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ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

ACI WEB SESSIONS

Photocatalytic Concrete Field Trial Along Ontario's Freeways

Ministry of Transportation Ontario

by

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Senior Concrete Engineer, MTO

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Prepared by:
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Photocatalytic Concrete

- Concrete that contains titanium dioxide (TiO_2)
  - Sunlight accelerates natural oxidation to decompose air pollutants
- TiO_2: non-toxic, abundant, chemically stable, semiconductor
  - Used in cosmetics, food products, toothpaste & skim milk
  - Used in anti-fog, anti-bacterial, self-cleaning products and water treatment since early 70's
- Researchers have reported a wide range of NO_x degradation rates from 50 to 350 mg/day/m2
- Photocatalytic concrete the area of a soccer field has the capability to remove emissions equivalent to approx 190,000 car-km/yr (60 mg/day/m2 NO_x)
- Potential to reduce other airborne pollutants such as SO_2, particulate matter (PM10, PM2.5) in addition to NO_x

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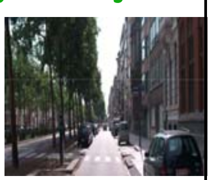
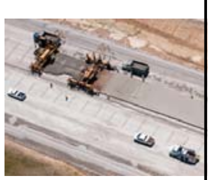
Notable Photocatalytic Projects

Miseracordia (Jubilee) Church, Rome Italy (2003)



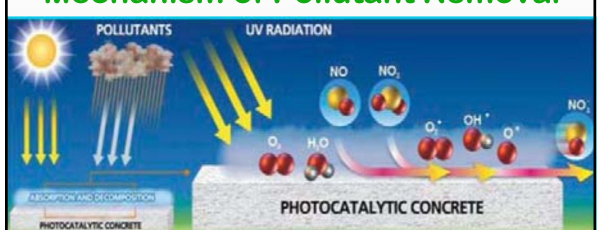
Paving Block Antwerp Belgium (2005)

Umberto Tunnel, Italy (2007)



Hwy 141 St. Louis Missouri (2011)

Mechanism of Pollutant Removal



1) $NO + OH + uv \rightarrow\rightarrow NO_2 + H^+$
2) $NO_2 + OH + uv \rightarrow\rightarrow N0_3 + H^+$
3) $HNO_3 + CaCO_3 \longleftrightarrow CA(NO_3)^2 + H2O + CO_2$

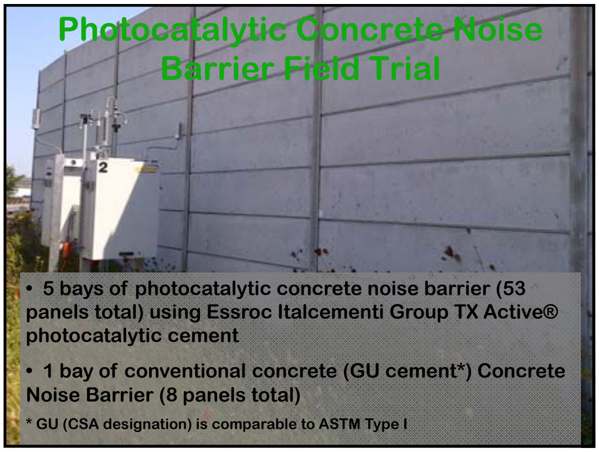
MTO Objectives

- The greenest roads in North America
- Assess photocatalytic concrete material properties
  - Academic partner: University of Toronto
- Work in partnership with environmental arm of Ontario government to identify air quality improvements as a result of use of photocatalytic concrete in a noise barrier installation
- Assess viability of larger-scale field installation

Photocatalytic Noise Barrier Field Trial

- Part of a short noise barrier replacement project
- One of North America's busiest highways--450,000 AADT

Photocatalytic Concrete Noise Barrier Field Trial



- 5 bays of photocatalytic concrete noise barrier (53 panels total) using Essroc Italcementi Group TX Active® photocatalytic cement
- 1 bay of conventional concrete (GU cement*) Concrete Noise Barrier (8 panels total)

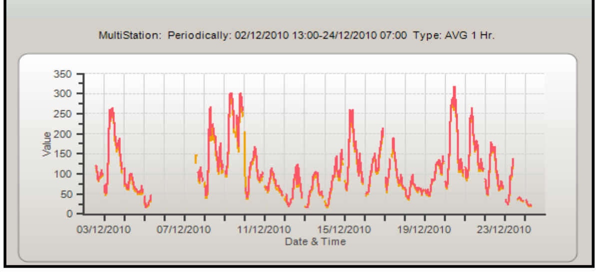
* GU (CSA designation) is comparable to ASTM Type I

Air Monitoring Protocol for Field Trial

- Two-year NO_x field air quality monitoring using Airpointer® units
  - Four to six 3-week sampling campaigns
- Incorporate cement supplier guidelines for measuring NO_x
- Two units monitor air quality simultaneously;
  - One unit in close proximity to the wall,
  - Other unit two metres from the wall outside side zone of influence of the photocatalytic process.
- Difference in NO_x readings indicates impact of photocatalytic process

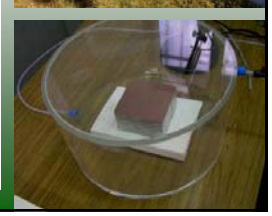
Background Air Monitoring (Control)

- Portable air monitoring systems targeting NO, NO_2, NO_x;
- Maximum observed NO_x 300 ppb
- Unit 1 (orange) fixed 0.1m from barrier wall
- Unit 2(red) sample location varied to identify sensor location bias (2m, 1m, 0.1 m)

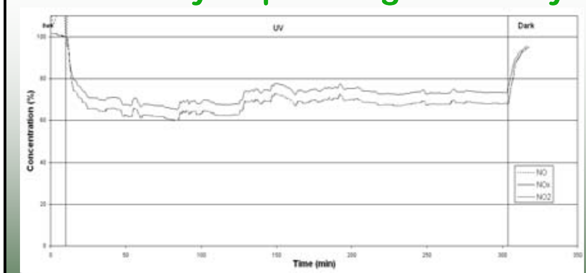


Concrete Noise Barrier Panels

- Propriety concrete noise barriers panels manufactured by Durisol (Armtec) Mitchell Ontario
- Normal Portland Cement (GU) and TX Active® Photocatalytic Cement supplied by Essroc (Italcementi Group) Front Royal West Virginia Plant
- Noise barrier samples tested for photocatalytic depolluting efficiency by cement supplier
  - Flow-through test (continuous) UNI 11247-2010 (CEN draft standard) and
  - Recirculation test (draft UNI standard)



Laboratory Depolluting Efficiency



Continuous flow test (Axim laboratory – USA)

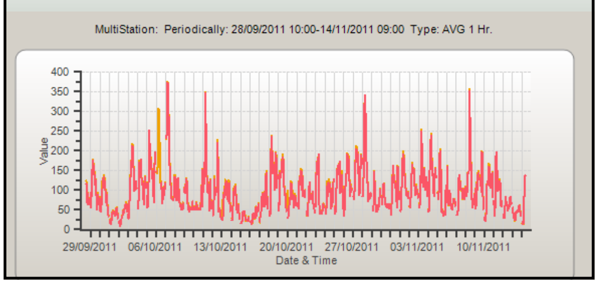
- Achieved approx. 25% NO_x reduction

Field Air Quality Monitoring

- Air quality monitoring conducted Oct/Nov 2011 & June 2012

Field Air Quality Monitoring

- Unit 1(orange) sample location varied (2m, 1m, 0.1m)
- Unit 2 (red) fixed 0.1 m from barrier wall; Max ~400 ppb NO_x
- To date, no significant difference in periodic and overall NO_x concentrations have been identified (Oct 11, June 12 trials)



Discussions – Air Monitoring

- Sensors recorded constant wind presence parallel to wall (200° to 230°) possibly traffic induced
  - In comparison the wind speed of continuous flow rate (3 L/min) of laboratory test is (0.7 km/hr
- Less sun than expected
- Lower than expected background NO_x concentrations
- Research indicates contact time, wind direction, light intensity, high relative humidity are significance factors in effectiveness of photocatalytic mechanism
  - (e.g. $NO \rightarrow NO_2 \rightarrow N0_3 \rightarrow Ca(NO_3)^2$)
- Self-cleaning & field durability to be assessed after a significant exposure period

Other Methods for Measuring Field Depolluting Efficiency

- On site test box (Beeldens, Belgian Road Research Centre)
  - UV-transparent lid
  - NO-concentration
  - Controlled relative humidity & air flow
- Nitrate collection
  - Nitrates generated from photocatalytic reaction washed off panels (mg/l)
  - Analyzed by spectrophotometry and by ion chromatography

Conclusions – Air Monitoring

- Interim results; unable to detect air quality improvement (NO_x reduction) in the vicinity of the photocatalytic concrete barrier

- Orientation, wall geometry, distance from NO_x source, total exposed surface area, contact time and surface texture have impacted the effectiveness of the photocatalytic process or its measurement
  - E.g. A ribbed photocatalytic barrier wall may be more effective

- Changes to the air monitoring procedures may increase ability to detect air quality improvement

Proposed Revisions to Air Monitoring

- Monitor air quality on back of wall
  - Sunny side – greater light intensity
  - No traffic-induced wind
- Install baffles
  - Increase contact time
- Move sampling port as close as possible to wall (0.05 m)

Laboratory Assessment of Photocatalytic Concrete (University of Toronto)

- Research being carried out under MTO Highway Infrastructure Innovation Funding Program (HIIFP)
- Compared mechanical, transport and durability properties of four concrete mixes:
  - 100 % "General Use" (GU)* cement
  - GU cement with 25% ground granulated blast furnace slag (GGBFS)
  - 100% Photocatalytic (PH) Cement
  - PH cement with 25% GGBFS
- Batching parameters
  - Total cementitious materials 430 kg/m3
  - 0.42 fixed water cementitious ratio
  - Air entraining admixture adjusted to achieve air in plastic concrete between 5.5% and 7.0%
  - No other admixtures used to reduce risk of interaction with the photocatalytic mechanism

* GU (CSA designation) is comparable to ASTM Type I

Interim Results of Laboratory Study

Test Method	GU	GU 25S	PH	PH25S
28-day Compressive Strength (normalized)	1.0	+3%	-5%	-1%
Slump at 0.43 w/cm (mm)	210	160	70	75
Air Plastic Concrete (%)	6.8%	5.7%	5.6%	5.6%
Air in Hardened Concrete (%)	6.5%	5.1%	5.2%	5.3%
Air Spacing Factor (mm)	0.13	0.14	0.16	0.15

Interim Results of Laboratory Study

Property Test Method	GU	GU25S	PH	PH25S
Ultrasonic Pulse Velocity (m/s)	4700 ----- 4900			
Initial Sorptivity @ 56 days (mm/sec$^{1/2}$) ASTM C1585	14 ----- 18 x10^{-4}			
Durability Factor (%) ASTM C666	97%	96%	96%	92%
Rapid Chloride Permeability @ 28 days (Coulombs) ASTM C1202	3900	1700	3900	1800
Resistance to Salt Scaling finished surface (kg/m^2) MTO LS-312	0.2	0.3	2.0	2.6

Interim Conclusions – Laboratory Study

- Physical properties of photocatalytic concrete appear comparable to conventional concrete with some exceptions:
  - Higher water demand for same slump
  - Higher air entraining admixture dosages for same air content
  - Requires admixture to be checked for compatibility with photocatalytic cement
  - May be more susceptible to salt scaling but freeze-thaw resistance appears comparable
- Investigate suitability of high range water reducer (HRWR) for photocatalytic concrete
  - Comparison of HRWR modified PH mixes is underway

Interim Overview

- Field air quality monitoring showed no reduction in NO_x but measurement and methods may not have been optimum
  - Changes proposed for next field air quality monitoring campaign
  - Investigating other methods for measuring the effectiveness photocatalytic concrete installation
- Plastic and hardened concrete properties are comparable
  - Potential sensitivity to scaling is being investigated further

Acknowledgement

<u>Project Partners</u>

University of Toronto

Ministry of the Environment

Durisol (Armtec)

Essroc Italcementi

Additional Information

MTO MERO

Materials Engineering and Research Office

Thank You!