Field Performance of High Molecular Weight Methacrylate Monomers and Silanes

On a D-Cracked, Jointed Reinforced Concrete Pavement
Current maintenance techniques for the repair of D-cracked concrete pavements are costly and not very effective. In an effort to solve this problem two relatively new materials were used on a section of I-90 in southwestern Minnesota. Silanes were used in an attempt to retard the D-cracking process by protecting the pavement from moisture and chemical damage. The other material, High Molecular Weight (HMW) Methacrylate monomers generally act as a "glue" to cement the fractured concrete particles back together. Both materials were placed on three separate test sections. Four silanes and three HMW methacrylates were used. Each test section varied in the extent of D-cracking present.

Results to date indicate that the effectiveness of silanes in extending the service life of D-cracked concrete pavements is questionable. They appeared to reduce cracking in one test section but performed similar, or worse, than the control in the other two. HMW Methacrylates appear to be effective in holding a D-cracked pavement together for approximately 18 months. However, the pavement must have cracks wide enough for the material to penetrate and form a substantial bond.
FIELD PERFORMANCE OF HIGH MOLECULAR WEIGHT METHACRYLATE MONOMERS AND SILANES ON A D-CRACKED, JOINTED REINFORCED CONCRETE PAVEMENT

Final Report

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The author and the Minnesota Department of Transportation do not endorse products or manufacturers. Trade or manufacturers’ names appear herein solely because they are considered essential to this report.
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2. Mn/DOT District 7B, Windom, Maintenance Personnel
3. Steve Oakey, Mn/DOT District 7, Mankato, Materials Engineer
4. Duane Pingeon, Mn/DOT District 7B Maintenance Superintendent
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EXECUTIVE SUMMARY

Current maintenance techniques for the repair of D-cracked concrete pavements are costly and not very effective due to various reasons including the gradual progression of D-cracking distress. Bituminous patching is labor intensive, the repair rarely lasts for more than one year, and the resulting ride is usually poor. In an effort to solve this problem two relatively new materials were used on a section of I-90 in southwestern Minnesota. Each of these materials attacks the problem in a different manner. Silanes were used in an attempt to retard the D-cracking process by protecting the pavement from moisture and chemical damage. The other material, high molecular weight (HMW) methacrylate monomers generally act as a "glue" to cement the fractured concrete particles back together.

Both materials were placed on I-90 in southwestern Minnesota on three separate test sections. Four silanes and three HMW methacrylates were used. Each test section varied in the extent of D-cracking present. Strategic Highway Research Program (SHRP) tests confirmed that some alkali-silica reactivity (ASR) gel was present but the cracking did not appear to be related to ASR. Also, the cracking pattern observed through core analysis was different than the bottom-up pattern usually observed in D-cracked pavements. Most of the cracking was taking place in the center section of the core.

Results to date indicate that the effectiveness of silanes in extending the service life of D-cracked concrete pavements is questionable. They appeared to reduce cracking in one test section but performed similar, or worse, than the control in the other two. HMW Methacrylates appear to be effective in holding a D-cracked pavement together when the existing pavement had cracks wide enough for the material to penetrate. "Hairline" cracks were difficult for the material to penetrate and form a substantial bond. Sections with less severe cracking, both in width and quantity, at the beginning of the test, performed similar to the control. When effective, the HMW methacrylates held the pavement together for approximately 18 months.

From this study, it appears that if HMW methacrylates are applied at the appropriate time within a pavement life, they will extend the service life of D-cracked pavements. Reapplication of the HMW methacrylate, when new cracks develop, could extend the life of the pavement even further. At this time, silanes cannot be recommended as an effective method to retard D-cracking. The above mentioned test sections will continue to be monitored for long-term performance.
FIELD PERFORMANCE
OF
HIGH MOLECULAR WEIGHT METHACRYLATE MONOMERS
AND
SILANES
ON A D-CRACKED,
JOINTED REINFORCED CONCRETE PAVEMENT

PURPOSE

Approximately 88 miles (142 km) of Interstate 90 in southwestern Minnesota, Mn/DOT District 7, are known to contain D-cracking susceptible aggregate. Of these 88 miles (142 km), approximately 41 miles (66 km) have either been reconstructed or overlaid with bituminous or unbonded concrete. The purpose of this study is to see if the application of silanes or high molecular weight (HMW) methacrylate monomers could slow or repair the damage caused to the concrete pavement from D-cracking on the remaining 47 miles (77 km) of effected Interstate 90. Current maintenance and construction fixes are costly, not very effective, usually result in a poor ride, and interfere with traffic flow. These new materials, if proven successful, may offer a quick and relatively inexpensive rehabilitation method for this type of distress when applied at the proper time.

BACKGROUND

Silanes

Silane is a polymer that has two important components, each with a separate role to play in resisting moisture and chloride intrusion. The organic hydrocarbon component provides hydrophobicity and the alkoxy group component is responsible for bonding and penetrating into the concrete substrate. The depth to which silane penetrates is dependant on the molecular size of the silane particles, porosity of the concrete, moisture and silica content of the concrete, and pH of the concrete. The action of "capillary suction forces" is the main factor that provides for the high absorption rate, which normally exceeds the rate of evaporation. The penetration depth is important for resistance to wear and protection from degradation due to UV radiation.
The material may be applied by brush, roller, or as was used on this project, spray. The surface must be clean enough to allow the solution to penetrate into the concrete pores and capillaries. Traffic should not be allowed on the pavement until the treatment solution has fully penetrated and the solvent evaporated, normally within 20 to 45 minutes.

The material is surface applied, therefore only the surface and the areas that can be reached by open joints and cracks are protected from water and salt. D-cracking generally starts beneath the concrete pavement where moisture already present raises the degree of saturation of the coarse aggregate to a critical level. Silanes are intended to protect concrete from water and chlorides entering from the surface, therefore it appears unlikely that any protection from the "bottom-up" D-cracking phenomena will result.

**Methacrylates**

HMW methacrylate monomers are intended to act as a penetrating crack sealer. The low viscosity material penetrates the crack, cures in place, and thus keeps water from further damaging the concrete by filling and cementing the crack back together.

HMW methacrylates are applied with a brush, spray, or squeegee, as was used on this application. Approximately 20 minutes after the final application, the methacrylate should receive a sand broadcast to insure good skid resistance. Surface cure time under ideal conditions is approximately 3 to 6 hours.

HMW methacrylates cannot penetrate fine hairline cracks. Cracks need to be open and relatively clean for the material to penetrate. Air blasting is the recommended technique for cleaning out the cracks. Sand blasting tends to clog the cracks, and the moisture from water blasting inhibits the bond. In addition, all bituminous patches should be removed before placement of the HMW methacrylate because it deteriorates the asphalt. The asphalt is softened initially and then appears to return to its original state after cure.

**ORIGINAL PROJECT CONDITIONS**

The existing jointed reinforced concrete pavement was constructed in 1973 from RP 45.408 to 58.012 and in 1974 from RP 58.012 to 87.787. The pavement has 1 inch (25.4 mm) diameter dowels, skewed joints spaced at 27 feet (8.23 m), and a 24 feet (7.32 m) wide. The pavement constructed in 1973 rests on 3 inches (76.2 mm) of Class 5 and 3 inches (76.2 mm) of Class 3 and the pavement constructed in 1974 is on 6 inches (152 mm) of Class 5. Class 3 and 5 are different types of Mn/DOT aggregate base.
Course aggregate for the this section of roadway typically contained a split aggregate composed of quartzite for the 3/4 inch (19 mm) plus fraction, and limestone for the 3/4 inch (19 mm) minus fraction. The fine aggregate (sand) was from various local aggregate sources and does not appear to enter into the D-cracking problem. The following table lists the course aggregate sources for each original construction project:

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>5380-41</td>
<td>45.408 - 50.749</td>
<td>Northwood, Iowa</td>
<td>New Ulm, MN</td>
</tr>
<tr>
<td>3280-22</td>
<td>50.749 - 58.012</td>
<td>Northwood, Iowa</td>
<td>Sioux Falls, SD</td>
</tr>
<tr>
<td>3280-23</td>
<td>58.012 - 65.516</td>
<td>Hallet-Esterville, Iowa</td>
<td>Sioux Falls, SD</td>
</tr>
<tr>
<td>3280-24</td>
<td>65.516 - 72.861</td>
<td>Hallet-Esterville, Iowa</td>
<td>Sioux Falls-Dell Rapids, SD</td>
</tr>
<tr>
<td>3280.25</td>
<td>72.861 - 81.127</td>
<td>Hallet-Esterville, Iowa</td>
<td>Sioux Falls-Dell Rapids, SD</td>
</tr>
<tr>
<td>4680-24</td>
<td>81.127 - 87.787</td>
<td>Esterville S&amp;G, Iowa</td>
<td>New Ulm, MN</td>
</tr>
</tbody>
</table>

TRAFFIC

The 1991 two-way AADT for this section was approximately 5850 with an HCADT (Heavy Commercial) of 1040. The 20 year one-way design lane CESALS from a nearby project on I-90 was estimated to be approximately 8,500,000.

CONSTRUCTION

The HMW methacrylate test sections were placed from October 7 to 9, 1991. The silanes were placed on I-90 between October 14 and 19, 1991. Each material was placed according to the manufacturers recommendations. The layout of the test sections is shown in Appendix A. The HMW methacrylate test sections are shown in Figure 1 and the silane test sections are shown in Figure 2. All the materials were placed by Mn/DOT Maintenance personnel from District 7B, Windom. The following test sections were constructed:
<table>
<thead>
<tr>
<th>Location</th>
<th>Material</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP 47.6 to RP 48.0</td>
<td>HMW Methacrylate</td>
<td>Distressed areas only</td>
</tr>
<tr>
<td>RP 58.9 to RP 59.3</td>
<td>HMW Methacrylate</td>
<td>All transverse joints and cracks</td>
</tr>
<tr>
<td>RP 66.4 to RP 67.0</td>
<td>Silane</td>
<td>Entire driving lane</td>
</tr>
<tr>
<td>RP 78.6 to RP 79.3</td>
<td>Silane</td>
<td>Entire driving lane</td>
</tr>
<tr>
<td>RP 81.6 to RP 82.0</td>
<td>HMW Methacrylate</td>
<td>Entire first four panels, then all joints and cracks</td>
</tr>
<tr>
<td>RP 83.5 to RP 84.1</td>
<td>Silane</td>
<td>Entire driving lane</td>
</tr>
</tbody>
</table>

Silanes

Weather - Sunny, windy. High mid-50's, low mid-30's.
Preparation - Each section was shot blasted. (Except for the last 100 feet (30 m) of the sections on RP 83.5 - 84.1)
Application - Spray entire driving lane at the rates listed below.

<table>
<thead>
<tr>
<th>Material</th>
<th>Rate</th>
<th>Cost</th>
<th>Cost $ / lane mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sil-act</td>
<td>125 ft² / gal</td>
<td>$24.00/gal</td>
<td>$12,165.00</td>
</tr>
<tr>
<td></td>
<td>(3.1 m²/ liter)</td>
<td>($6.34/liter)</td>
<td>($7,540.00 / km)</td>
</tr>
<tr>
<td>ATS 42</td>
<td>125 ft² / gal</td>
<td>$24.00/gal</td>
<td>$12,165.00</td>
</tr>
<tr>
<td></td>
<td>(3.1 m²/ liter)</td>
<td>($6.34/liter)</td>
<td>($7,540.00 / km)</td>
</tr>
<tr>
<td>Sil-act Water Base</td>
<td>125 ft² / gal</td>
<td>$24.00/gal</td>
<td>$12,165.00</td>
</tr>
<tr>
<td></td>
<td>(3.1 m²/ liter)</td>
<td>($6.34/liter)</td>
<td>($7,540.00 / km)</td>
</tr>
<tr>
<td>Enviroseal</td>
<td>125 ft² / gal</td>
<td>$17.80/gal</td>
<td>$9,020.00</td>
</tr>
<tr>
<td></td>
<td>(3.1 m²/ liter)</td>
<td>($4.70/liter)</td>
<td>($5,590.00 / km)</td>
</tr>
<tr>
<td>Fosroc Dekguard P-40</td>
<td>110 ft² / gal</td>
<td>$38.00/gal</td>
<td>$21,890.00</td>
</tr>
<tr>
<td></td>
<td>(2.7 m²/ liter)</td>
<td>($10.04/liter)</td>
<td>($13,570.00 / km)</td>
</tr>
</tbody>
</table>

Comments - The Fosroc Dekguard P-40 took on a dark appearance after traffic and also exhibited some tracking.
**HMW Methacrylates**

Weather - Partly cloudy, windy. High low 70's, low in 40's
Preparation - Air blast only to remove loose material on surface.
Application - A squeegee was used to spread the material after it was placed on the concrete surface with a watering can. All products were applied at the following rates.

<table>
<thead>
<tr>
<th>Location/Coverage</th>
<th>Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>RP 47.6 to 48.0</td>
<td>100 ft / gal</td>
</tr>
<tr>
<td>Distressed areas only</td>
<td>(26 m / liter)</td>
</tr>
<tr>
<td>(2.5 feet (0.76 m) wide)</td>
<td></td>
</tr>
<tr>
<td>RP 58.9 - 59.3</td>
<td>66 ft / gal</td>
</tr>
<tr>
<td>Joints or cracks only</td>
<td>(17 m / liter)</td>
</tr>
<tr>
<td>(2-2.5 feet (.61-.76 m) wide)</td>
<td></td>
</tr>
<tr>
<td>RP 81.6 to 82.0</td>
<td>130 ft² / gal</td>
</tr>
<tr>
<td>Entire first four panels</td>
<td>(3.2 m² / liter)</td>
</tr>
<tr>
<td>Remainder</td>
<td>66 ft/gal (17 m / liter)</td>
</tr>
</tbody>
</table>

**Cost**

The following cost information is for materials only. All labor and traffic control was completed by Mn/DOT maintenance personnel.

<table>
<thead>
<tr>
<th>Product</th>
<th>Cost</th>
<th>Cost/Lane Mile - Joints Only (Cost/Lane km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sika Pronto19</td>
<td>$83.75/gal</td>
<td>$3470.00</td>
</tr>
<tr>
<td></td>
<td>($22.13/liter)</td>
<td>($2160.00)</td>
</tr>
<tr>
<td>3M 4R Concrete Restorer</td>
<td>$70.00/gal</td>
<td>$2900.00</td>
</tr>
<tr>
<td></td>
<td>($18.50/liter)</td>
<td>($1800.00)</td>
</tr>
<tr>
<td>Transpo T70X</td>
<td>$38.00/gal</td>
<td>$1580.00</td>
</tr>
<tr>
<td></td>
<td>($10.04/liter)</td>
<td>($980.00)</td>
</tr>
</tbody>
</table>

Comments - The two part Sika product came in preproportioned containers and was therefore easier to mix, and it set quicker than the other products. The other products were three part and not preproportioned. A overnight lane closure was required to allow the HMW methacrylate enough time to cure. This extended curing time was required because of the cool air temperature.
METHOD OF RESEARCH

The research portion of this project was based entirely on the visible observations of how the various products performed under actual field conditions. The initial condition of the test sections varied. Generally speaking, the initial severity of the D-cracking increased with increasing Reference Post. The condition of each joint was rated as a unit. Each joint was given a rating of low, medium, high or severe with high and severe cracking considered as a failed joint condition. The ratings were based on the following definitions:

Low - The characteristic staining and crack pattern of closely spaced fine cracks appears near the joints and cracks.

Medium - Low to moderate level corner cracks have developed.

High - High severity spalling with loose material exists in the affected area.

Severe - Patching of spalls has occurred and considerable loose material exists in the joint area.

The first formal rating of the products occurred on March 4, 1993, and second on August 12, 1993, 17 and 22 months respectively after the application. All ratings were made by visual inspections of each joint. Several other visits to the site to review performance occurred between October 1991 and March 1993.

RESULTS

The Figures showing the performance ratings are found in Appendix B for the silanes and Appendix C for the HMW methacrylates.

Silanes

Location - RP 66.4 - 67.0
1991 Condition - Some staining, just starting to D-crack, can see shading but no visible (open) cracks, 20 - 30% edge corner cracks.

Comments -
1. Silane treated sections have less medium to severe cracking than control. (Figure 3, page B-1)
2. Silane treated sections have slightly less high and severe cracking. (Figure 3, page B-1)
3. The failure rate for all the sections, high and severe cracking, appears to be at a relatively slow rate. (Figure 4, page B-2)
Location - RP 78.6 - 79.3
1991 Condition - D-cracking just starting, not much staining, and faulting in initial stages.
Comments -
1. Silane treated sections have more medium to severe cracking than control. (Figure 5, page B-3)
2. Silane treated sections have generally slightly more high and severe cracking. (Figure 5, page B-3)
3. The failure rate for most of the products appears to increase 17 months after application. (Figure 6, page B-4)

Location - RP 83.5 - 84.1
1991 Condition - D-cracking very visible, some corner breaks at center, and faulting apparent.
Comments -
1. Silane treated sections have less medium to severe cracking than control. (Figure 7, page B-5)
2. Silane treated sections have slightly more high and severe cracking. (Figure 7, page B-5)
3. The failure rate for most of the products is very close to the control. (Figure 8, page B-6)

A combined average of all silane test sections is shown in Figure 9, page B-7. It shows that the sections treated with silane have approximately the same high and severe cracking as the control. It also shows that the silane treated sections have slightly less medium to severe cracking.

HMW Methacrylates

Location - RP 47.6 - 48.0
1991 Condition - Slight D-cracking along joints, occasional delamination visible, no large cracks, and corner breaks at 95 - 100% of joints.
Comments -
1. HMW Methacrylate treated sections have slightly more high and severe cracking than the control. (Figure 10, page C-1)
2. The failure rate, high and severe cracking, appears to increase sharply 17 months after application. (Figure 11, page C-2)

Location - RP 58.9 - 59.3
1991 Condition - D-cracking apparent, larger cracks, corner breaks at most joints, and 10% of center joint delaminated at intersection with transverse joint.
Comments -
1. HMW methacrylate treated sections have less high and severe cracking than control. (Figure 12, page C-3)
2. The failure rate increases sharply for two HMW methacrylates 17 months after application. (Figure 13, page C-4)

Location - RP 81.6 - 82.0
1991 Condition - D-cracking very visible, some corner breaks at center, and faulting apparent.
Comments -
1. Two HMW methacrylate treated sections have much less high and severe cracking than the control. (Figure 14, page C-5)
2. The failure rate for the HMVV methacrylate treated sections increases sharply 17 months after application. (Figure 15, page C-6)

A combined average of all HMW methacrylate test sections is shown in Figure 16, page C-7. It shows that the sections treated with methacrylate have generally less high and severe cracking than the control, with two products performing at a higher level. It also shows that even the best performing HMW methacrylate treated sections have approximately 40% of the joints exhibiting high and severe cracking 22 months after application.

Coring

The coring was completed on November 1, 1993. Five, five inch (127 mm) diameter cores were taken at the following locations to determine the depth of penetration of the HMW methacrylate into the cracks and the condition of the concrete pavement. All cores were taken over a HMW methacrylate filled crack in the leave slab. (Except the mid-panel crack which was approximately 14 feet (4.27 m) from the previous joint.)

<table>
<thead>
<tr>
<th>Core</th>
<th>Section (RP)</th>
<th>Material</th>
<th>Joint Edge Length (in)</th>
<th>Distance From Edge Length (in)</th>
<th>Recovered Length (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>58.9 - 59.3</td>
<td>Transpo</td>
<td>1.75 (44 mm)</td>
<td>16.5 (419 mm)</td>
<td>2* (51 mm)</td>
</tr>
<tr>
<td>2</td>
<td>&quot;</td>
<td>3M</td>
<td>5.0 (127 mm)</td>
<td>8.0 (203 mm)</td>
<td>9 (229 mm)</td>
</tr>
<tr>
<td>3</td>
<td>&quot;</td>
<td>Sik</td>
<td>1.5 (38 mm)</td>
<td>8.0 (203 mm)</td>
<td>2* &amp; 2* (51 &amp; 51 mm)</td>
</tr>
<tr>
<td>4</td>
<td>81.6 - 82.0</td>
<td>Transpo</td>
<td>2.0 (51 mm)</td>
<td>16.0 (406 mm)</td>
<td>9 (229 mm)</td>
</tr>
<tr>
<td>5</td>
<td>&quot;</td>
<td>Transpo</td>
<td>Mid-panel (178 mm)</td>
<td>7.0 (178 mm)</td>
<td>9 (229 mm)</td>
</tr>
</tbody>
</table>

*Average length **Two pieces
Core Descriptions

Core 1 - This core varied in thickness from 0 inches (0 mm) to almost 4 inches (102 mm). Parallel horizontal cracking spaced at approximately 0.75 inches (19 mm) was observed at approximately the 2 inch (51 mm) depth. Cracking occurred through the mortar and the 0.75 inch (19 mm) minus limestone aggregate and around the larger quartzite aggregate. This core was not drilled to the bottom of the pavement. There was rubble to a depth of about 7 inches (178 mm).

Core 2 - This core is probably the most interesting of the set. It is 9 inches (229 mm) long with one small piece missing from the bottom. Again there is a definite horizontal cracking pattern starting at about the 2 inch (51 mm) depth and continuing to within 1 inch (25 mm) of the bottom. Cracking again occurred through the mortar and the 0.75 inch (19 mm) minus limestone aggregate and around the larger quartzite aggregate. The cracking pattern is only on the side of the core (120 degrees) near the joint, the other side has no cracking. The cracks are randomly spaced from 0.25 - 1.5 inches (6.3 - 38 mm). Steel for the dowel bar basket was encountered at a depth of 5.0 inches (127 mm).

Core 3 - This core was taken to full depth. Two pieces were removed intact, one from the bottom and one from the top, each varying in thickness from 1.25 - 3.25 inches (32 - 83 mm). The remaining 4.5 inch (114 mm) center portion came out of the hole as rubble. Cracking again occurred through the mortar and the 0.75 inch (19 mm) minus limestone aggregate and around the larger quartzite aggregate. Steel for the dowel bar basket was encountered.

Core 4 - The entire 9 inch (229 mm) core length was recovered from the pavement. This core was similar in appearance to Core 2 except the cracking was much more severe. Here, the core is broken in two pieces in an almost horizontal plane at the 4.5 inch (114 mm) depth. The cracks are wider and some material is missing but the pattern is similar to Core 2. The cracks almost extend around the circumference of the core (270 degrees). Cracking again occurred through the mortar and the 0.75 inch (19 mm) minus limestone aggregate and around the larger quartzite aggregate.

Core 5 - This core was taken at a mid-panel crack that had been filled with HMW methacrylate. Steel reinforcing mesh was encountered at a depth of 3.0 inches (76 mm). The midpanel crack was the only crack in the core. This crack extended vertically down to the steel where the crack width appeared to narrow and then disappeared in the next 2 inches (51 mm). Cracking again occurred through the mortar and the 0.75 inch (19 mm) minus limestone aggregate and around the larger quartzite aggregate.
Each core was also examined for the presence of alkali-silica reactivity (ASR) by the technique developed by SHRP and contained in the Handbook for the Identification of Alkali-Silica Reactivity in Highway Structures, SHRP-C/FR-91-101. By applying a uranyl acetate solution to a surface containing ASR gel, the uranyl ion substitutes for alkali in the gel. When exposed in the dark using short wavelength (254 nanometer) ultraviolet light, a characteristic yellowish-green glow results. ASR gel fluoresces much more brightly than cement paste due to the greater concentration of alkali.

This technique also led to a method for determining the depth of HMW methacrylate penetration into the crack. It is very difficult to determine the crack penetration of HMW methacrylate from visual inspection. Even when the core was split at the crack it was difficult to see how far the material had penetrated. However, when uranyl acetate was applied to the crack face and exposed to the UV light the depth of penetration could be seen. The HMW methacrylate acted as a barrier to the reaction between the uranyl acetate and the alkali throughout the entire concrete matrix resulting in a dark area with very little fluorescence. Areas where dirt and grime have built up were found to react in the same way. Care must be taken to distinguish between the two. Surfaces such as these must be cleaned with tap water to insure the removal of any grime build-up.

Each core was broken open at the crack using a hammer and a chisel. Uranyl acetate was applied to both exposed crack faces and the circumference of the core. The following observations were made on each of the cores:

Core 1 - ASR gel was located on the surface of the larger voids, at two small aggregates, and along the surface of several of the larger quartzite aggregates. HMW methacrylate penetration varied with maximum penetration at about 1.5 inches (38 mm). The cracks in the core do not appear to be related to the occurrence of the ASR gel.

Core 2 - Again the ASR gel was located on the surface of the larger voids, at a few small aggregates and around some of the larger quartzite aggregates. HMW methacrylate penetration varied to a maximum penetration of 2 inches (51 mm). Under indoor lighting the HMW methacrylate appeared to have a slightly yellow hue. The cracks in the core do not appear to be related to the occurrence of the ASR gel.

Core 3 - ASR gel was limited to the surface of a few of the quartzite aggregates. Penetration of the HMW methacrylate varied from 0 to 2 inches (51 mm). Again, the cracks in the core do not appear to be related to the occurrence of the ASR gel.
Core 4 - ASR gel was located on two small aggregates, on a large sandstone aggregate, and on the surface of the large voids. Penetration of the HMW methacrylate varied from 0 to 1.5 inches (38 mm). The cracks in the core do not appear to be related to the occurrence of the ASR gel.

Core 5 - Uranyl acetate was applied to the surface of two sections sawn from the core. ASR gel was located on the surface of some of the large quartzite aggregates. Penetration of the HMW methacrylate extended to a depth of 3 inches (76 mm), to within 0.25 inches (6 mm) of the wire mesh reinforcing. The crack in the core is not related to the occurrence of the ASR gel.

The results of the coring indicate that the depth of penetration of the HMW methacrylates varied from 0 to 3 inches (76 mm). This may have been due to the small size of the cracks and/or the presence of various precipitates within the cracks. The coring also revealed the varying conditions of the pavement beneath the surface. Similar looking surface distress did not always reflect in the condition of the core throughout its depth. This may have had an effect on the relative performance of the test sections.

The cracking pattern observed in these cores was not the same as other D-cracked concrete pavements. Typically, D-cracked pavements crack from the bottom up. Cores 2, 3, and 4, all had more cracking in the center of the core.

CONCLUSIONS

This study attempted to measure the ability of silanes and HMW methacrylates to extend the service life of known D-cracking pavements. Several different manufacturer's products were used to determine if there would be any difference in performance. Based on the data collected to date, the following conclusions are made:

1. The effectiveness of silanes in extending the service life of D-cracked pavements is very questionable. They appeared to do the most good in the sections that had the least D-cracking. Silanes performed similar or worse than the control in the sections with more advanced D-cracking.

2. HMW Methacrylates appear to be effective in holding a D-cracked pavement together in certain cases. The section with the most advanced D-cracking before placement of the HMW methacrylates had a 40% reduction in high and severe cracking over the 22 months. It is important for the cracks to be wide enough for the HMW methacrylate to penetrate and "glue" the concrete back
together. Our core examinations indicate that HMW methacrylate crack penetration varied from 0 to 3 inches (76 mm). Core results also indicate that performance may be related more to the original condition of the pavement than the effectiveness of the HMW methacrylate.

3. The effectiveness of the HMW methacrylate appears to last about 18 months. There is a sharp increase in high and severe cracking at this time. Reapplication of the product at that time may extend the service life another 18 months. Traffic levels must be considered when using this product. Higher traffic levels may reduce the effective time period.

4. The Transpo T70X and 3M 4R Concrete Restorer HMW methacrylate products appear to provide the best performance. These products were clearly superior in performance to the Sika product when the HMW methacrylates were most effective (Figure 13). In addition, they were less costly with the Transpo T70X at less than 50% the cost of the Sika.

5. HMW Methacrylates should only be applied near the joints and cracks. It is critical that the cracks are wide enough for the material to penetrate. There appears to be no benefit to applying the product over the entire surface.

6. If a minimum lane closure is desired both materials should be placed when both the air temperature and the slab temperature is approximately 70° F (21° C). The materials will cure much faster under these conditions.

FURTHER STUDIES

The Physical Research Section of Mn/DOT's Materials Research and Engineering Office will continue to monitor these test sections as long as they can for any additional performance information that can be gathered. An attempt to re-apply the HMW methacrylates should be made as soon as possible to see if that technique will provide additional service life to the pavement. We also would like to try new promising products such as Transpo T70-M HMW methacrylate. Silanes may give us some long-term benefit not apparent at this time, but from results to date it appears that the D-cracking mechanism will not be effected by this surface treatment.
Appendix A

Test Section Layout
**Figure 1 - I-90 Eastbound - HMW Methacrylate Test Sections**

<table>
<thead>
<tr>
<th>Transpo</th>
<th>3M</th>
<th>Sika</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Diagram" /></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Application**

RP 47.6 — Distressed areas only ———> RP 48.0

RP 58.9 — All transverse cracks and joints ———> RP 59.3

RP 81.6 — Entire first four panels then all joints and cracks ———> RP 82.0

All sections D-cracked, higher RP, poorer condition of section.

**Figure 2 - I-90 Eastbound - Silane Test Sections**

<table>
<thead>
<tr>
<th>Sil-act</th>
<th>Sil-act</th>
<th>Fosroc</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATS-42</td>
<td>Water Base</td>
<td>Enviroseal</td>
<td>Dekguard P-40</td>
</tr>
<tr>
<td><img src="image2.png" alt="Diagram" /></td>
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<td></td>
<td></td>
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</tbody>
</table>

**Application**

RP 66.4 — Entire driving lane ———> RP 67.0

RP 78.6 — Entire driving lane ———> RP 79.3

RP 83.5 — Entire driving lane ———> RP 84.1

Higher RP poorer original condition
All sections in early stages of D-cracking, some staining apparent.
Appendix B

Silane Performance
Figure 3 - Silane Test Sections

I-90 Eastbound
RP 66.4 - 67.0

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sil-act ATS-42</td>
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</tr>
<tr>
<td>Sil-act Water Base</td>
<td></td>
</tr>
<tr>
<td>Enviroseal</td>
<td></td>
</tr>
<tr>
<td>Fosroc Dekguard P-40</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- Low
- Medium
- High & Severe

Condition as of August 12, 1993
Figure 4 - Silane Test Sections

I-90 Eastbound
RP 66.4 - 67.0

Percent High & Severe Cracking

Months from Application

Sill-act ATS-42

Sill-act Water Base

Enviroseal

Fosroc Dekguard P-40

Control
Figure 5 - Silane Test Sections
I-90 Eastbound
RP 78.6 - 79.3

Material

Sil-act ATS-42
Sil-act Water Base
Enviroseal
Fosroc Dekguard P-40
Control

Percent Cracking

Low  Medium  High & Severe

Condition as of August 12, 1993
Figure 6 - Silane Test Sections
I-90 Eastbound
RP 78.6 - 79.3

Percent High & Severe Cracking

Months from Application

Sil-act ATS-42  Sil-act Water Base  Enviroseal

Fosroc Dekguard P-40  Control
Figure 7 - Silane Test Sections
I-90 Eastbound
RP 83.5 - 84.1

Material

Sil-act ATS-42

Sil-act Water Base

Enviroseal

Fosroc Dekguard P-40

Control

Percent Cracking

Low  Medium  High & Severe

Condition as of August 12, 1993

B - 5
Figure 8 - Silane Test Sections

I-90 Eastbound
RP 83.5 - 84.1

Percent High & Severe Cracking

Months from Application

Sill-act ATS-42  Sill-act Water Base  Enviroseal

Fosroc Dekguard P-40  Control
Figure 9 - Silane Test Sections

I-90 Eastbound
Average

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sil-act ATS-42</td>
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</tr>
<tr>
<td>Sil-act Water Base</td>
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<tr>
<td>Enviroseal</td>
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</tr>
<tr>
<td>Fosroc Dekguard P-40</td>
<td></td>
</tr>
<tr>
<td>Control</td>
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</tr>
</tbody>
</table>

Low | Medium | High & Severe

Condition as of August 12, 1993
Appendix C

HMW Methacrylate Performance
Figure 10 - HMW Methacrylate Test Sections

I-90 Eastbound
RP 47.6 - 48.0

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent Cracking</th>
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</thead>
<tbody>
<tr>
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<tr>
<td>Sika</td>
<td>95</td>
</tr>
<tr>
<td>Control</td>
<td>100</td>
</tr>
</tbody>
</table>

Condition as of August 12, 1993

C - 1
Figure 11 - HMW Methacrylate Test Sections

I-90 Eastbound
RP 47.6 - 48.0

Percent High & Severe Cracking

Months from Application

Transpo 3M Sika Control

C-2
Figure 12 - HMW Methacrylate Test Sections
I-90 Eastbound
RP 58.9 - 59.3

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Percent Cracking</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transpo</td>
<td></td>
</tr>
<tr>
<td>3M</td>
<td></td>
</tr>
<tr>
<td>Sika</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td></td>
</tr>
</tbody>
</table>

Percent Cracking

- Low
- Medium
- High & Severe

Condition as of August 12, 1993
Figure 13 - HMW Methacrylate Test Sections
I-90 Eastbound
RP 58.9 - 59.3

Percent High & Severe Cracking

Months from Application

Transpo  3M   Slka  Control

C - 4
Figure 14 - HMW Methacrylate Test Sections
I-90 Eastbound
RP 81.6 - 82.0

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Condition as of August 12, 1993</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transpo</td>
<td>Low (0-20%), Medium (20-60%), High (60-100%)</td>
</tr>
<tr>
<td>3M</td>
<td>Low (0-20%), Medium (20-60%), High (60-100%)</td>
</tr>
<tr>
<td>Sika</td>
<td>Low (0-20%), Medium (20-60%), High (60-100%)</td>
</tr>
<tr>
<td>Control</td>
<td>Low (0-20%), Medium (20-60%), High (60-100%)</td>
</tr>
</tbody>
</table>
Figure 15 - HMW Methacrylate Test Sections
I-90 Eastbound
RP 81.6 - 82.0

Percent High & Severe Cracking

Months from Application

Transpo 3M Sika Control

C - 6
Figure 16 - HMW Methacrylate Test Sections
I-90 Eastbound
Average

Material

<table>
<thead>
<tr>
<th>Material</th>
<th>Low</th>
<th>Medium</th>
<th>High &amp; Severe</th>
</tr>
</thead>
<tbody>
<tr>
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<td></td>
</tr>
<tr>
<td>Control</td>
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</tbody>
</table>

Percent Cracking

Condition as of August 12, 1993

C - 7