average, than the CBR of the laboratory-mix SRSG. A similar difference between CBRs of mixtures prepared with fly ash in the laboratory and field is reported in Bin-Shafique et al. (2004) for fine-grained subgrade soils. They report that field mixtures of silty clay and Class C fly ash typically have a CBR that is two-thirds lower than the CBR of comparable mixtures prepared in the laboratory.

There was no apparent effect of fly ash type at the Chisago site, where two different fly ashes were used from Riverside Units 7 and 8 (see Table 2). For instance, off-specification Unit 8 ash was used at Stations 27+30, 60, and 70, whereas Class C fly from Unit 7 was used whereas at Station 40. Despite the use of different ashes, there is no significant difference in CBR between these stations.

Box plots in Fig. 2b show the distribution of CBR of the pavement materials, field-mix FASM, and laboratory-mix FASM at five of the sites. The centerline in the box corresponds to the median (50th percentile), the outer edges of the box correspond to the 25th and 75th percentiles, and the whiskers correspond to the 10th and 90th percentiles of the CBR. Fly ash stabilization increased the CBR of the pavement materials at all five sites. CBR of the fine-grained subgrade soils at the Scenic Edge, STH 60, and STH 32 increased from 1.5 – 3 before stabilization to 21 - 65 after stabilization, on average. A smaller increased in CBR was observed for the coarse-grained materials, which had initial CBR in the range of 9 - 24 and CBR in the range of 29 – 60 after stabilization, on average.

The field-mix CBR was 52% lower, on average, than the CBR of the laboratory-mix FASM. Bin-Shafique et al. (2004) attribute the higher CBR of the laboratory-mix FASM to more thorough blending of pavement materials and fly ash in the laboratory compared to the field, resulting in more uniform distribution of fly ash within the mixture.

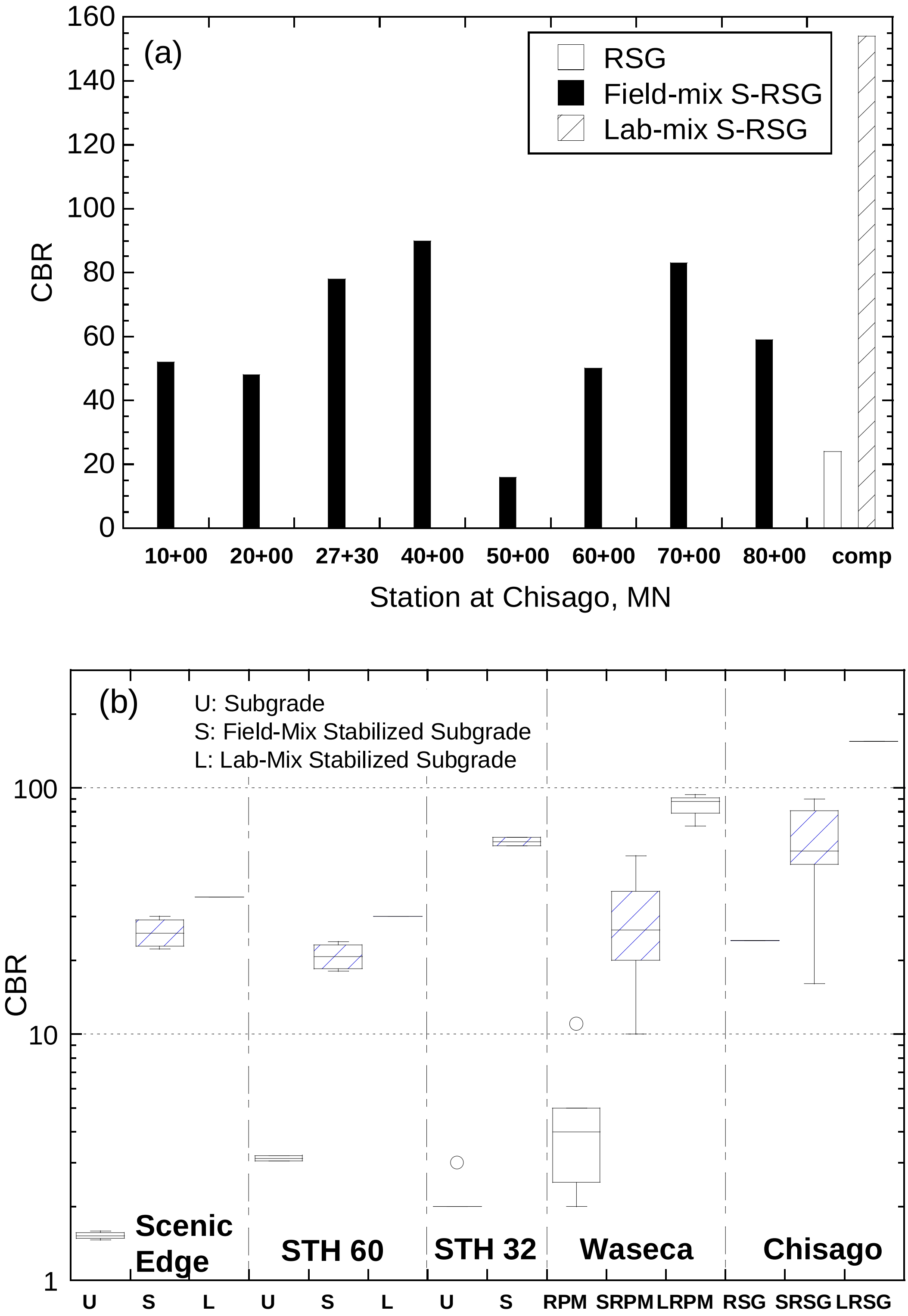

Fig. 2. **CBR of pavement materials and fly ash stabilized materials (laboratory-mix and field-mix) after 7 d of curing: (a) at Chisago site, (b) box plot at five sites.**

Resilient Modulus

Resilient modulus of subgrade, field-mixed FASM, and laboratory-mix FASM at the USH 12 site are shown in Fig. 3a. These M_r correspond to a deviator stress of 21 kPa, which represents typical conditions within the base course of a pavement structure (Trzebiatowski et al. 2004). As observed for CBR, there is no systematic variation in M_r along the alignment. Comparison of the M_r for subgrade and fly ash stabilized subgrade in Fig. 3a indicates that adding fly ash increased the M_r appreciably. The M_r of the existing subgrade ranges between 34 and 42 MPa (mean = 38 MPa), whereas the field-mix FASM had M_r between 60 and 129 MPa (mean = 88 MPa) and the laboratory-mix FASM had M_r ranging between 115 and 167 (mean = 139 MPa). As with CBR, M_r of the field-mix FASM is lower (37%, on average) and more variable than the M_r of the laboratory-mix FASM.

Box plots showing the distribution of M_r of pavement materials, field-mix FASM, laboratory-mix FASM at four of the sites are shown in Fig. 3b. Adding fly ash increases the M_r of the pavement materials at each site,a comparable amount (2-3 times) at each site. However, the actual M_r of the stabilized material depended on the material type. For example, the M_r of the clayey subgrade at STH 32 increased from 14 MPa to 46 MPa, on average. In contrast, the mean M_r of the field-mix SRSG at Chisago (153 MPa) is markedly higher than the mean M_r SRPM at Waseca (78 MPa), and both the SRPM and SRSG have higher M_r than the clayey subgrades.

As with CBR, M_r of the field mix FASM is lower, on average, than M_r of the laboratory-mix FASM. The exception was the Chisago site, where the M_r of the field mix SRSG was higher, on average, than the M_r of the laboratory-mix SRSG.

CONCLUSIONS

Six field sites have been described where Class C and off-specification fly ash were used to stabilize soft clay soil, asphaltic recycled pavement material (RPM), and road-surface gravel (RSG). The fly ash stabilized pavement materials were used to create working platforms or stabilized base for construction of flexible and rigid pavements. California bearing ratio (CBR) and resilient modulus (M_r) tests were conducted on the pavement materials alone and on fly-ash stabilized materials (FASM) mixed in the field and laboratory to evaluate how addition of fly ash improved the bearing resistance and stiffness.

The FASM had significantly higher CBR and M_r than the pavement materials, which suggests that the FASM should be beneficial in terms of increasing pavement capacity and service life. However, the CBR and M_r of most FASM mixed in the field were lower than those for FASM mixed in the laboratory (30-66% lower for CBR, 25-52% lower for M_r). Similar biases between mixtures prepared in the laboratory and field have been observed by others and need to be considered when pavement design is based on data obtained by testing mixtures blended in the laboratory.

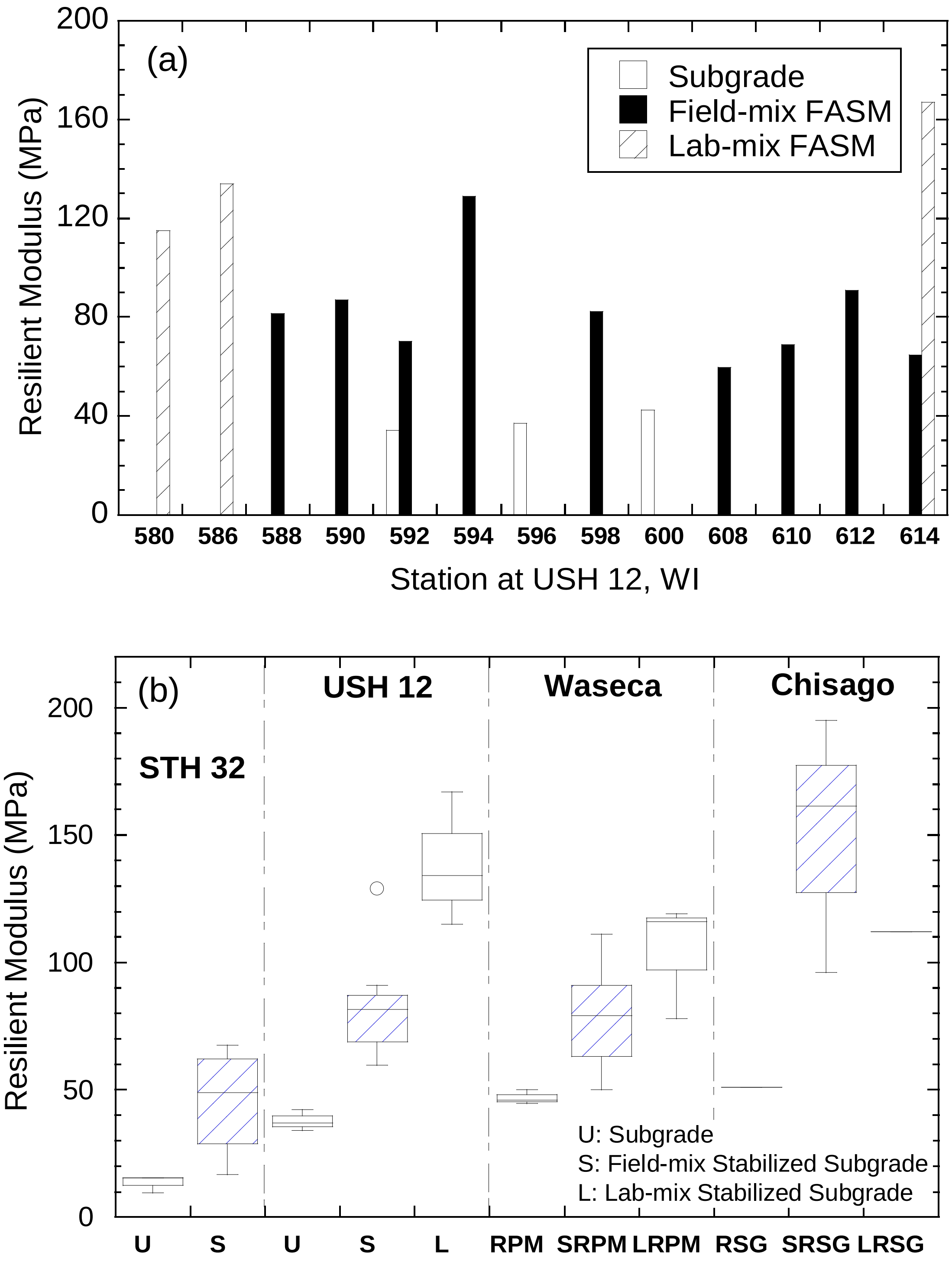

Fig. 3. Resilient modulus of pavement materials and fly ash stabilized materials (laboratory-mix and field-mix) after 14 d of curing: (a) at USH 12 site, (b) box plot at four sites. All resilient moduli are at deviator stress of 21 kPa.

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