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Properties of Latex-Modified Shotcrete Beneficial to Concrete Repairs

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ABSTRACT

The inclusion of a latex into a shotcrete mix imparts a new set of mechanical properties to shotcrete and enhances the benefits of shotcrete when used for the repair of concrete. The effects of the polymer binder on the shotcrete matrix are discussed and then related to the mechanical properties of latex-modified shotcrete. The mechanical properties of latex-modified shotcrete are presented along with a discussion of how they benefit the repair of concrete structures that have experienced corrosion or freeze-thaw damage, particularly in environments subject to chloride exposure. The application of latex-modified shotcrete is discussed and guidelines are provided for preparing the mix proportions and specifications.

Latex-modified shotcrete refers to the inclusion of a latex into a conventional shotcrete mixture of portland cement and aggregate that is conveyed through a hose and pneumatically projected, at high velocity, onto a surface (1). A latex is a form of polymer system, and it generally consists of a water emulsion of a synthetic plastic or natural rubber (2). The most commonly used latex for shotcrete applications utilizes a styrene-butadiene polymer that is the same polymer system used for latex-modified concrete bridge deck overlays. The inclusion of a latex into a shotcrete mixture results in the development of a polymer binder throughout the shotcrete matrix, which imparts a new set of mechanical properties to the shotcrete.

The mechanical properties of the latex-modified shotcrete system are the result of the individual and combined effects of the cement and polymer binders. The proper interaction of these two binders is essential in obtaining the benefits of the latex-modified shotcrete (LMS); this interaction is dependent on the mix proportions and the development of bonds between the binders as the material cures.

The cement in LMS will hydrate and cure in the same manner as in conventional shotcrete and the polymer particles bond to each other as the latex emulsion dries. Bond development between the polymer and cement, however, is dependent on the chemical reactions that take place during the hydration of the cement.

The bond between the polymer and cement appears to occur in the early stages of the cement hydration process with the polymer bonding through the calcium ions present in the cement (3). Once this bond is developed, it is strong and irreversible. As the cement hydration process continues, the polymers will coalesce and bond to form a continuous polymer film. This film formation is the result of loss of water from the latex emulsion, either to evaporation or to the cement hydration, after which the polymer particles are forced together, either by the growth of the cement hydrate or by capillary action created by the water loss. In order to obtain the benefits of LMS, it is important that sufficient polymer particles be present in the mix to develop a continuous polymer film throughout the shotcrete matrix.

As the LMS begins to dry, the cement paste will shrink and microscopic cracks will develop throughout the shotcrete matrix. The polymer binder is capable of undergoing strain and can bridge these cracks and restrain their propagation. The high bond strength of the polymers to the cement paste allows the polymer to sustain the tensile stresses resulting from the restraint of the microscopic cracking and results in an increased tensile capability for

LMS. This increased tensile capability is reflected in improved bond, flexural, and tensile strengths. The ability of the polymer binder to undergo strain while maintaining its bond to the cement paste results in improved flexibility of LMS, which is reflected in a reduced modulus of elasticity and an increased impact resistance. The bridging action of the polymer binder across the micro-cracks in the cement paste coupled with the continuous polymeric film throughout the shotcrete matrix results in a reduced permeability and is reflected in a reduced absorption rate, reduced penetration of chlorides and water, and improved resistance to freeze-thaw and wet-dry cycles.

MECHANICAL PROPERTIES OF LMS

The addition of a latex to a shotcrete mixture imparts a new set of mechanical properties to the shotcrete and improves its performance as a repair material. In general, LMS is more durable than conventional shotcrete and its improved bond and flexibility makes it a more desirable repair material.

Compressive Strength

The addition of a latex to a shotcrete mixture does not improve compressive strength. In fact, tests indicate that variances in the styrene-butadiene ratio or a high polymer-to-cement ratio can cause a decrease in the compressive strength. It has been suggested that the plastic film throughout the shotcrete matrix may act as an internal lubricant that reduces the resistance to compressive stresses; however, the compressive strength of LMS is still in the range of 5,000 to 7,000 psi. Conventional shotcrete with a comparable mix design will have a compressive strength range of 5,000 to 9,000 psi (4-7).

Flexural Strength

The flexural strength of LMS is greater than conventional shotcrete as a result of the capability of the polymer binder to transmit tensile stresses. A normal range of flexural strengths for LMS is 1,300 to 1,600 psi. A comparable range of flexural strengths for conventional shotcrete is 600 to 1,000 psi (4-6).

Tensile Strength

The tensile strength of LMS is increased by 40 to 60 percent over conventional shotcrete because of the polymer binder's capability to transmit tensile stresses. Tensile strength of LMS is in the range of 400 to 700 psi as compared to 200 to 400 psi for conventional shotcrete (5).

Bond Strength

Bond strength capacity of LMS to concrete is 30 to 50 percent greater than conventional shotcrete although both materials will typically exceed the shear and tensile strength of the concrete material to which they are bonded. The primary benefit of LMS is that the polymer binder can undergo strain in addition to transmitting tensile stresses, which makes the bond more resistant to impact or movement. Shear bond strength of LMS to concrete is in the range of 350 to 450 psi and is generally governed by the shear strength of the concrete. Shear bond strength between layers of LMS is in the range of 700 to 900 psi (4,6).

Absorption

A reduced permeability of LMS is reflected in the reduced rate of absorption, which is typically 2 to 4 percent as compared to 6 to 9 percent for conventional shotcrete. The lower absorption of LMS is attributed to the continuous polymer film throughout the shotcrete matrix and the polymer's ability to bridge the micro-cracks that develop in the cement paste (5,6).

Modulus of Elasticity

The high bond strength of the polymer to cement and the ability of the polymer binder to remain elastic results in a modulus of elasticity of approximately one-half that of conventional shotcrete. The modulus of elasticity of LMS is normally in the range of 2.5 million psi.

Freeze-Thaw Resistance

Latex-modified shotcrete's low water-cement ratio, low absorption rate, and high tensile strength combine to provide excellent resistance to freeze-thaw action. An accelerated freeze-thaw test conducted by the U.S. Army Corps of Engineers showed a weight loss of 0.3 to 4.1 percent for LMS after 300 freeze-thaw cycles. Samples of conventional shotcrete tested at the same time showed a weight loss of 41.5 percent after only 105 freeze-thaw cycles (5).

Impact Resistance

The combination of the high bond strength of the polymer to the cement with the polymer's ability to transmit tensile stresses while remaining elastic makes LMS much more flexible and resistant to impact. Impact tests indicate that an average of 250 blows were required to develop the first crack in LMS samples as compared to only 50 blows for conventional shotcrete (5).

BENEFITS OF LMS IN CONCRETE REPAIRS

The primary benefits of using LMS for concrete repairs is its enhanced durability and improved bond. The enhanced durability of LMS improves its performance for repairing concrete that has deteriorated as a result of corrosion of the reinforcing steel or because of freeze-thaw damage. It is particularly useful in repairing damaged concrete that is also exposed to wet-dry cycles. LMS-improved bonding characteristics resulting from the polymer binder's tensile strength and elastic properties make LMS a more compatible repair material than conventional shotcrete by improving the reliability of the bond between the two materials.

Corrosion damage in concrete is initiated when air, moisture, and an electrolyte (usually chlorides) come in contact with the reinforcing steel. Exposure to these combined elements begins the cell action necessary for steel to corrode, and then the resulting corrosion exerts tensile stresses on the surrounding concrete and ultimately causes the concrete cover to spall. Corrosion damage is particularly severe in areas subject to wet-dry cycles, which causes cracking of the concrete cover and increases exposure to water, and also in areas subject to high concentrations of chlorides, which accelerates the penetration of the electrolyte to the steel. Structures subject to severe corrosion damage

would include waterfront structures, especially along coastal regions, and bridges that are exposed to de-icing salts.

The normal means of repairing corrosion damage is to remove the surrounding concrete material so that all corrosion can be removed from the steel. When all corroded steel is exposed and cleaned, it is protected by placing a new cover material over it and restoring the structure to its original condition. The improved properties of LMS make it well-suited as a repair material because the low absorption of LMS reduces the penetration of moisture to the steel. In addition, tests have shown that the penetration of chlorides through LMS is insignificant beyond a 0.75-in. depth. If either the chloride or the moisture is prevented from coming into contact with the steel, the recurrence of corrosion is prevented. In areas subject to wet-dry cycles, LMS performance is superior because the low absorption of the material reduces extreme dimensional changes that would cause cracking, and the tensile strength of the polymer binder further inhibits the development of cracks.

Freeze-thaw damage in concrete is caused by the expansion of water within the concrete as the water freezes. The expansion exerts tensile stresses within the concrete matrix and results in cracking of the concrete material. The cracking allows more moisture to accumulate with a greater expansion potential and eventually leads to a complete breakdown of the concrete material. Freeze-thaw damage is greatest in structures exposed to moisture such as waterfront structures, bridge substructures, and retaining type structures.

The normal method of repairing freeze-thaw-damaged concrete is to remove all damaged concrete until sound concrete is exposed. After the removal of all deteriorated concrete, the structure can be rebuilt to its original condition with a new repair material. LMS is extremely durable against freeze-thaw action. The low absorption of LMS inhibits the penetration of moisture and reduces the potential of damage during freezing. The high bond strength of the polymer to cement and the ability of the polymer to transmit tensile stresses while remaining elastic allows it to resist the expansive stresses that may develop during freeze-thaw cycles.

The primary reason for LMS durability against freeze-thaw action is its ability to reduce the penetration of moisture which, upon freezing, causes the damage. This characteristic restricts the use of LMS in repairing structures, in regions subject to frequent freeze-thaw cycles, which would result in encapsulating a water-saturated concrete substrate. Examples would include lining the exterior of a water tank or completely coating the face of a retaining structure exposed to groundwater. Although the bond between the two materials and the durability of the LMS would not be affected, the substrate concrete would be maintained in a saturated condition because of the LMS lower rate of permeability. If the structure is located in a region that experiences frequent freeze-thaw cycles, the repair would fail because the substrate concrete material would rapidly deteriorate from freeze-thaw actions, resulting in a separation of structure and repair material.

The success of any repair depends on the ability of the repair material to remain bonded to the concrete structure. Many repair failures have occurred because of differential movement between the repair material and concrete surface. These movements may be caused by excessive shrinkage, different thermal expansion coefficients, or a different reaction to flexural movement, all of which develop a concentra-

tion of stresses at the bond plane and usually result in delamination.

LMS is compatible with concrete because it is basically a portland cement product. The latex modification of the shotcrete results in a more flexible repair material that will distribute stresses throughout its cross section rather than concentrating the stresses at the bond plane. In addition, the high bond strength of the polymer binder, coupled with its ability to remain elastic, allows the LMS to absorb impact-loading and large deflections without reducing the bond with the concrete.

APPLICATION OF LMS

As with any repair material, the benefits of LMS can be realized only if the material is properly applied. The American Concrete Institute (ACI) report, Specification for Materials, Proportions and Application of Shotcrete (7), can be readily adapted for an LMS application. The general methods of applying LMS are similar to conventional shotcrete and either the wet-mix or dry-mix process may be used. There are, however, special features that must be considered when using LMS.

Mix Design

Latex-modified shotcrete mix proportions are designed for maximum durability rather than strength. The favorable material properties of LMS are dependent on the inclusion of the proper quantity of polymer solids, and on ensuring that an adequate paste content is available in the mixture. There must be enough polymer solids in the mix to allow the formation of a continuous polymer film throughout the shotcrete matrix. The amount of polymer solids required has been determined by testing and is expressed as a polymer-cement ratio of 0.15, by weight, for the styrene-butadiene latex. LMS is normally more effective in richer mixes and experience suggests that a minimum of 750 lb of cement per cubic yard of in-place material be used to ensure adequate paste content.

Most LMS is applied to vertical and overhead surfaces. In order to prevent sloughing, the material is shot relatively dry with a water-cement ratio between 0.26 and 0.35. At this low water-cement ratio, most of the water for cement hydration is provided by the latex emulsion. Accordingly, it is necessary to control the moisture content of the aggregate to ensure that an adequate amount of latex solids can be added during application. The maximum allowable moisture content of the aggregate will vary according to the solids content of the latex used, but is normally around 3 percent.

Quality Control

The addition of latex to a shotcrete mixture does not produce a significant change in compressive strength and, therefore, the commonly specified compressive strength should not be used as a quality control measure for LMS. The changes in mechanical properties that result from the addition of the latex is reflected in an increased tensile capacity and its reduced permeability. More accurate and convenient indicators of the quality of LMS are the flexural strength and absorption tests. Unless a specific project requires more stringent control over the material properties, a minimum flexural strength of 1,300 psi and a maximum absorption of 4

percent can be specified. The samples required for these tests can be cut from the standard shotcrete test panels described in ACI 506.2.

Latex Material

Styrene-butadiene latexes should meet the product specification guidelines suggested by the Federal Highway Administration (8). No other admixtures are recommended for LMS. Air-entraining cement and air-entraining admixtures should not be allowed for LMS because the surfactant used to keep the polymer suspended in the latex emulsion will cause a higher-than-normal entrained air content.

It is desirable for the latex to be delivered with all polymers, water, stabilizers, and additives blended at the point of manufacture. No water or additives should be added to the latex after delivery unless specifically allowed by the specifications. Latex has limited freeze-thaw stability and should be protected against freezing. Latex that has been stored for a long period of time should be stirred or agitated in some manner, before use, to resuspend any latex solids that may have settled during storage.

Proportioning and Preconstruction Testing

Latex-modified shotcrete mix proportions should be selected on the basis of preconstruction testing. The mix proportions selected for use should produce the specified flexural strength, absorption, and other design requirements. Proportions should be selected on the basis of test specimens that are moist-cured for 1 day and dry-cured for the remaining curing period. Three flexural test specimens should be sawed from the test panel no earlier than 5 days after shotcreting and should each measure 3 x 3 x 12 in. Absorption tests can be performed using the broken flexural test specimens.

Batching and Mixing

Batching and mixing of LMS for the wet-mix process is the same as conventional wet-mix shotcrete. The cement, aggregate, and latex are blended, maintaining the proper polymer-cement ratio, and the minimum amount of water is added to provide a pumpable mix with a water-cement ratio that is within the range of 0.26 to 0.35. After mixing, the LMS is conveyed through a hose and pneumatically projected onto the prepared surface.

Batching and mixing of LMS for the dry mix process is the same as for conventional dry mix shotcrete when a pressurized tank or booster pump is used. The cement and aggregate are blended dry and pneumatically conveyed through a hose, and the latex is added through the nozzle body just before projecting the material onto the prepared surface. The latex is normally placed in a tank capable of maintaining sufficient pressure to overcome the latex line losses and to adequately inject the latex through the water ring assembly. Latex that is conveyed or pressurized by pumping should not be pumped with a high shear action pump because of the possible excessive foaming action of the latex. A long nozzle is normally used, which injects latex into the material hose at a point approximately 7 to 15 ft from the nozzle tip. The use of the long nozzle provides the additional time needed to more thoroughly mix the cement, aggregate, and latex. This extra mixing time is desirable because of the lower mois-

ture content of the aggregate and the need to uniformly distribute the polymer solids throughout the shotcrete matrix.

Placement of LMS

The placement of LMS is similar to the placement of conventional shotcrete with the quality of the final product depending largely on the skill of the nozzleman. LMS does, however, require special precautions due to effects of the polymers.

Avoid spilling or spraying latex onto a substrate surface. Latex emulsions are frequently used as bonding agents when applying fresh concrete material onto existing concrete. However, latex that is allowed to dry will form a plastic film that inhibits development of a bond of concrete materials placed over it. To prevent reduced bond and possible delamination of the LMS, any substrate surface contaminated with latex that has been allowed to dry should be sandblasted or waterblasted clean.

The surface of LMS, which has been freshly shot, will develop a surface film of polymer solids and laitance. This film, if not removed, will reduce the bond of succeeding layers of LMS. If the film has not taken its final set, it can be broken by brooming with a stiff broom or cutting back the surface with a trowel. If a final set is established, the film should be removed by sandblasting or waterblasting.

The latexes used in LMS are excellent adhesives and, as a result, rebound and overspray will tend to adhere and build up around the work area rather than blow free of it. Extra precautions must be taken by the workmen to prevent the accumulation of rebound and overspray on the prepared substrate surface and reinforcement. LMS placed over accumulations of rebound and overspray will result in inadequate bond, laminations, and sandpockets, and will produce a nondurable LMS material.

LMS should not be placed at ambient temperatures below the minimum temperature recommended by the manufacturer. At temperatures below the minimum film formation temperature (MFT), the polymer solids become rigid and resist being forced together to form a continuous film. At temperatures above the MFT, the polymers exhibit plastic behavior and thus will coalesce. The MFT will vary between latexes and is normally around 45°F.

Curing

LMS should initially be moist-cured for the first 24 hr by continuous sprinkling or covering with an absorptive mat that is kept continuously wet. After the initial curing period, LMS should be allowed to air cure.

It should be noted that curing applies to all layers, not just to the final surface of the LMS. If the LMS is applied in layers, each layer should be moist-cured for the first 24 hr or until the succeeding layer is placed, whichever is less.

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Applications of Permanent Precast Polymer Concrete Forms for Concrete Rehabilitation

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ABSTRACT

Two case studies are presented of the use of precast polymer concrete stay-in-place forms for rehabilitation of transportation structures. The first study is on precast median barrier shells used by the Pennsylvania Turnpike Commission. The new barrier replaced an obsolete, deteriorated 4-ft-wide concrete island. The shells are 1-in.-thick and come in 20-ft-long sections. They are placed on the roadway, aligned, anchored with anchor bolts, then filled with conventional concrete through holes at the top of each section. The system is easily and rapidly installed, and provides a more impact-resistant and durable barrier than conventional concrete barriers. The second study is on precast bench panels that replaced deteriorated bench walls in Boston's Sumner Tunnel. Polymer concrete panels were selected because of their high strength and high modulus, good impact resistance, and their outstanding resistance to de-icing salts, chemicals, and freeze-thaw. The work, performed during the night, consisted of placing and anchoring panels, sealing off vent openings to prevent backfill concrete from coming out, then placing concrete behind the panels. In addition to improved performance properties, rapid construction time was a major benefit.

The continual use of salts to remove snow and ice and the adverse effects of freeze-thaw cycles and water penetration have combined to accelerate the deterioration of U.S. highways and bridges at an alarming rate. To overcome the deteriorating ef-

fects, use of polymer concretes have increased. The high strength-to-weight ratio of polymer concretes and their resistance to freeze-thaw cycles and road salts enable them to be used for rehabilitating and upgrading highway and transportation structures. Because polymer concrete formulations do not include water, the tiny capillaries that remain in conventional cement concrete after the curing water evaporates are not present. Therefore, the material is nonporous and provides a sealing and protective barrier from the elements.

The two case studies included in this report are descriptions of projects completed in the fall of 1983. In both cases, a special formulation of polymer concrete was chosen over other materials because of its ability to decrease life-cycle costs, prevent shear bond failures, and simplify the construction operation while solving particular engineering design requirements that other methods or materials could not accomplish economically.

POLYMER CONCRETE MEDIAN BARRIER--PENNSYLVANIA TURNPIKE

The Pennsylvania Turnpike Commission installed 4,900 linear ft of polymer concrete median barrier on the Susquehanna Bridge as part of a \$2.4-million bridge rehabilitation program. The new nonporous and extremely durable material will be more impact-resistant and reflective than traditional precast or poured-in-place concrete barriers.

Located on the Pennsylvania Turnpike between exits 18 and 19, the continuous-span Susquehanna Bridge was built in 1953. Before the bridge rehabilitation, there was a 4-ft concrete island curb with guard rail on top that proved to be unsatisfactory. Figure 1 shows a schematic of the old concrete island. Turnpike engineers investigated precast and poured-in-place barriers but had problems with the precast type because of difficulties with the anchoring system as a result of the condition of the