Bridge Views

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Portland-Limestone Cement—A Choice Material for Sustainable Concrete

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"New" Technology

Portland-limestone cement (PLC) is a relatively new technology for the US, with requirements defining Type IL adopted in 2012 in specifications ASTM C595 and AASHTO M 240 (in parallel thanks to efforts of a joint AASHTO-ASTM task group). However, experience with this type of cement has been developed over several decades in Europe and other countries around the world. A key driver for the development of US specification requirements was the interest in providing options to continue to improve the sustainability of cement and concrete construction. Typically, PLC has about 10% lower CO2 footprint compared to portland cement, due to the replacement of clinker by about 12% fine limestone which is not pyroprocessed and is easier to grind. This directly helps lower the initial sustainability impact of concrete roads, bridges and other structures.

Fig. 1. Lost Creek Road in Morgan UT utilizes PLC cement, and is a major transportation route handling heavy truck traffic for a cement plant

Performance Attributes

Why would adding 10% to 15% of limestone, an essentially inert material, improve strength and other properties? Three primary reasons are particle packing, improved hydration, and some slight chemical reaction.

Since limestone is a softer material than clinker, it is easier to grind. Finer limestone particles can fill in gaps between larger clinker grains in the cement. This can reduce the volume of water required for workability and porosity of the paste. In addition, the higher surface area of fine limestone particles provides surfaces for hydrating cement phases to form and grow, and they develop away from the reactive grains, possibly allowing more complete reactions of the clinker. A small amount of limestone does chemically react (it is essentially inert), but the solids that form also can reduce the porosity, improving strength and reducing permeability and shrinkage. All of these changes are small but positive.

Strength

Early- and later-age concrete strengths are similar when made with PLC or portland cement. For example, see Figure 2 with data for concretes made with a water:cement ratio of 0.40, for specimens with no supplementary cemeticious material SCM, or a water:cement ratio of 0.45 for specimens with 35% slag cement or 20% Class F fly ash. Note that the ability to use SCMs in concrete is not adversely impacted, which further improves concrete sustainability characteristics.

Permeability

Permeability, a durability indicator, is also comparable in concretes made with PLC and portland cement, with and without SCMs. Figure 3 provides ASTM C1202/AASHTO T277 data.

Shrinkage

A common question for those new to PLC is how shrinkage is impacted. PLC is generally about 100 m2/kg (Blaine) finer that comparable portland cements. However, this does not increase shrinkage, in part because the finer ingredients in a PLC are relatively inert and help with particle packing. Data from Bucher et al. (2009) are provided in Figure 4. Total shrinkage is the autogenous shrinkage plus the free (drying) shrinkage. A concrete made with a PLC with 10%

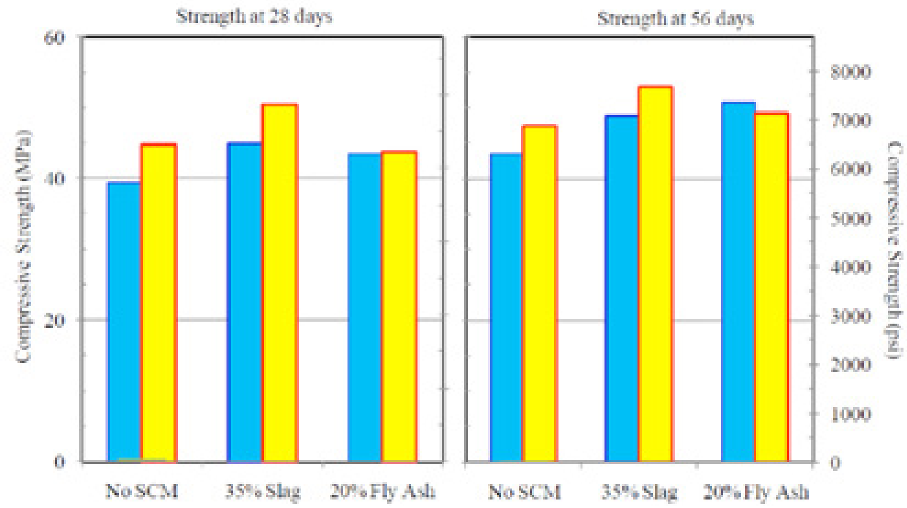

Fig. 2. ASTM C39/AASHTO T 22 compressive strengths of concretes at various ages made with PLC or portland cement, with or without SCMs (Thomas and Hooton, 2010).

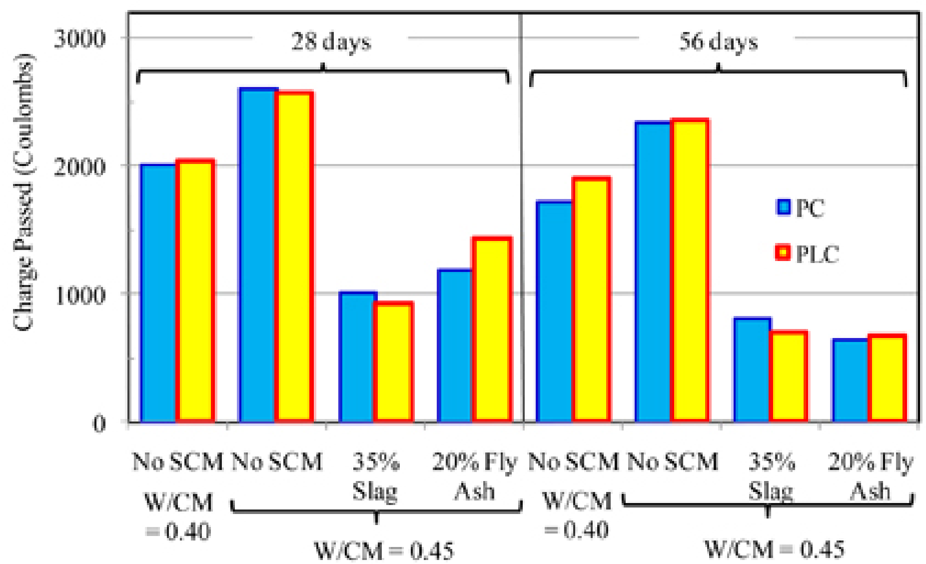

Fig. 3. ASTM C1202/AASHTO T 277 results for concretes made with PLC or portland cement, with and without SCMs (Thomas et al. 2010).

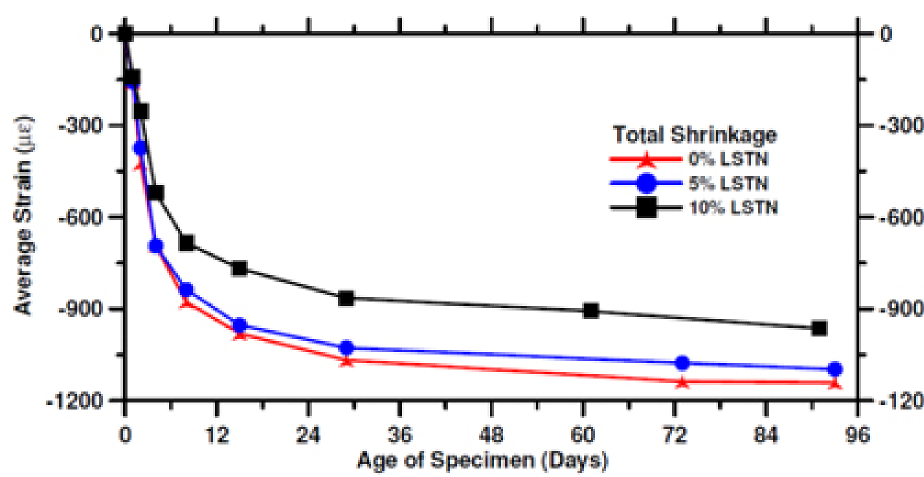

Fig. 4. ASTM C157/AASHTO T 160 shrinkage of mortars made with cements with 0%, 5% or 10% limestone (Bucher et al. 2009).

limestone lowered the shrinkage measurably.

Portland-limestone cement is a relatively new option for North American concrete, but has a long-history of use elsewhere in the world. Generally, a PLC will have a CO2 footprint about 10% less than a portland cement with comparable performance characteristics. Although concrete's durability makes it an inherently sustainable construction material choice, use of PLC is an option to make concrete even more environmentally friendly.

References

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4. Thomas, M. D. A.; Cail, K.; Blair, B.; Delagrave, A.; and Barcelo, L., "Equivalent Performance with Half the Clinker Content using PLC and SCM," 2010 Concrete Sustainability Conference, National Ready Mixed Concrete Association, April 13 to 15, 2010, Tempe, Arizona.

Michigan's Experience with Floodcoats

Jason DeRuyver, Michigan DOT

Epoxy floodcoats have been used as a preventive maintenance treatment on bridge decks in Michigan since the early 1990's. The early floodcoats were expensive, time consuming and left many questions regarding effectiveness and longevity. Since then, improvements in material and application made through state employee ingenuity and industry innovation has driven the price of doing a two-coat thin epoxy overlay in Michigan down to $3.80/sq. ft. and a penetrating healer sealer down to $1.80/ sq. ft.

Fig. 1. Michigan Workers Placing Thin Epoxy Overlay on US-2 over the Cut River.

Floodcoat is a term used to describe the flooding of an entire bridge deck with a material to seal or bridge cracks to prevent moisture intrusion. The floodcoat method pours material on the deck and then squeegees or brooms the material over the entire surface, essentially flooding the deck. Epoxy is typically usedfor floodcoats in Michigan, however, the term may be applied to other materials similar in nature such as polyesters or methacrylates.

Michigan uses two different kinds of epoxy floodcoats. For a penetrating healer sealer floodcoat, the deck is flooded with a one-coat, epoxy that soaks into the deck surface and fills deck cracks. The epoxy is then covered with a fine sand to provide a temporary wearing surface. (See Table 1 for a list of products and application rates used in Michigan) For a thin epoxy overlay, the deck is flooded with a two-coat epoxy that bonds to the bridge deck. After each coat, the epoxy is covered with a course aggregate to provide a permanent wearing surface. The end result is a flexible overlay of the deck that seals the entire surface, (See Table 2 for a list of products and application rates used in Michigan.)

Michigan applies thin epoxy overlays and penetrating healer sealers by both contractor and state forces. Since 2006, Michigan's state forces have placed 1.7 million square feet of thin epoxy overlay and 2 million square feet of penetrating healer sealer. In the same time, Michigan has contracted out 3.2 million square feet of thin epoxy overlay and 750,000 square feet of penetrating healer sealer.

When scoping a bridge for the appropriateness of a thin epoxy overlay or healer sealer, several factors must be considered. These are preventive maintenance treatments and they will not repair a structurally deficient bridge deck. While most manufacturers recommend a minimum deck rating of 7, as long as the engineer understands the criticality of the surface preparation, Michigan has successfully performed these treatments on bridge decks rated as low as 5.

Penetrating healer sealers are more forgiving and the surface wears off over time. They may be applied to a deck with any condition rating; however, flooding decks with a poor rating will not substantially extend their current condition nor justify the cost of the application. At a minimum, the deck should have a 5 rating, but use of the material on decks rated at 7 or 8 with repeated applications every 5 to 10 years will substantially increase their life expectancy.

Epoxy coated reinforcement (ECR) continues to be the preferred corrosion protection system of most DOTs.[3] Research conducted by the VDOT indicates that the initial corrosion protection provided by the coating depends on its condition and quality, but over time, the coating can delaminate allowing water and chlorides direct access to the steel surface.[4] The coating can trap moisture, preventing the water from evaporating and

	2014 Cost	**Coverage for Estimating**	**Approved Manufacturer**	**Approved Aggregate**
Epoxy Overlay	$25/Gallon	25 SFT/Gallon	Euclid Flexolith	Best Sand #612 Quartz
			Euclid Flexolith Summer	US Silica EP-5 Modified Quartz
			Euclid Flexolith HD	Manufacturers Minerals BT 6x10 River Rock
			Unitex Propoxy Type III DOT	Flint Rock Products #7 Chipped Flint
			Poly Carb Flexogrid Mark 163	
			Poly Card Flexogrid Mark 154	
			E-Bond 526 Lo-Mod	
			Axson Akabond 811	

Table 1. Michigan Healer Sealer Estimating and Approved Products

	2014 Cost	**Coverage for Estimating**	**Approved Manufacturer**	**Approved Aggregate**
Healer Sealer	$35/Gallon	75 SFT/Gallon	Unitex Bridge Seal	Cheboygan Mason Sand
			Euclid Dural 335	Wexford Sand W448
			Euclid Dural 50LM	Sand Products Co AFS 50
			Poly-Carb Mark 127	Nugent Sand Co 480
			Sikadur 55 SLV	
			Epoxseal GS Structural	

Table 1. Michigan Healer Sealer Estimating and Approved Products

increasing the rate of corrosion. Figure 3 shows the corroded ECR in a section of deck that failed in shear in 2009 on I81 near Marion Virginia after 17 years in service.[4] The green coating has turned brown in the vicinity of the leaking construction joint that was approximately 0.5 mm wide, the typical width of cracks in decks constructed with HPC. For a number of reasons, including geometry, cracks may create a more corrosive environment than joints.

Surface preparation is the key to success for thin epoxy overlays, and Michigan prepares all bridge decks to receive a thin epoxy overlay to the International Concrete Repair Institute's (ICRI), Concrete Surface Profile 7 (CSP 7). CSP 7 is a heavy shotlblast that removes all of the concrete paste, exposes aggregate and leaves the surface irregular. This heavy shotblast must remove all of the paint lines and surface tining for a successful application. Also, because the epoxy adheres to the exposed aggregate, all of the concrete must be sound and the aggregate well bonded. Unsound areas must be patched and allowed to cure for 28 days prior to overlaying, otherwise the epoxy will crack/debond, reducing effectiveness.

While thin epoxy overlays bridge cracks and provide a high friction wearing surface to the deck, penetrating healer sealers fill the cracks. For this application Michigan prepares the deck surface to a CSP 3, which lightly abrades the surface and rounds the edges of the cracks. Also the deck tining may remain. This allows penetrating healer sealers to be installed much more quickly than thin epoxy overlays. Michigan's healer sealers are expected to penetrate hairline cracks up to ½ inch. This penetration has been verified by coring cracks and measuring.

When choosing between an epoxy overlay and a penetrating healer sealer, weigh the advantages and disadvantages of each. Is speed of application important? Aesthetics? Budget?

The advantages of thin epoxy overlays are:

- Seals cracks in bridge deck
- Provides aesthetic wearing surface
- Increases skid resistance The darker aggregate retains more heat and reduces icing of the bridge.

The disadvantages of thin epoxy overlays are:

- Time consuming (3 day operation minimum)
- Extremely sensitive to deck preparation
- Susceptible to snow plow damage

The advantages of penetrating healer sealers are:

- Seals cracks in bridge decks
- Quick operation (1 day typical operation)
- Very inexpensive aggregate (mason sand)
- Not reliant on preparation. Same material as used for filling individual cracks by hand, and not through the floodcoat method.

The disadvantages of penetrating healer sealers are:

- Does not provide a wearing surface
- Can be aesthetically displeasing
- Shorter life expectancy

For more information on Michigan's extensive thin epoxy overlay and penetrating healer sealer program visit:

http://www.michigan.gov/documents/mdot/Thin_Epoxy_Overlay_and_Healer_Sealer_Treatments_on_Bridge_Decks_395120_7.pdf

(articles continue on next page)

Washington State DOT's use of Modified Concrete Overlays to preserve bridge decks

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Fig. 1. The photo on the left shows SR532 near Stanwood, WA during construction.

Background

WSDOT has a comprehensive Bridge Deck Program with the primary goal of economically repairing and overlaying concrete bridge decks to prolong their lifespan and avoid expensive deck replacements (sustainability). WSDOT manages 3,109 vehicular bridges over 20 feet in length as part of the state highway system. The majority of these bridges have reinforced concrete decks.

The use of salt in winter deicing practices causes premature deterioration in many concrete bridge decks through corrosion of the reinforcing steel. Once the rebars start to corrode they cause the concrete to spall and deteriorate. Each summer WSDOT Regional Maintenance crews repair any of these spalled areas. These repairs are considered to be temporary and typically last 1-3 years. Once the total areas of repairs and / or patching exceed 2% of the total deck area then the bridge is added to the list of future needs for adding an overlay. When funding becomes available then a contract is developed and advertised for a contractor to perform deck repairs and add a protective overlay (normally a 1.5" thick modified concrete).

WSDOT Modified Concrete overlay types

WSDOT has developed five separate modified concrete overlay mix designs for deck rehabilitation, two of which has been discontinued. The mix designs consist of either Latex or Microsilica (silica fume) or Fly-ash (42 hour cure time). WSDOT also installed a few rapid-set Latex Modified Concrete (LMC) overlays (4 hour cure) but their use has been discontinued. The following modified concrete mix designs provide over 5,000 psi compressive strength and a permeability value of less than 1,000 coulombs:

- Low Slump Dense Modified Concrete (LSDMC) was first applied in 1979 and has been used on 35 bridges to date (0.4 million sq.ft.). This overlay type has been discontinued due to poor performance.
- LMC was first applied in 1979 and has been used on 324 bridges to date (8.0 million sq.ft.).
- Microsilica Modified Concrete (MMC) was first applied in 1987 and has been used on 126 bridges to date (3.4 million sq.ft.).
- Fly-Ash Modified Concrete (FAMC) was first applied in 1995 and has been used on 43 bridges to date (1.2 million sq.ft.).
- Rapid-Set Latex Modified Concrete (RSLMC) was first applied in 2002 and has been used on 5 bridges to date (0.2 million sq.ft.). The use of this overlay has been discontinued due to excessive cracking. Difficulties with the supplier prevented a mix design that could be verified during construction.

WSDOT Modified Concrete overlay types

The overlay process begins by setting up traffic control and closing all or part of a bridge. The amount of time a contractor can have to do the project is a very important issue with more emphasis being made toward rapid construction. WSDOT requires a contractor to use a hydromilling machine with at least 7,000psi of water pressure to remove ½” of good concrete and any previous patches. The removal of the top ½” of concrete also removes a high percentage of the salt in the bridge deck. The contractor must do a trial on a portion of the deck with good concrete and then use the hydromill setting for the good concrete on the rest of the bridge. These settings will remove concrete in poor condition up to several inches. The contractor has to properly contain and dispose of the waste water used during the hydromill process. The next step is to fill repair areas below the top mat of reinforcing steel with a standard 4,000 psi concrete (WSDOT does not allow fast curing patching materials). These areas have to be cured for about 24 hours to achieve the strength desired of 2500 psi prior to applying the modified concrete overlay.

The construction process is nearly the same for any of the modified concrete overlay types. The main difference is that LMC is mixed and delivered to the bridge deck with a mobile mixing truck verses MMC and FMC that are mixed at a r plant and then delivered to the site in a ready mix truck. After a hydromill is used to remove ½” of the existing concrete and prepare the surface the contractor uses a finishing machine to place the concrete overlay and to ensure a uniform placement for the desired 1.5 inch thickness. The temperature of the existing bridge deck must be more than 45 degrees and less than 75 degrees prior to placement. WSDOT also sets a criteria for the evaporation rate at the time of placement. The modified concrete overlay is wet cured under burlap for a minimum of 42 hours. The overlay is then checked for strength per ASTM C805, and if the concrete is above 3,000psi then the contractor can remove the curing blankets and open the bridge deck to traffic. More details on the WSDOT modified concrete overlay specifications are available in section 6-09 of the WSDOT 2014 Standard Specifications for Road, Bridge, and Municipal Construction.

Concrete overlay service life

Modified Concrete Overlays are a very effective part of WSDOT’s bridge deck preservation strategies as evident by how few number of total deck replacements have been necessary (only 14 bridges to date). There are 165 bridges with modified concrete overlays that have provided more than 25 years of service. WSDOT has replaced 13 modified concrete overlays to date (0.8 million sq. ft.) and has identified another 30 (1.1 million sq. ft.) that will need to be replaced over the next 8-10 years.

Further Information

For further information about this article, contact the author at wilsond@wsdot.wa.gov.