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Sustainable Polymer Concrete Materials for Bridge and Concrete Rehabilitation, Maintenance, and Preservation

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ABSTRACT

This paper examines the use of different types of polymer material systems and precast products for the sustainability of bridges and other components of the infrastructure. High Molecular Weight Methacrylate has the unique ability to fill and seal cracks in horizontal concrete surfaces using nothing more than gravity. Methyl Methacrylate Polymer Concrete can be formulated with compressive strength of 20 to 90 MPa and has been used for spall repair, expansion joint headers, bridge bearing seats and anchor pockets. Thin Polysulfide Epoxy and Methyl Methacrylate Polymer Overlays for bridge deck wearing surfaces can be applied in thicknesses of 9 – 13mm and have been successfully used on both steel and concrete deck surfaces. Precast Polymer Concrete Panels for bridge barrier rails and tunnel bench walls and liners are corrosion resistant and the panel's bright white surface and retro-reflective safety stripe enhance tunnel lighting. Timely use of Polymer Concrete materials extends the requirement for major rehabilitation or replacement of concrete structures.

POLYMER MATERIAL SYSTEMS

High Molecular Weight Methacrylate

High Molecular Weight Methacrylate (HMWM) concrete crack healer/sealer was developed to be able to seal cracks in existing horizontal concrete surfaces. This material is formulated with a very low viscosity and chemical surfactins that enable it to penetrate deep into very small cracks 0.5mm (0.02 in). Most older concrete bridge decks and some newly constructed decks have cracks both plastic shrinkage cracks that develop during concrete curing and structural cracks due to loading. Structural cracks tend to be greater than 0.5mm (0.02 in) in width and they can be treated by applying HMWM directly to the crack. Depending on the crack width and depth several applications of HMWM may be required to completely seal the cracks. Small plastic shrinkage cracks (map cracking) are usually treated with a flood coat of HMWM over the entire bridge deck surface.

HMWM application requires that the surface and cracks be clean and dry, it is recommended that all large cracks be cleaned with dry compressed air. HMWM systems are comprised of resin, initiator and promoter. They are supplied as either a two component (resin pre promoted) or three component systems. Two component systems exhibit shorter shelf life and are not recommended if the material is not to be used in a short period of time. The HMWM resin is mixed by adding the promoter to the base resin and mixing thoroughly before adding the initiator and finish mixing. After the materials are mix they are applied to the concrete surface and can be spread with squeegees or stiff brooms. Care should be taken to move the HMWM resin to the cracked areas so that there will be sufficient material to fill the cracks. Once the cracks have been filled excess HMWM resin should be brushed/ squeegeed from the area. (Figure 1) Some material will always remain on the surface and a light broadcast of dry coarse sand should be applied before the material cures, this will maintain the skid resistance of the bridge deck surface. The coarse sand and residual resin on the surface will wear off under normal traffic conditions leaving all of the cracks sealed. Cured HMWM will effectively seal concrete cracks and because of its high bond strength to the walls of cracks it will restore the structural integrity of the concrete. After the sealer has cured it will restore between 50 to 80% of the original compressive strength of the concrete. Table 1 shows the physical properties of high molecular weight methacrylate.

Fig 1. HMWM Resin brushed/squeegeed onto bridge deck.

Table 1. Physical Properties Of High Molecular Weight Methacrylate

Property	**Unit of Measure**	**Test**
Viscosity	10 – 15 mPa.s (cP)	Brookfield
Tack Free Time	5-6 hours @ 70°F	AASHTO T237
PCC Bond Strength	4.2 MPa (615 psi)	CA Test 551
Tensile Elongation	30%	ASTM D638

Methyl Methacrylate Polymer Concrete

Methyl Methacrylate (MMA) Polymer Concrete has been developed to be used as a rapid curing high strength material [Table 2] that can be used for a variety of applications. MMA polymer concrete is made up of MMA resin, specially formulated pre-packaged powder filler and coarse aggregates. MMA polymer concrete can be installed as a neat mortar for thin installations of less than 25mm (1in) and for deeper installations it can be extended with coarse aggregate can be added up to 100% by weight of the neat mortar. In addition to the excellent physical properties of MMA polymer concrete as shown in Table 2**,** it can be installed and will cure at temperatures as low as -10deg C (14deg F). The low temperature capability and long term durability make the material ideal for emergency repairs that must be accomplished when standard concrete repair materials cannot be used.

MMA polymer concrete installation requires the existing concrete to be clean, sound and dry. When repairs are on steel reinforced concrete, it is strongly recommended that the existing concrete be removed below the reinforcement so that there will be an additional mechanical bond between the reinforcement and the MMA polymer concrete. The repair area must first be primed with an MMA primer resin that can be brushed or rolled onto the surface and allowed to dry (30 minutes). The MMA polymer concrete can be applied at anytime after the primer has cured which allows for preparation of many areas ahead of time making placement more efficient. After the primer is cured the MMA polymer concrete resin is mixed with the specially formulated powder and coarse aggregates in standard concrete mixing equipment. Finishing can be accomplished with standard finishing tools.

MMA polymer concrete has been successfully used for spall repairs, emergency full depth repairs, bridge expansion joints/headers, bearing pads, closure pours and concrete structural beam repairs. (Figure 2) Timely use of polymer concrete materials will prolong the requirement for major rehabilitation or ultimate replacement of concrete structures increasing the sustainability for many years.

Fig. 2 MMA Polymer Concrete for a Bridge Expansion Joint/Header

Table 2. Physical Properties of Polymer Concrete

Property	Unit of Measure	Test
Viscosity	10 -12 mPa.s (cP)	Brookfield
Pot Life (@70°F)	24 min.	AASHTO T237
Compressive Strength**	>34 MPa (5000 psi) – 1 hour	ASTM C109
	>51 MPa (7500 psi) – 3 hours	ASTM C109
	>58 MPa (8500 psi) – 24 hours	ASTM C109
Flexural Strength**	13 MPa (2000 psi)	ASTM D790
Tensile Adhesion***	>1.7 mPa (250 psi) - 2 hours	ACI 503R
Primer		
Viscosity	40 -60 mPa.s (cP)	Brookfield
Pot Life (@70°F)	8-15 min.	AASHTO T237
Tensile Adhesion***	>1.7 mPa (250 psi)	ACI 503R

**no extension varies with temperature ***pull-off concrete

Polysulfide Epoxy and Methyl Methacrylate Polymer Slurry Overlays

Thin Polymer Concrete Bridge Overlays have been used for many years and the overlay systems vary on installation methods, materials and physical properties. Two different thin polymer concrete overlay systems that have been developed are polysulfide epoxy slurry, and methyl methacrylate slurry systems. These overlay systems are made up of a special formulated resins each one having excellent physical properties and a uniquely formulated slurry powder component that allows the overlays to be installed in thicknesses of 9mm to 12mm (3/8in to 1/2in) in a single application. Most standard thin polymer overlays currently available use the broom and seed method of application. These overlays are installed by applying a coat of mixed resin on the bridge deck surface followed with a broadcast of coarse aggregate onto the surface. This procedure must be repeated 3 times in order to obtain the desired total overlay thickness. History has shown that this method of application is susceptible to contamination between applications from moisture, dust and debris. Anything trapped in the overlay between layers could result in premature overlay failure. Multi Layer overly systems also exhibit some level of porosity which is the root cause of concrete deterioration.

A polysulfide epoxy slurry overlay is installed in a single operation which involves the application of a primer coat on the surface using the same resin as the slurry component. Immediately after the primer is installed the overlay slurry can be applied to the surface. The slurry is a mixture of the polysulfide resin and the prepackaged slurry powder component and it is spread over the surface using gauge rakes that are preset to a specified thickness which will result in the specified overlay thickness. The slurry is formulated so that it self levels within minutes after the gauge raking is completed resulting in a smooth uniform surface. Any minor irregularities in the original concrete surface will be eliminated by the slurry.

Once the slurry has leveled the surface is then covered with the coarse broadcast aggregate. Depending on ambient temperatures the overlay will cure in as little as 2 hours.

A methyl methacrylate slurry overlay is installed in a single operation which involves the application of a special primer coat designed to seal the existing concrete surface and enhance the PPP of the overlay slurry. After the primer coat cures (15-30 minutes) the overlay slurry can be applied to the surface. The slurry is a mixture of the methyl methacrylate resin, pre-packed slurry powder component and hardener powder. The hardener powder quantity can be adjusted which allows methyl methacrylate overlays to be applied at low temperatures and still obtain full cure in the required time. The mixed slurry is spread over the surface using gauge rakes that are preset to the required thickness (Figure 3). The slurry will self level within minutes resulting in a smooth uniform surface. Once the slurry has leveled the surface is then covered with the coarse broadcast aggregate. After the overlay has cured (Approx. 1 hour) the loose broadcast aggregate should be removed with brooms or clean, dry compressed air. A final topcoat of methyl methacrylate should be applied to lock in the broadcast aggregate. The overlay can be opened to traffic in as little as 1 hour.

Thin polysulfide epoxy and methyl methacrylate overlays can be used on existing structures to restore skid resistance and eliminate the egress of moisture which leads to steel corrosion and deterioration. They are also used on newly constructed bridge decks to the sustainability of the structure by eliminating the corrosive effects of moisture. The physical properties of the cured polysulfide overlays shown in Table 3 and Table 4 make them material systems that have been successfully used on concrete bridge decks as well as steel orthotropic decks.

Fig 3. MMA Slurry Overlay spread with gauge rakes.

Table 3. Physical Properties of Polysulfide Epoxy Slurry Overlay

Property	Unit of Measure	Test
Neat Resin		
Pot Life (@70°F)	15-30 min.	AASHTO T237
Tensile Adhesion to Concrete	>1.7 MPa(>250psi)	ACI 503 R
Tensile elongation	45-60%	ASTM D638
Filled System (mortar)		
Compressive Strength	34-48 MPa(5000-7000 psi	ASTM C109
Flexural Strength	12-14 MPa (1800 – 2000 psi)	ASTM D790
Wet Skid Resistance	40-55	ASTM E274

Table 4. Physical Properties of Methyl Methacrylate Slurry Overlay

Property	Unit of Measure	Test
Neat Resin		
Pot Life (@70°F)	10-15 min.	AASHTO T237
Tensile Adhesion to Concrete	>1.7 MPa(>250 psi)	ACI 503 R
Tensile elongation	50%	ASTM D638
Filled System (mortar)		
Compressive Strength	10-17 MPa(1500-2500 psi)	ASTM C109
Flexural Strength	3-7 MPa (500-1000 psi)	ASTM D790
Wet Skid Resistance	40-55	ASTM E274

PRECAST POLYMER CONCRETE

Precast Polymer Concrete panels are manufactured in a variety of configurations, to be used as a finished surface as well as a permanent stay in place concrete form. The panels are light weight with high compressive strength, corrosion resistant and can include a unique vertical retro reflective safety stripe. Precast polymer concrete panels have been installed as median barriers, bridge rails, tunnel bench walls (as shown in figure 4) and tunnel wall panels. Each panel is manufactured with a bright white exterior surface that enhances delineation, visibility and increases motorist safety. The white surface will remain bright when installed and can also easily be cleaned with environmentally friendly solutions. The body of each panel is constructed of a high strength polymer matrix shown in Table 5 that is impervious to liquids and corrosion. Installation can be done on new structures with threaded inserts in each panel for attachment to standard steel reinforcement and special panels with thru bolt connections have been used to rehabilitate existing structures. Retrofit installations can be accomplished with little or no demolition of the existing concrete structure. Lower installation costs and long term durability make precast polymer concrete panels a cost efficient solution to extending the serviceable life of existing and newly constructed structures. Tunnel installations have shown that the bright white surface increases the efficiency of the existing tunnel lighting.

Fig 4. Precast Polymer Concrete panels used for tunnel bench wall.

Table 5. Physical Properties of Precast Polymer Concrete Panels

Property	Value	Test
Average compressive strength	96 MPa (14000 psi)	ASTM C109
Average flexural strength	22 MPa (3200 psi)	ASTM C384
Average impact strength	0.23 kg.m.sec (100 ft.lb.min)	ASTM D-2444
Fire resistance	Class "A"	
Flame spread	<25	ASTM E-84
Smoke development	<75	ASTM E-84

CONCLUSION

Polymer material systems and precast products offer engineers and owners solutions to many bridge and concrete structure premature deterioration problems. The key to the ultimate success of a project is selection of the proper material and/or product of a specification that is detailed enough so that proper installation procedures are followed. For the selection of polymer overlay and polymer concrete material systems engineers should consult with several manufacturers as well organizations that develop specifications like the American Concrete Institute (ACI) to determine critical factors before project specifications are finalized. Some factors to consider for rehabilitation are the condition of the structure and the strength of the concrete, low concrete strength could lead to premature polymer overlay or patching failures. Projects with limited working times need to consider the time required to install polymer overlays, single application slurry systems with reduced installation times might be the most appropriate for some projects. For steel orthotropic decks, porosity of a polymer overlay might be the most important factor when selecting a material.

Precast polymer concrete panels, although more costly than standard construction materials and methods, offer long term sustainability. When considering the use of polymer concrete panels speed of installation should be a factor however the most important issue will be the durability. High strength, resistance to moisture and corrosion will make the use of polymer concrete panels a viable selection when life cycle costs are taken into account.

PROJECT REFERENCES

High Molecular Weight Methacrylate (HMWM) Healer/Sealer

Clinch Avenue Bridge – Seal Concrete Structural Bridge Beams – *Knoxville, Tennessee*, USA

Kung Nae Bridge – Seal Concrete Bridge Deck – *Seoul, Korea*

LaGuardia Airport – Seal Concrete Structural Bridge Beams – *Flushing, New York, USA*

Main Avenue Bridge – Seal Concrete Bridge Deck – *Sacramento, California, USA*

Methyl Methacrylate (Mma) Polymer Concrete

George Washington Bridge – *Concrete Spall Repair – New York, New York, USA*

Kung Nae Bridge – Concrete Toll Plaza – *Seoul, Korea*

Massachusetts Turnpike – *Concrete Deck Replacement – Boston, Massachusetts, USA*

Woodrow Wilson Bridge – *Bearing Pads, Joint Headers – Washington, DC, USA*

Polysulfide Epoxy Slurry Overlay

Angus MacDonald Bridge - Steel Orthotropic deck *8,400 sq m (90,000 sq ft) Halifax, Nova Scotia, Canada*

Kung Nae Bridge – Concrete deck *15 sq m (160 sq ft) Seoul, Korea*

Poplar Street Bridge-Steel Orthotropic deck *21,400 sq m (230,000 sq ft) St Louis, Missouri, USA*

Seu Hae Highway – Concrete slab *150 sq m (1600 sq ft) MokPo, Korea*

TriBoro Bridge – Steel Orthotropic deck *23,225 sq m (250,000 sq ft) New York, New York, USA*

Precast Polymer Concrete Panels

Interstate 10 – Bridge Rail Retrofit *11,000 m (36,000 ft) Shreveport, Louisiana, USA*

Kingston Rhinecliff Bridge – Bridge and Median *Barrier 2,900 m (9500 ft) Kingston, New York, USA*

Ted Williams Tunnel – Bench Wall Flat Panel *11,000 m (36,000 ft) Boston, Massachusetts, USA*