Application of Concrete Crack Sealant in Infrastructure Repairs

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The infrastructure condition in the United States has been deterioration over the past few decades. According to the American Society of Civil Engineers Infrastructure Report Card, the overall rating of US infrastructure projects is C-. Severe deterioration is attributed to the inability of the Federal Highway Administration (FHWA) and State Departments of Transportation (DOTs) to sufficiently maintain and/or replace deteriorated elements due to lack of funding. In this research, maintenance of concrete cracking through the application of sealant is addressed. In order to determine the most effective sealant types in crack repairs, literature review is conducted, and specifications of several State Departments of Transportation are reviewed. The analysis of crack sealant effectiveness considered the type of crack, the type of sealant used, concrete surface preparation, sealant application, curing procedure and associated quality control methods. Finally, the appropriate testing procedures for sealant are determined. The outcome of this research will provide State DOTs personnel with efficient methodology to select and apply the appropriate types of sealants to different infrastructure project cracks to attain optimized and most-economic maintenance outcomes.

Key Words: crack sealant, concrete, repair, maintenance, infrastructure projects, state DOTs

Introduction

The American Society of Civil Engineers (ASCE) Infrastructure Conditions Report Card shows that the overall rating of in-service infrastructure projects in the United States is C-. This low rating reflects the structural and functional deterioration of infrastructure projects. The severe deterioration in infrastructure conditions is attributed to aging infrastructure and insufficient maintenance, repair, and replacement activities due to lack of funding. The Federal Highway Administration (FHWA) and State Departments of Transportation (DOTs) have considered possible alternatives to improve the infrastructure conditions including the use of high-performance materials (Akhnoukh and Buckhalter, 2021, Akhnoukh, 2020, 2013, and 2008), accelerated construction and repair techniques, and early-detection of potential deleterious reactions.

The deterioration of infrastructure projects in general, and reinforced/prestressed concrete projects in particular, is attributed to the ingress of water, de-icing salts, chlorides, and aggressive chemicals through hair cracks initiated at the extreme fibers of the structural member. The infiltration of the afore-mentioned chemicals in concrete structures results in concrete spalling, reinforcing steel and prestressing strands corrosion. In addition, concrete hair cracks – when left untreated – tends to aggregate and form larger cracks that leads to spalling and may lead to premature failure of concrete structures (see figure 1).

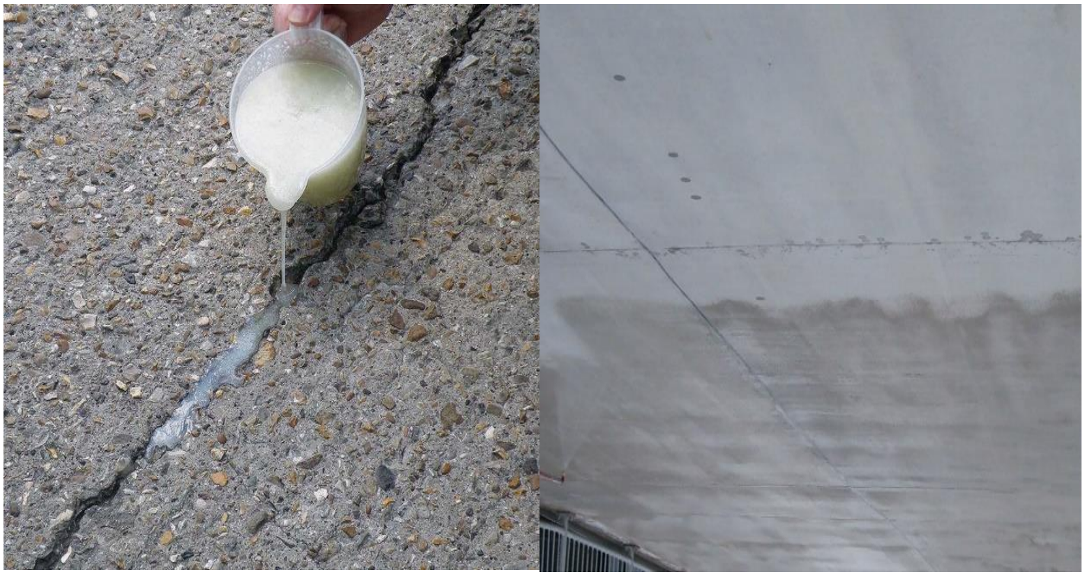
Figure 1. Structural deterioration due to concrete cracking and spalling

A common strategy to reduce the adverse effect of concrete cracks on the service life of concrete structures is to seal cracks using appropriate sealants to hinder or prevent the water infiltration into the structure. The main objective of this research is to investigate different types of sealants, identify their appropriate application given the crack type, direction, size, and depth. The research will consider the surface treatment prior to sealant application, how the sealant is applied, cured, maintained, and tested.

Literature Review

The maintenance of DOTs infrastructure projects is a topic of interest for all State DOTs. Maintenance and repair of hot mix asphalt projects (HMA) has been considered for several decades and resulted in well-developed standards and specifications that are currently used on federal and state levels. On the contrary, the maintenance and repair of rigid "concrete" pavement projects has been under research and investigation since the 2000s. Therefore, there is no national standards that address these major activities.

A variety of sealants are commercially available and have been used by different State DOTs to protect and preserve the national infrastructure and help preventing crack growth and/or continued infrastructure deterioration. Cracks are classified into two major types: a) active cracks, which are moving and growing. These include cracks developed due to continuous "cyclic" loading, continuous ground settlement, and/or cracks acting as concrete expansion/contraction joints, and b) dormant cracks where future expansion is not anticipated. Crack repairs are conducted using two different techniques (see figure 2). First, concrete crack sealant where the sealant is applied to the crack in order to form a surface that prevents water or chemicals to penetrate to the crack. Second, concrete crack filler where the crack repair material is injected to fill the crack and enhances the structure integrity of the concrete member, thus, crack won't widen and the crack filler will prevent any moisture from penetrating into the crack (Mazumder et al., 2019).



(a) (b)

Figure 2. (a) Concrete crack filler, and (b) concrete crack sealant

Materials used for crack repair should ideally block the moisture from entering the concrete member, remain flexible under temperature variations to accommodate expansion and contraction of concrete, and should not soften under high temperature or harden under extremely cold weather (Lu et al., 2022). Different types of sealants and repair materials are being used by the FHWA and State DOTs that are believed to fulfil the performance requirements of sealants (see Table 1).

Table 1.

List of commonly used sealants

Type of Sealant	**Subcategory**	**Sealant Functionality**	**Quality Control Test.**
Silicates	Penetrating sealant; pore blocker	Fill the pores and block the moisture from penetrating through capillarity	Absorption through sealed face
High molecular weight polymethyl methacrylate (HMW MMA)			
PoreShield SME-PS			
Siliconates	Penetrating sealant; hydrophobic; water repellants	Lowered substrate surface tension and prevents water ingress	Chloride ingress
Silanes			Freeze-thaw resistivity
Siloxanes			
Linseed	Film maker; pore blocker	Film is performed that prevents water and moisture ingress	Rapid chloride permeability
Epoxies			De-icer scaling resistance
Methacrylate			

Despite the availability of a wide range of sealants, comprehensive studies comparing the performance of different sealants are limited. It has been shown in the literature that the performance of silanes and siloxanes are highly depended on their concentration and chemical composition (McGettigan, 1992). The depth of penetration of the sealants is believed to be an indicator of their long-term performance. The deeper the sealant penetrates into cracks, the lesser will be its susceptibility to "exterior" abrasion (McGettigan, 1995). Absorption characteristics of sealants are measured in the lab through a modification of ASTM C642 procedure and in the field are measured by extracting cores in the field (Rasoulian et al., 1988; and Wright et al., 1993).

As shown in Table 1, different sealants are commercially available; however, their relative performance is largely unknown due to the lack of field experience and laboratory measurements with some of the sealants. In addition, the recent supply chain interruptions have resulted in low availability and increased cost of some of the commonly used sealants. Therefore there is a need to investigate sealants characteristics that can deliver satisfactory performance to avoid increased cost and delay of projects.

Methodology and Investigation Procedures

In order to provide North Carolina Department of Transportation (NCDOT) with sufficient recommendations for the most effective means and methods of concrete crack sealant. The research team conducted an extensive literature search and reviewed State DOTs manuals for data collection. The following represents the main criteria investigated in this project:

- Sealant material properties
- Cracked surface preparation
- Sealant application method
- Sealant curing procedures
- Optimum quality control methods for different sealant types
- Advantages and disadvantages of different sealant types

The research team focused on eight different State DOT and the District of Colombia for the analysis of concrete sealant applications. Selected states included the following:

- Five states (South Carolina, Georgia, Tennessee, Virginia, Kentucky) and the District of Columbia. The afore-mentioned list is selected due to their proximity to the State of North Carolina, comparable weather, and comparable project sizes
- Two states (Florida and New Hampshire) are selected due to the significant weather variation
- One state (New York) due to its stringent restrictions associated with infrastructure projects construction, maintenance, and repair

Data Collection and Analysis

Information relevant to the main criteria of investigation in this project were gathered from different State DOTs manuals. Data were compiled to develop final guidelines and recommendations regarding best concrete sealants practices for NCDOT. The first set of data compilation (see table 2) included:

- The sealant types commercially available in the local market (HMWM, Penetrant, Epoxy)
- The crack surface preparation required

Table 2.

Florida DOT sealant types and concrete surface preparation (FDOT, 2022)

Sealant Type			Concrete Surface Preparation		
HMWM	Penetrant	Epoxy	HMWM	Penetrant	Epoxy
Consists of methacrylate monomer, cumene hydroperoxide initiator, and cobalt promoter. Min. Compressive strength is 6,500 psi and tensile strength is 1,300 psi	Penetrant sealer with 40% solids and active material dispersed in water. Must be resistant to chloride ion penetration	Type E compound used for injection, and type F-1 compound used for surface sealing	Power sweep surface area, power vacuum used on grooved bridge decks. Oil based substances must be removed with solvent	Water blast surface area. Do not allow surface abrasion to exceed 0.016 inches	Seal the surface of the crack with type F-1 epoxy before injection

Second set of data compilation included the appropriate application method for each sealant type as recommended by the DOT guidelines. Application method of crack sealant is function in sealant type, flowing ability, and the depth of the crack to be sealed (see table 3).

Table 3.

Florida DOT sealant application method(s) and curing specifications (FDOT, 2022)

Sealant Type			Concrete Surface Preparation		
HMWM	Penetrant	Epoxy	HMWM	Penetrant	Epoxy
Applied via mobile equipment with a spray bar at a rate of 100 sqft per gallon. On riding surfaces, sand must be uniformly distributed over the area of polymer application	Typically applied via air or airless sprayers with approximately 20 psi. Application rate ranges between 155 and 255 sqft per gallon. Applied from lowest elevation to highest	Type E compound used for injection, and type F-1 compound used for surface sealing	Power sweep surface area, power vacuum used on grooved bridge decks. Oil based substances must be removed with solvent	Water blast surface area. Do not allow surface abrasion to exceed 0.016 inches	Seal the surface of the crack with type F-1 epoxy before injection

The final set of data collection includes information relevant to concrete sealant quality control and possible inspection (testing) techniques (see table 4).

Table 4.

Florida DOT sealant quality control and testing (FDOT, 2022)

Quality Control and Testing		
HMWM	Penetrant	Epoxy
Can not apply HMWM if it has rained on the past 48 hrs. For every 1,000 sqft, a core sample 2 in. diameter and 1.5 in. deep must be extracted	Ambient temperature must be between 50 and 90 F to apply the sealant, and it can not be applied during rainfall or if wind speed is 25 mph or higher. The Engineer will take sample of the sealant from each lot delivered to jobsite. There is no destructive testing	Three core samples must be drilled for each workday. Voids greater than 0.006 in. wide needs to be filled (with 10% tolerance for this requirement)

Conclusions

The DOT database reviews revealed that there are three main types of sealants used in concrete crack repair: high molecular weight methacrylate (HMWM), Penetrating sealers, and epoxy injection. The processes for each sealant differ slightly state by state, but all ten states reviewed used all three of these sealants in some capacity.

HMWM sealants are composed of methacrylate monomer, an initiator, and a promoter. HMWM has a low viscosity, typically 25 centipoise or below, low odor, a high flash point, and bond strength of 1,500 psi. After analyzing the processes used by each DOT, the researchers were able to outline the recommended procedure that should be specified by the NCDOT for HMWM sealants.

- Surface Preparation
    - Air blast all visible cracks with oil free compressed air using sufficient air pressure to remove all loose material from the cracks and surface. Cracks wider than 0.03 inches should be pre-filled with sand before application.
- Application
    - Applied via mobile sprayer and spread evenly over the cracked surface with brooms and squeegees. Ensure that the HMWM is spread so that there is no ponding.
    - Sand shall be applied to the riding surface no more than 20 minutes after the HMWM is applied.
- Curing
    - Cotton ball test: consider the material fully cured when polymer does not adhere to the cotton ball when pressed against the treated surface.
- Quality Control
    - The ambient temperature must be at least 50 degrees Fahrenheit, and the surface must not be wet.
    - Seal joints and scupper drains to prevent runoff.

Penetrating sealants are any silanes, siloxanes, and silicones that penetrate the concrete and form a chemical barrier without changing the surface appearance. The researchers recommend that the DOT specify the use of silicones, as they are breathable and capable of withstanding movement. It is recommended that silicones be specified to withstand +/- 50% joint movement. The following is the recommended procedure for Silicone penetrating sealants.

- Surface Preparation
    - All cracks less than 1/2" wide must be sawn so that they are at least 1/2" thick and 1 1/2 to 2" deep. The cracks should then be sandblasted and blown with compressed air.
- Application
    - When a primer coat is needed (vertical surfaces) it shall be applied via brushes or spray equipment. The silicone sealant shall be directly pumped into the cracks via an air-powered pump with a nozzle sized appropriate to the size of the cracks.
- Curing
    - Must be tack free within an hour.
- Quality Control
    - The sealant should be visually inspected to assure there are no gaps or obvious defects. Adhesion to the joint faces shall be spot-checked with a simple knife test.
    - Do not apply if the surface is wet or if rain is expected within 4 hours of application.

Epoxy is a polymer resin that is known for its excellent bond strength and quick curing time. Liquid epoxy is used for high pressure injection by all ten state DOTs that were reviewed, and epoxy paste is used to seal the surfaces of cracks before injection by all ten DOTs as well. However, the properties of the liquid epoxy mix used for injection varies state by state, and the researchers recommend that the NCDOT specify Type IV or V, Grade 1, Class B epoxy resin for injection.

- Surface Preparation
    - Flush the cracks with water under pressure and dry them with oil-free compressed air. The surface of the cracks must then be sealed with epoxy paste prior to injection of the liquid epoxy.
- Application
    - Injection ports must first be inserted. For cracks that go completely through a member, ports shall be inserted at a maximum spacing along the crack of no more than the thickness of the element being repaired. For members with multiple cracks, ports shall be spaced no less than 8 inches apart.
    - Epoxy is to be injected via a self-mixing machine at a pressure of 200 psi.
- Curing
    - Allow epoxy paste to cure before injection.
- Quality Control
    - Core samples shall be taken, and epoxy mix shall be sampled before injection.

The aforementioned recommendations for sealant types, methods of application, concrete surface treatment, curing, quality control and testing procedures could be used as a guideline for NCDOT and other State DOTs in concrete maintenance and repair. Adequate and appropriate maintenance would potentially result in improved infrastructure conditions in the United States.

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