The Exploratory Advanced Research Program

EXPLORATORY ADVANCED RESEARCH

Novel Alternative Cementitious Materials for Development of the Next Generation of Sustainable Transportation Infrastructure

TECHBRIEF

U.S. Department
of Transportation
Federal Highway
Administration

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Technical Report Documentation Page

1. Report No. FHWA-HRT-16-017	2. Government Accession No.	3. Recipient's Catalog No.

4. Title and Subtitle Novel Alternative Cementitious Materials for Development of the Next Generation of Sustainable Transportation Infrastructure	5. Report Date October 2015 6. Performing Organization Code:
7. Author(s) Lisa Burris, Kimberly Kurtis, and Tom Morton	8. Performing Organization Report No.
9. Performing Organization Name and Address Georgia Institute of Technology North Avenue Atlanta, GA 30332 Woodward Communications, Inc. 1420 N Street, NW, Suite 102 Washington, D.C. 20005	10. Work Unit No. 11. Contract or Grant No. DTFH61-15-A-00001 DTFH61-14-H-00003
12. Sponsoring Agency Name and Address Office of Infrastructure Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296	13. Type of Report and Period Covered TechBrief, September 2014 14. Sponsoring Agency Code HRTM-30

15. Supplementary Notes
FHWA's Contracting Officer's Task Manager (COTM): Zachary Ellis, HRTM-30
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16. Abstract

Georgia Institute of Technology and collaborators from Oklahoma State University, Tourney Consulting, and the Army Corps of Engineers, for an Exploratory Advanced Research Program project funded by the Federal Highway Administration, are performing a comprehensive and systematic investigation of novel alternative cementitious materials (ACMs) for applications in sustainable transportation infrastructure. These cements include calcium aluminate, calcium sulfoaluminate, calcium sulfoaluminate belite, magnesium phosphate, and alkali-activated and carbonate-binder systems that provide potential advantages over traditional portland cement through reductions in embodied energy and greenhouse gases, as well as enhanced performance, which contributes to sustainability. The research includes evaluation of early-age and long-term material properties, in addition to multiscale durability investigations. The research team aims to provide guidance for recommended test methods and, where relevant, test limits for acceptance of ACMs for transportation infrastructure, including highway structures and rigid pavements, as well as preliminary specifications for use.

17. Key Words novel materials, cement, next generation, transportation, infrastructure, sustainability, alternative cementitious material, ACM.	18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161.

19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 40	22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
TEMPERATURE (exact degrees)				
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
AREA				
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
VOLUME				
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
MASS				
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact degrees)				
°C	Celsius	1.8C+32	Fahrenheit	°F
ILLUMINATION				
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS				
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

Table of Contents

List of Figures

List of Figures, cont'd.

List of Tables

List of Acronyms and Abbreviations

AA	alkali-activated
ACM	alternative cementitious material
CAC	calcium aluminate cement
CALTRANS	California Department of Transportation
CO_2	carbon dioxide
CO_{2e}	carbon dioxide emissions
CSA	calcium sulfoaluminate
CSAB	calcium sulfoaluminate belite
DOT	department of transportation
EAR	Exploratory Advanced Research
FHWA	Federal Highway Administration
MPC	magnesium phosphate cement
OPC	ordinary portland cement

Abstract

Georgia Institute of Technology and collaborators from Oklahoma State University, Tourney Consulting, and the Army Corps of Engineers, for an Exploratory Advanced Research (EAR) Program project funded by the Federal Highway Administration's (FHWA's) Turner–Fairbank Highway Research Center, are performing a comprehensive and systematic investigation of novel alternative cementitious materials (ACMs) for applications in sustainable transportation infrastructure. These materials include calcium aluminate cement (CAC), calcium sulfoaluminate (CSA), calcium sulfoaluminate belite (CSAB), magnesium phosphate cement (MPC), and alkali-activated (AA) and carbonate-binder systems that provide potential advantages over traditional portland cement through reductions in embodied energy and greenhouse gases, as well as enhanced performance, which contributes to sustainability. The research includes evaluation of early-age and long-term material properties, in addition to multiscale durability investigations. The research team aims to provide guidance for recommended test methods and, where relevant, test limits for acceptance of ACMs for transportation infrastructure, including highway structures and rigid pavements, as well as preliminary specifications for use.

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Research Conclusions

In the first phase of this project, the research team investigated ACMs that were either currently commercially available or almost commercially available in the United States through review of technical and trade literature, site visits, and consultation with producers and users. This led to an increased understanding of the benefits, shortcomings, and potential changes in standard construction processes surrounding the increased use of ACMs. They are currently primarily used in pavement and bridge repairs and joints of precast panels. The research team will note additional conclusions as the research moves forward into the next phase.

Next Steps

In the next research phase, the research team will begin to conduct experimental work to better characterize the selected materials and learn about their viability for use in pavements and bridge decks throughout the United States. The research team will use this research to recommend guidelines for test methods and, where relevant, test limits for acceptance of ACMs for transportation infrastructure. Of particular interest are performance criteria that can be incorporated in preliminary specifications for use.

Background

Concrete is the world's most widely used construction material. As a result of the vast quantities produced each year, it also represents a significant worldwide environmental impact, accounting for 4.8 percent of global anthropogenic carbon dioxide emissions (CO_{2e}).[1] These emissions primarily result from the calcining of limestone and the burning of fuel during the manufacture of portland cement clinker, a key component of concrete. The manufacture of cement results in the emission of 830 kg (1,830 lbs) of carbon dioxide (CO_2) per metric tonne of clinker because of the raw materials required for processing, in addition to further emissions resulting from the energy required to heat the cement kiln to temperatures of nearly 1,450° C (2,640°F).[2]

Increasing the use of ACMs, such as those listed in table 1, and in other publications,[3] can result in the production of concretes with equal or greater strengths and durability than traditional portland cement concrete and is one possible method for reducing the total greenhouse gas contribution of the construction industry.

Table 2 shows rough estimates of the quantity of CO_{2e} that could be avoided by replacing portland cement with an equal quantity, by mass, of ACM binder.[3] Table 2 also shows that a substantial CO_{2e} savings can be achieved through the use of ACMs with the greatest CO_{2e} savings associated with the use of CSAs, CACs, and chemically-activated aluminosilicate binders.

The numbers shown in table 2 fail to consider other aspects of these materials that may also contribute to, or detract from, increased sustainability.[4] These aspects can be difficult to quantify, and their contributions to overall sustainability of a structure are often not obvious. Material features that contribute indirectly to improvements in sustainability

Table 1. Binder abbreviations.

BINDER SYSTEM	ABBREVIATION
Ordinary portland cement	OPC
Alkali-activated binders	AA
Calcium aluminate cement	CAC
Calcium sulfoaluminate cement	CSA
Calcium sulfoaluminate belite cement	CSAB
Magnesium phosphate cement	MPC

include increased strength and better durability. The research team is currently investigating these features for many of the alternative binders. Higher strength materials may enable the use of smaller members, reducing both the quantity of concrete required outright for the structural member, while also reducing the overall dead load of the structure. This reduction in weight could lead to further material savings. Improved durability can also result in greater time before repairs or replacement is required. For example, using a single bridge for 100 years will result in the need for less material, and will generate less CO_{2e} when compared to building, then rebuilding, a bridge with a 50-year lifespan. Claims that these materials are of higher durability have not fully been investigated, however, leading to uncertainty about this aspect of binder sustainability. Moreover, other aspects of these materials may lead to decreased sustainability, including increased shipping distances because of the currently limited regional availability of many of these binders. With increased usage and economies of scale, these negative aspects can be reduced; therefore, although the improvements in CO_{2e} shown in table 2 suggest that ACMs can contribute to greater sustainability in highway infrastructure, their full impact is not completely understood at this time.

Table 2. CO_2 emitted in the manufacture of “pure” cement compounds.

BINDER SYSTEM	GRAMS CO_{2e} PER GRAM OF CEMENT[3]	PERCENT CO_{2e} v. USING OPC
OPC[5]	0.55	100%
CSA[6]	0.28	51%
CSAB[7]	0.46	84%
CAC[8]	0.29	53%
MPC[9]	0.30	55%
AA[10]	Emissions result from manufacture of alkali solutions and transportation only. Precursor materials (fly ash, slag, etc.) were assumed to contribute no CO_{2e} as they are byproducts of other industries.	44–64%

Note: Quantities reflect emissions associated with release of CO_2 from calcination of raw materials, and from coal, to heat the materials to required calcination temperatures. The research team calculated CO_{2e} reductions assuming a 1:1 replacement of ordinary portland cement (OPC) with alternative cementitious materials.

In the past, most ACM users found limited (i.e., specialty) or small-scale applications for the materials, such as rapid repairs and creating joints for precast panel road replacements;[11,12] however, the research team found that there is limited understanding of the scalability of these material systems, their long-term performance and durability in a range of environments, or their structural response when subjected to transportation-relevant loading conditions. Appropriate test methods, or well-defined alternatives to standard test methods, are also required. The researchers noted that these are needed to provide pathways for specification of ACMs, which can increase their use.

Technical Approach

Assessment of Current Practice

To assess the current state of knowledge and practice, the research team reviewed technical and trade literature that involved large-scale ACM use, made site visits to evaluate pavements, and communicated with material suppliers. In addition, the researchers met with producers and users and created a technical working group comprised of user stakeholders who represented various State and Federal agencies.

For the literature review, the research team focused on hydration mechanisms, set times, usage of admixtures, and durability testing. The literature review offered insight into historical use of ACMs throughout the United States and abroad, and enabled the research team to obtain observations from test sections throughout the United States. Table 3 summarizes general information found in the literature about each of the ACM classes investigated. Further information on hydration kinetics research needs is available in a joint National Institute of Standards and Technology–FHWA publication and road map for coordinated cement research. The joint publication was developed following an International Summit on Cement Hydration Kinetics and Modeling.[13]

Table 3. Basic ACM information from literature review.

LITERATURE REVIEW TOPIC	CALCIUM ALUMINATE CEMENT (CAC)	CALCIUM SULFOALUMINATE CEMENT (CSA)	CALCIUM SULFOALUMINATE BELITE CEMENT (CSAB)	MAGNESIUM PHOSPHATE CEMENT (MPC)	ALKALI-ACTIVATED (AA) BINDERS/ GEOPOLYMERS	CARBONATE SYSTEMS
BASIC HYDRATION	Calcium aluminate compounds react with water to form one of three calcium aluminate hydrate phases ($6CaOAl_2O_3.10H_2O$, $2CaO.Al_2O_3.8H_2O$, or $3CaO.Al_2O_3.6H_2O$), depending on temperature and the amount of moisture present. Only the $3CaO.Al_2O_3.6H_2O$ form is stable long term, with the phase transformation generally referred to as conversion.	$4CaO.3Al_2O_3.SO_3$ (Klein's compound) reacts quickly with water to form monosulfate, ettringite or stratlingite.	Klein's compound is used in conjunction with high belite content cement to create a binder system capable of generating high early strengths in addition to continued improvement of properties over time from the slow hydration of the belite.	Magnesia, $NH_4H_2PO_4$ (ammonium phosphate), and water react to form $NH_4MgPO_4.6H_2O$. Chemical bonding is formed by a rapid through-solution acid-base reaction between dead burned magnesia and phosphate.[14]	AA binders are formed through three steps: 1. Covalent Si-O-Si and Al-O-Al bonds are broken down by a high pH solution; 2. Products accumulate; and 3. an amorphous aluminosilicate structure reforms and precipitates.	Carbonate "cement" powder and sand are mixed with water and CO_2. The cement reacts with CO_2 to form calcium carbonate and silicate hydrate gel, gaining strength through solidification.
TYPICAL WATER-TO-CEMENT RATIOS USED	0.30–0.40 [15–18] ≤0.4 is necessary for good long-term strength.[19]	0.20–0.70[7, 20–26]	0.40–0.70[27–33]	0.10–0.52[14, 34–38]	0.28–1.10[39–46]	N/A
COMPRESSIVE STRENGTHS (POUNDS PER SQUARE INCH)	3,000–4,200 @ 3 hrs 6,500–7,900 @ 28 days with 0.38 w/c.[47, 48]	87–3,800 @ 3 hrs depending on accelerator/ retarder usage.[20, 23]	1,200 @ 28 days (for 0.8 w/c) 5,000 @ 28 days (for 0.26 w/c).[49, 50]	2,900–7,300 @ 3 hrs. [37, 51]	2,000 @ 3 hrs 10,000–20,000 @ 28 days.[52]	9,000 @ 24 hrs (personal communications—Solidia Technologies, 25 Sept 2014).
TIME TO INITIAL SET AT 23°C WITH NO ADMIXTURES	2–6 hrs.[53] However, no superplasticizers are effective for longer than 15 min, so working time is very limited (personal communications—Kerneos Inc., May 2015).	8–22 min.[20, 23]	10–15 min with no admixtures.[28]	9 min.[37]	As little as 35 min (based on U.S. Army Engineer Research and Development Center in-house report).	Product is currently available as a precast product only. Elements typically require 24 hrs to cure.
RETARDING ADMIXTURES	Retarders recommended by CAC manufacturer include lignosulfonates, Melmet 50, Chryso AL810, Grace Daratard 17, and BASF Pozzolate 100XR (personal communications—Kerneos Inc., May 2015).	Organic acids, such as citric acid, tartaric acid in doses not exceeding 0.25% by mass of cement.[48]	Nanoparticles can be used to accelerate hydration; dopants can be used during clinkering to distort belite structure to make it more reactive.[49, 54]	Borax can be used in dosages of 2–25% by weight of cement, but higher dosages may affect compressive strength.[35, 51, 55]	Sodium silicate can increase the speed of binder nucleation and polymerization. [56, 57]	N/A

In addition, the research team was able to summarize survey results on the usage of ACMs by State departments of transportation (DOTs). The American Association of State Highway and Transportation Officials' Subcommittee on Materials conducted a survey about ACMs. Of the 27 responding States, 14 States (50 percent) indicated that they had experience using ACMs, as shown in figure 1. The specific ACMs used by each State and anecdotal assessments of performance by ACM class are provided in table 4.

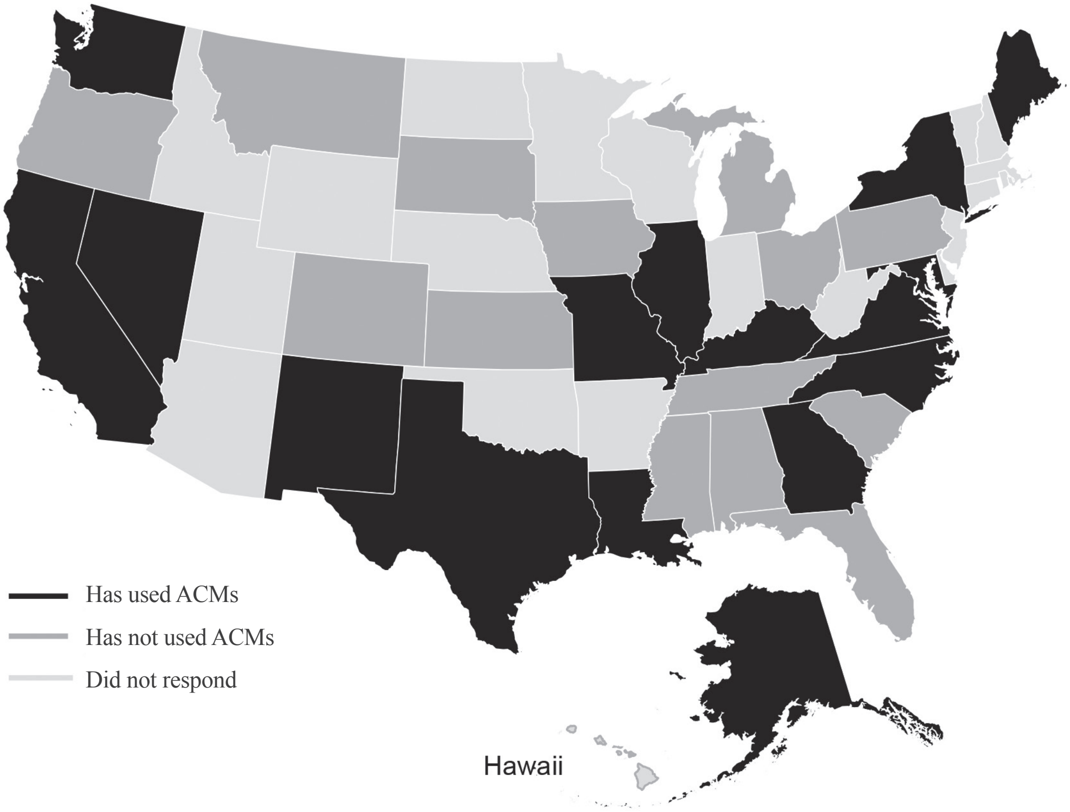

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Figure 1. Survey responses for States' ACM usage.

Table 4. State DOT ACM usage survey results.

MATERIAL	STATE USAGE	APPLICATIONS	ANECDOTAL MATERIAL OBSERVATIONS
CSA	California Kentucky Maine Missouri New Mexico New York North Carolina Texas Virginia Washington	Patching Rapid set overlays Closure pour application with precast deck panels Bridge joint repairs Partial depth concrete pavement repairs Short-term replacement for bridge departures/ entrances Bridge sleeper slab replacements Precast deck slab closures LMC overlays Peer cap to deck slab connections Panel replacements and DBR pour back material	"Performed well." "Performed well in construction and service." "Performed well so far with no issues." "Good field performance, one large transverse crack but no debonding." "Worked very well for more than 5 years, even with a profoundly under-designed and very thin pavement." "Excellent performance–fewer cracks and lower permeability than concrete overlays." "Good when mixed, placed, and cured properly." "Field tests show good performance, after one year, from CSA pavements."
CSA-latex mixtures	Missouri	Rapid set bridge deck overlays Partial depth repairs	"Some scaling issues, discoloration, and reduction in compressive strength."
CAC	Illinois Maryland New York Texas	Roadway patching Precast deck slabs closures Bridge armor joint repairs Full-depth pavement repairs	"Material has held up well, but experienced and well-organized contractors with top-notch placement equipment are absolutely necessary in order to obtain good results." "Performed well for many years after placement." "One product showed scaling the first year and performed well for the next 17 years, others have had very poor durability with lots of scaling and freeze-thaw loss." "Have had good experiences with CAC."
MPC	Alaska Maryland Virginia	Bridge deck patching and overlays Precast panel joints	"14 years after placement, some joints have slightly delaminated and cracking has occurred where the material was subjected to torsion, but overall the material seems to have worked reasonably well." "CSAs preferred because of cost."
AA	Georgia Kentucky Texas Virginia	Full- and partial-depth concrete slab pavements and bridge decks, and repairs to pavements and bridge decks Patching	"Getting a level finish in the short set window was challenging, but otherwise the material performed well." "Performed well in construction and service." "Had low strength issues, but activator may have been out of date." "Field tests show good performance, after 1 year, from AA fly-ash pavements."
Polyester Cement	California	Bridge overlays	"Doing well so far after 1 year of placement."

Site 1: I-16 in Dublin, GA

The research team examined full-depth chemically-activated binder concrete slabs, originally placed on U.S. Interstate 16 in Dublin, GA. Images from the site are shown below in figures 2 and 3. These slabs were originally placed in early 2008 and remained in service until 2013, when a full highway section replacement was completed. Since then, the slabs have been stored at a Georgia DOT storage yard.

The research team observed that the slabs appeared to be in excellent condition, with only very minimal cracking. This cracking was likely caused by removing the slab from the roadway and transporting it via a front-end loader from the original site to a Georgia DOT storage area. The slab surface showed exposed aggregates; however, this was assumed to be a result of the paving process, and perhaps grinding of the surface to smooth it and improve rideability, rather than a durability issue, as no evidence indicated salt scaling or delamination.

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Figure 2. The wearing surface of the I-16 slab section in Dublin, GA, and one of the few cracks present. (It is not known if the crack was present before slab removal.)

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Figure 3. Cast surface of the slab section in Dublin, GA.

Site 2: Los Angeles, CA

The California DOT (Caltrans) has used rapid-setting ACM binders since the 1990s to reduce road closure times for weekend replacement in highly trafficked roadways. The research team visited four sites in the San Gabriel Valley in the Los Angeles, CA, area.

California State Route 60W to State Route 71S Interchange

The California State Route 60W to State Route 71S interchange near Pomona, CA, was constructed in 1997 with a commercially available ACM, which Caltrans has described as an 85-percent CSA and 15-percent portland-cement binder. Figures 4–7 show the condition of the pavement. After the pavement had been exposed for 17 years, the research team observed that the pavement was still in very good condition with only occasional spalls noted at the joints, although the research team noted some evidence of surface abrasion.


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Figure 4. The Route 60W/71S interchange in the Los Angeles, CA, area shows good performance after 17 years of continual heavy traffic loads.


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Figure 5. A close-up view of the Route 60W/71S interchange in the Los Angeles, CA, area.


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Figure 6. The Route 60W/71S interchange in the Los Angeles, CA, area. (A defect, perhaps caused by a placing or finishing issue, is apparent in the passing lane.)


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Figure 7. Surface wear and minor joint spalling on the Route 60W/71S interchange in the Los Angeles, CA, area.

California State Route 60E to State Route 71N Interchange

The California State Route 60E to State Route 71N interchange near Pomona, CA, was constructed in 1997 with a 100-percent CSA binder. The pavement required grinding after placement, possibly caused by poor compactability or a set time that was too rapid for proper finishing. Despite this grinding, the research team noted that this pavement was in good condition, as shown in figures 8 and 9.


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Figure 8. The Route 60E/71N interchange in the Los Angeles, CA, area shows good performance after 17 years of continual heavy traffic loads.


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Figure 9. A close-up view of the Route 60E/71N interchange in the Los Angeles, CA, area shows good performance after 17 years of continual heavy traffic loads. (Surface wear and perhaps early grinding for rideability is apparent.)

U.S. Interstate 10

Forty-five km (28 mi) of U.S. Interstate 10 (I-10) near Los Angeles, CA, also called the San Bernardino Freeway, were placed in 1999 using a 100-percent CSA binder. The research team observed that pavement slabs in both the eastbound and westbound directions at this site showed significantly more damage than did the previous sites. The condition of pavement on I-10E is shown in figures 10 and 11. The slabs showed evidence of damage, including joint deficiencies and spalls. In addition, the research team noticed mid-panel cracking and corner cracking in many of the slabs in these sections, including both ACM and portland cement concrete, leading the team to conclude that the ACMs did not contribute to the damage. Caltrans attributed the damage to the combination of subgrade deficiencies and underdesign and a slab thickness that is too low for today's traffic loads. The flow of water down an adjacent hillside also contributes to the poor subgrade conditions.

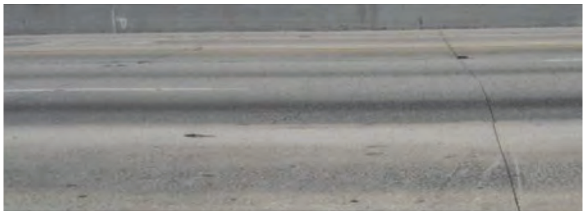
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Figure 10. A close-up view of pavement slabs on I-10E near Los Angeles, CA, shows deterioration after 15 years.


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Figure 11. Pavement slabs on I-10E near Los Angeles, CA, shows deterioration after 15 years.

California State Route 60

Sixty-four km (40 mi) of the Pomona Highway (California SR 60) between California State Route 57 and California Interstate 605 (I-605) were constructed in 2012 using a 100-percent CSA binder. Figures 12 and 13 show the condition of the pavement. Pavement was placed in both the eastbound and westbound directions over new base material, with the pavement designed for higher traffic loads constructed with an increased slab thickness and doweled joints. Similar to what was seen with the Route 60E to 71N interchange, the surface of this pavement was intentionally ground after placement because of pavement irregularities observed during placement. Despite its short time in service and improved design, the research team observed some spalling at joints, extensive longitudinal cracking, and corner cracking. Patches were required in several areas.


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Figure 12. Pavement slabs on Route 60W in Los Angeles, CA, show some cracking and spalling at joints after 1 year of use.


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Figure 13. An example of pavement slabs cracking and spalling at joints after 1 year of use on Route 60W near Los Angeles, CA.

Site 3: Dalton Highway, AK

In 1991, the Alaska DOT undertook a massive project to rehabilitate 18 bridges on the Dalton Highway, which runs north–south from Livengood, AK, to Prudhoe Bay, AK. Because of the extremely short construction season in Alaska, in addition to heavy truck usage of the road during the summer months, construction crews used MPCs in conjunction with precast concrete deck panels to facilitate rapid deck replacement of bridges along the Dalton Highway.[11] After speaking with Alaska DOT officials, the research team obtained a representative picture of an MPC bridge joint, shown in figure 14. After more than 20 years of service, Alaska DOT officials were satisfied overall with the performance of the material. The officials attributed some cracking in the joint to torsional forces from bridge deck bending at those locations, rather than deterioration because of material deficiencies.

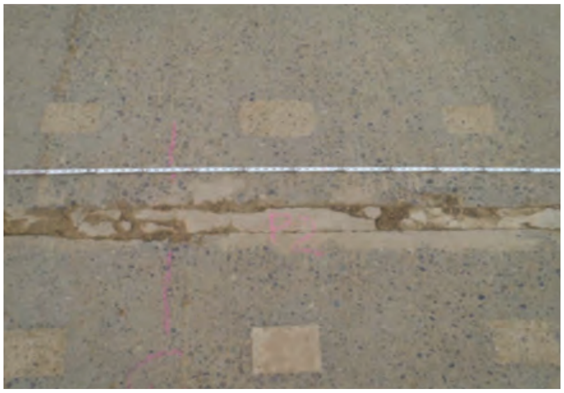
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Figure 14. Magnesium phosphate bridge grout on a bridge on the Dalton Highway, AK, located at mile point 78.8, after more than 20 years in service.

Site 4: U.S. Interstate 90/I-94 N, Chicago, IL

In 2009, the Illinois DOT replaced a significant section of interstate highway pavement in downtown Chicago with CAC concrete after what they described as a "catastrophic blowup of a section of pavement" resulting from nearby tunnel construction. Figures 15 and 16 show the repaired section of pavement. The Illinois DOT chose CAC as the replacement material for the damage to three northbound lanes of I-90/94 between Jackson and Adams Streets because of its capacity for high early strength. The Illinois DOT placed the CAC using mobile volumetric mixers and poured 58.3 m^3 (76.25 yd^3) of concrete and reopened the road within 5 hours after the start of the construction repairs. The engineer of record noted that the material seems to be holding up well, but that "experienced and well-organized contractors with top notch placement equipment" are required to obtain good results.


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Figure 15. Repaired pavement on northbound I-90 in Chicago, IL, shows good performance of the CAC concrete after 5 years.


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Figure 16. Vehicles travel over the repaired pavement on northbound I-90 in Chicago, IL, which shows good performance of the CAC concrete after 5 years.

Site 5: Treat Island, ME

The U.S. Army Engineer Research and Development Center has a large outdoor exposure site located at Treat Island just south of Eastport, ME.[58] Researchers at this site placed 15 by 15 by 53 cm (6 by 6 by 21 in) beams (shown in figures 17–19) on a pier in the tidal zone. The researchers exposed the concrete to both freezing and thawing during the winter, as the beams are alternately immersed in sea water and then exposed to the air and freezing weather conditions, as well as to salt water wetting and drying exposure year round.

The research team examined beams, produced from a fly ash-based geopolymer, a slag-based geopolymer, and a CSA cement, for signs of deterioration. These signs included scaling, cracking, and expansion. No signs of expansion or cracking were apparent in any of the ACM samples after 1 year of exposure. Research is ongoing to determine the chloride diffusion coefficient of the beams, which will be useful in assessing the potential resistance to corrosion for reinforced members.

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Figure 17. Fly ash geopolymer beams after 1 year of exposure at Treat Island.

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Figure 18. CSA cement concrete beams after 1 year of exposure at Treat Island.

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Figure 19. Slag geopolymer beams after 1 year of exposure at Treat Island.

Summary

Usage Survey Results

The ACM usage survey results and the research team's observations made during site visits, in addition to information provided by users or owners at these sites, demonstrate that there is growing interest in the use of ACMs for large-scale transportation infrastructure construction in the United States. At this time, the materials most commonly used for larger scale pavement construction include CAC, CSA, and AA products.

In general, the research team found ACM usage to be concentrated mainly in large urban areas, where the rapid setting and high early strength of these materials contributed to minimal road closure time. Such time-saving advantages provided value that superseded potential increases in costs for materials and construction, as well as challenges associated with the construction itself. For example, because of the rapid-setting characteristics of some of these materials, volumetric mixer trucks capable of combining materials at the job site were employed in some ACM construction projects. In some cases, more rapid-than-anticipated set times required pavement surface grinding because of difficulties achieving smooth finishes.

The research team found few examples of MPC and belite cement usage for larger scale transportation construction. The most common examples of MPC usage include small road repairs and joint construction. The research team found that MPC availability in the United States has been limited. Seasonal availability, variability in composition and quality, and challenges with short working time of the material have all prevented more widespread adoption of MPCs. Although usage for small-scale rapid repairs seems practical, larger scale construction using MPCs does not seem practical at this time. The research team also found that use of belite cements was less common. These cements have required longer cure times and relatively low strengths compared to other materials. New formulations may improve these current challenges.

Further Testing

Based on the results of the initial literature review, the ACM survey, conversations with material suppliers, and consultation with FHWA and the project's technical working group, the research team identified a subset of materials for further testing. These materials include two CSA cements, two CA cements (in which one is a blend of CA and portland cement), one belite cement, and two AA cements. Because the research is aimed at the scalability of these materials, most cements examined by the research team are commercially available, with the exception of a geopolymer concrete that is being developed by using off-the-shelf constituent materials. Research is ongoing; the team is currently focused on screening of available ACM technologies by examining fresh and hardened concrete properties and assessing durability. The research team will use these assessments to identify viable candidate ACMs for further investigation and to construct larger test sections at the culmination of the project.

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Publication No. FHWA-HRT-16-017
HRTM-30/10-15(WEB)E