Colored Concrete Study

Research Need
Colored concrete can provide many benefits to pavement, such as improved aesthetics and safety. However, several recently constructed colored concrete pavements in Minnesota have experienced a considerable amount of early joint deterioration. Determining the cause for such deterioration is difficult, as there is very little knowledge in the literature on the performance of the material, especially in relation to its durability. Many different techniques have been used for obtaining colored concrete, such as granular pigments, acid dyes and stains, and dry shake powders. The various materials used to add color are all expected to influence the material properties of concrete differently.

While it is possible that the joint deterioration of colored concrete pavements is due to the material durability issues, it may also be a result of the construction practices used to produce, place and finish colored concrete. Colored concrete pavements are commonly used in crosswalks and small projects where extensive hand finishing is required. Due to the increasing use of colored concrete in city and county intersections, it is important that a comprehensive evaluation of its production and construction be done to reduce and eliminate future problems. Additionally, since there are several locations where issues already exist, there is an urgent need to identify low cost repair and/or rehabilitation solutions for these pavements.

Objective
The goal of this project will be to determine if the observed deterioration of colored pavements in Minnesota is a result of the material behavior associated with coloring agents, or of common construction practices associated with colored concrete pavements.

Research Method
This study will consist of four major tasks. The first task will be to visit existing colored concrete projects to document performance and gather any existing documentation on construction or materials. The second task will be to visit construction sites of new colored concrete projects and evaluate the construction practices being used. Next, an in-depth, detailed petrographic analysis will be done on cores collected from deteriorated colored concrete pavements. Finally, a laboratory study will include, but will not be limited to, scanning electron microscopy (SEM) of cores, trial batching and mechanical testing of different coloring agents, modified freeze thaw and scaling resistance testing. During these tasks, suitable techniques for the repair and rehabilitation of colored concrete pavements will be investigated. A final report will provide recommendations for future specifications or guidelines that will help ensure the construction of more durable colored concrete pavement.

Site Visits

Deteriorated Joints at Intersection: Centerville, MN
New Crosswalk Construction: Blaine, MN

Deteriorated Joint: Vadnais Heights, MN

**New Construction Observation and Sampling**

Three separate site visits were made to the construction of new colored concrete pavements. Forest Lake was visited twice for observation and sampling at two different colored concrete crosswalks. At both of these projects, the concrete was placed without consolidation, leveled with lumber, and hand troweled joints were formed. Additional color hardener (powder) was hand sprinkled to coat the surface. The surface was finished with multiple passes of steel trowels and floats while continually spraying the surface with a water-based compound. After finishing, the concrete was thickly coated with a Colorwax sealer, which was used as the curing method. Specimens were made at the second visit (Round 2) to be tested for flexural and compressive strength. Strengths seemed to be consistent with typical concrete pavement.

Next, a visit was made to the construction of a colored concrete median in Blaine. The first truckload of concrete (Mix 1) for this project was rejected for low air content, however samples were still made for comparison. The concrete was adjusted at the plant and the second truckload (Mix 2) achieved adequate air content. The concrete in this project was placed and consolidated with a vibrating roller screed, the edges were finished with steel trowels and the surface leveled with large floats and transverse joints were hand troweled. The surface was finished with a broom texture. No additional color or curing method was applied. Plastic concrete test results from all the colored concrete projects are shown below.

<table>
<thead>
<tr>
<th></th>
<th>Slump</th>
<th>Air</th>
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<tbody>
<tr>
<td>Forest Lake Round 1</td>
<td>0.5 in</td>
<td>5.0%</td>
</tr>
<tr>
<td>Forest Lake Round 2</td>
<td>3.0 in</td>
<td>6.6%</td>
</tr>
<tr>
<td>Blaine Mix 1</td>
<td>2.25 in</td>
<td>4.1%</td>
</tr>
<tr>
<td>Blaine Mix 2</td>
<td>3.75 in</td>
<td>6.2%</td>
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**Petrographic Analysis**

Multiple cores were taken from the following four different colored concrete pavement projects experiencing varying degrees of distress: TH 14 in Centerville, TH 96 in Vadnais Heights, Lake Johanna Blvd in Arden Hills, and Larpentuer Ave and Fernwood in Roseville. These cores were analyzed according to ASTM standard C856 “Petrographic Analysis of Hardened Concrete.” This test was done to describe the basic...
physical characteristics of the air-void system, effects of finishing and curing on the top/outer surfaces of the concrete, estimation of the water to cement ratio, signs of chemical attack, and many other important properties.

**Air Void Results**

Surprisingly, almost all the cores had an adequate original air void system to be considered freeze-thaw durable. There was no significant noted loss of air at the surface, which suggests that it was not over finishing or poor construction practices that were causing the early joint deterioration.

**Secondary Ettringite**

The colored concrete used in all four projects was experienced in-filling of the entrained air void system by ettringite. This phenomenon is most likely what is causing the concrete to behave as freeze-thaw susceptible at the joints when saturated. The large amounts of secondary ettringite is visible in almost all the fine air voids within several millimeters of the distressed joints, essentially causing the air void system to be ineffective for freeze-thaw purposes. Ettringite is found in all Portland cement concretes. However, secondary ettringite, as is visible in the colored concrete samples, is significant as it occurs after the initial hydration process of the concrete. The cause for this infilling is likely from saturation of the concrete paste by deicers. However, other possible sources of sulfate required for this ettringite formation may be the surrounding soils and sodium chloride minerals. As poor joint drainage permits an increased supply of deicer solution into the joints, the deterioration in these areas will likely continue.

**Alkali Silica Reaction**

Two midpanel cores from the Larpentur Ave and Fernwood intersection and two cores at the joints in the Lake Johanna crosswalk exhibited microcracking which is characteristic of alkali silica reaction (ASR) of the coarse and fine aggregates. The aggregates used in these projects however, are commonly used in Minnesota pavements and have proved unsusceptible to alkali-silica reaction under many different exposure conditions. A major sub-horizontal macrocrack in one core was most likely induced by structural or freeze-thaw forces in the ASR distressed zone. In addition, these cores contained ASR gel product, which lines or fills much of the microcracking and adjacent or intersecting voids. The cause of this deleterious behavior in previously sound aggregates is unknown, but of much interest. Further analysis will be done to determine if this may in any way be attributed to the colored pigments, or if it is a result of the other concrete materials.
ASR Microcracking through Aggregate

**Water to Cement Ratio**

The water-to-cement ratio (w/cm) from the cores tested ranged from 0.42 to 0.50. The w/cm ratios for most of the projects (with the exception being the Larpenteur and Fernwood project) are considered to be excessive for durable concrete pavements. TH 14 in Centerville has the highest w/cm, with an estimated maximum reaching 0.50. Higher w/cm in concrete leads to excessive porosity of the paste, which increases ingress of moisture and brines and susceptibility to freeze-thaw and chemical attack.

**Salts and Deicers**

One of the main causes of distress in these pavements may have been the use of salts and deicers. Cores taken from both Hwy 96 and the Larpenteur and Fernwood intersection display distress which is consistent with a chemical attack. More specifically, there is a chemical alteration of the paste that has been exposed within the joint, which is likely due to deicers other than sodium chloride. This altered paste is visibly lighter in color, which is also noted to be significantly softer than normal. Some of this altered paste is carbonated and some is free of calcium hydroxide. Besides the calcium carbonate, an innocuous mineral, the paste does not contain any secondary minerals. These samples will require further analysis to determine the chemical composition of this material.

**General Deterioration**

Other notable observations made during the petrographic analysis were as follows:

- There was a poor (weak) aggregate to paste bond in many of the cores tested. It was noted that it is common to find that pigmented, higher w/cm paste has issues bonding to rounded dense gravel particles.
- Despite construction methods lacking internal vibration, the concrete was noted to be fairly well consolidated in most cases. Small consolidation voids were present in only about half of the samples tested.
- Other types of distress present in the cores included corner spalling, sliver and incipient spalling near the surface, and drying shrinkage.

**Conclusions**

Based on the petrographic analysis, it does not appear that placement techniques or finishing practices associated with colored concrete are the direct cause of the early deterioration in these pavements. The excessive secondary ettringite, chemically altered paste, and alkali-silica reaction present in the cores suggest the deterioration may be material related. Further laboratory analyses have been recently completed, and the final project report is expected to be available by Spring 2014.

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