Highway 3 – Next Generation Concrete Pavement

Principal Author:
Tim Smith MSc. Eng., P. Eng.
Senior Technical Director Infrastructure and Specifications
1105-350 Spark Street, Ottawa, Ontario, K1R 7S8
Tel. (613-882-6415)
E-mail: tsmith@cement.ca

Co-Authors:
Alen Keri, P. Eng.
Director of Technical Services
Concrete Ontario
1 Prologis Boulevard, Suite 102B, Mississauga ON, L5W 0G2
Tel. (905-564-4772)
E-mail: akeri@concreteontario.org

Lucas Bromerchenkel, M.A.Sc..
Technical Services Representative
Concrete Ontario
1 Prologis Boulevard, Suite 102B, Mississauga ON, L5W 0G2
Tel. (905-564-4772)
E-mail: lbromerchenkel@concreteontario.org

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Abstract

This paper presents a case study on a concrete pavement constructed in 2023 on Highway 3 in the Windsor Essex area of Ontario. The background section provides detailed information about this Design Build project. It then explores the new concrete durability requirements introduced by the Ministry of Transportation of Ontario (MTO) aimed at enhancing the performance of concrete pavement. These requirements include specifications on concrete strength, air voids, rapid chloride permeability (RCP), increased slag content in the mix design, and a new single saw cut for transverse joints.

Subsequently, the paper examines the specification's smoothness requirements and provides actual smoothness values obtained by the contractor through diamond grinding the concrete surface. The discussion then shifts to pavement noise, comparing the noise levels of the newly specified longitudinally grooved concrete textures with those of two asphalt control sections (SuperPave 12.5 FC 2 and SMA 12.5) and other concrete texture types.

Further discussions focus on safety and how the new aggregate requirement for 60% acid insoluble residue will improve long-term skid resistance of the concrete pavement. The paper concludes by looking at the sustainability of concrete pavement including the actual CO_2 footprint of the placed concrete compared to the Ontario industry average baseline global warming potential for a 35 MPa concrete mix with air entrainment. Other sustainable benefits of using concrete pavement such as improved fuel consumption, improved light reflectance and its role as a carbon sink are also briefly discussed.

1.0 Introduction

Concrete pavement is known for its strength, long-term durability, and minimal maintenance. Two areas where concrete pavement has not been traditionally known for top performance are pavement noise level and initial construction smoothness. Advancements in slipform paver technology and use of diamond grinding techniques have substantially improved the initial smoothness of concrete pavement, making it comparable to, or even better than, asphalt pavement. Traditional transversely tined concrete pavements are noisier than asphalt pavement especially if the tining is too deep. However, new longitudinal grooving and tining textures have improved the noise level on concrete pavement, placing concrete at the forefront of new-generation pavement.

In 2010, Larry Schofield [1] conducted a survey in Ontario to measure On-Board Sound Intensity (OBSI) noise levels on concrete and asphalt pavements with distinct types of surface texture to compare noise levels. The study revealed that the Superpave section was the quietest with a 103 dBA, closely followed by the longitudinally tined concrete pavement at 103.2 dBA. The SMA pavement surface was the next quietest at 104 dBA followed by the FHWA random transverse tined section at 104.4 dBA and the standard transversed tined section at 105.8 dBA. These findings confirm longitudinal tined concrete pavements are much quieter than transverse tined pavements and have noise levels comparable to asphalt.

Initial smoothness and roughness progression over time are crucial for the long-term durability of highway pavements. The Nova Scotia Department of Transportation and Public Works conducted a study to compare the performance of the adjoining asphalt, and concrete pavements constructed in the same year. The results of the study showed although the concrete was constructed slightly rougher than the asphalt pavement, over a 5-year period the roughness progression on the asphalt was much steeper than the adjoining concrete pavement section. [2] More information is provided in the body of the report on this study.

This paper will provide a case study on a concrete pavement constructed in 2023 on Highway 3 in the Windsor Essex area of Ontario. Project details will be provided with a focus on the strength and durability requirements for the project and smoothness obtained during construction. Other key topics to be discussed are the noise level and safety considerations from specifying longitudinally grooved concrete. Some additional sustainable benefits of using concrete pavement will also be presented.

2.0 Background

This paper reviews a 7.9 kilometre 2-lane section of concrete pavement constructed in 2023 on Highway 3 in the Windsor Essex area of Ontario. The project was a Ministry of Transportation of Ontario (MTO) Design Build project. The contractor constructing the concrete pavement was Green Infrastructure Partners (GIP) and the designer for the pavement was Golder Associates (now WSP). Figure 1 below is an aerial view of the concrete pavement before opening to traffic.

Figure 1: Aerial view of Concrete Pavement Section on Highway 3.

Listed below are some additional project details obtained from MTO:

- Pavement Width: 3.75 m / lane
- Pavement Type: Jointed plain concrete pavement with dowels
- Shoulders: Asphalt pavement
- Pavement Structure
  240 mm Thick concrete pavement with 32 mm dowels
  100 mm OGDL (asphalt based)
  300 mm Granular A Base
  (Note: The project's geotechnical report did not provide the design inputs for the pavement thickness design, so no comments are made on the thickness design for this project.)
- Extended concrete pavement 0.5 m into outside shoulders to eliminate edge load conditions on main travelling lane.

- Traffic Level: approximately 2,500 AADTT
- Soil Type: Layers of fill, silty sand and silty clay to clayey silt

3.0 Durability and Jointing Requirements

The minimum strength and durability requirements necessary to provide long lasting and durable concrete pavements are specified in Standards Council of Canda [3] CSA A23.1:19. Table 1 in CSA A23.1:24 states concrete pavements are a Class C-2 exposure condition. Table 2 of the document states the following minimum requirements to provide quality and durable concrete pavement are as follows:

- 0.45 maximum water to cementitious materials ratio
- 32 MPa minimum specified compressive strength at 28-days
- Air category 1 for exposure to cycles of freeze / thaw
- No requirement for chloride ion penetrability

The Ministry of Transportation of Ontario OPSS.PROV 350 [4], released in July 2023 sets concrete pavement durability requirements that exceed the above stated CSA requirements. The new MTO specification states the following requirements for concrete pavement:

- 35 MPa minimum compressive strength at 28-days
- 3% or more air void system in hardened concrete with a spacing factor of 0.230 mm or less
- 2,500 (max.) coulombs permeability
- 60% acid insoluble residue requirement for concrete aggregates to improve the long-term durability of the concrete pavement’s skid resistance.
- Maximum 30% slag in the concrete mix design

The new requirement that fine aggregates contain a 60% acid insoluble residue will help maintain the long-term skid resistance of concrete pavements, thereby enhancing the safety of the traveling public. If it becomes necessary to improve friction later in the pavement's lifespan, diamond grinding can be performed to restore the pavement's friction value.

To address joint deterioration in provincially owned concrete pavements, MTO has also changed their jointing requirements, eliminating the use of a widened reservoir cut and backer rod on new projects. Figure 2 below is an excerpt from MTOD 508.020 [5] showing the new single saw cut dimension requirements for transverse joints. At the recent Concrete Ontario and Cement Association of Canada Pavement Seminar held in Mississauga on February 21, 2024, contractors noted that the 6 mm initial saw cut width for transverse joints makes it very difficult to fill the joint with joint sealant. They suggested a 9 mm saw cut would be more effective for speed of placement and the ability to get the hot pour asphalt into the bottom of the joint. This recommendation will be looked at by MTO staff, who will decide on its possible adoption in the future.

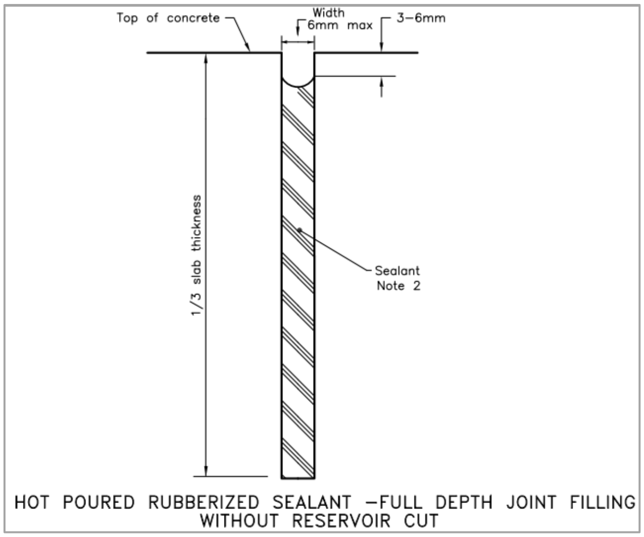


Figure 2: Excerpt from MTOD 508.020 Showing Single Saw Cut Dimension Details.

MTOD 508.020 [5] notes the following about the joint sealant requirements:

- Joint shall be filled to the bottom of the sawcut with sealant.
- shall be hot poured rubberized joint sealing compound according to the Contract Documents

Figure 3 below is an excerpt from MTOD 552.010 [6] Concrete Pavement Joint Details giving additional details on the transverse contraction joint and transverse construction joint requirements.

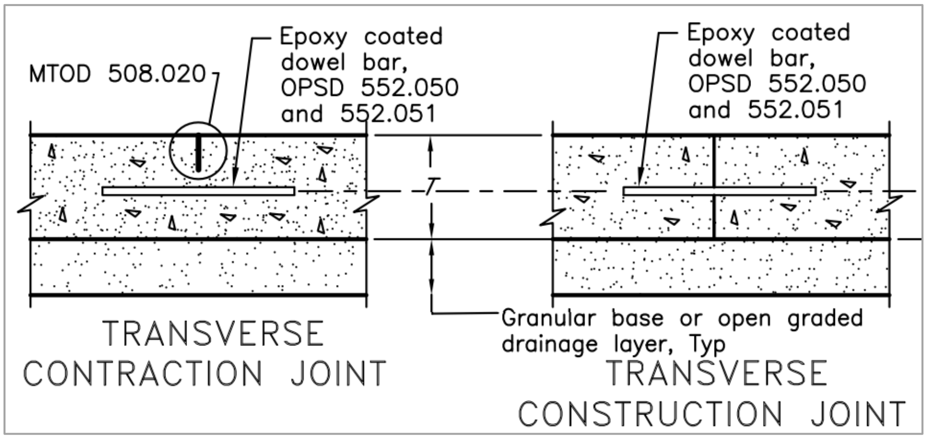


Figure 3: Excerpt for MTOD 552.010 Transverse Joint Requirements for Contraction and Construction Joints.

3.0 Smoothness and Safety

Next generation concrete texture is now being specified by MTO for new concrete pavement construction. The Highway 3 project utilized the specified MTO longitudinal grooving texture. The grooves are specified as follows in OPSS.PROV 350 (July 2023), Concrete Materials and Methods of Concrete Construction / Test Methods and Standards Practices for Concrete:

- Concrete will be grooved to the full width of the lane under construction with no grooves cut within 150 mm and no closer than 50 mm of longitudinal joints.

- Cut 2.5 mm in width, with a tolerance of plus 1.5 mm.
- Cut between 3.0 to 6.0 mm in depth, except over inductive loop detectors where they shall be cut between 1.5 and 3,0 mm in depth.
- Spaced 19 mm centre-to-centre with a tolerance of plus or minus 2.5 mm.

Figure 4 below shows a close-up of the longitudinally grooved concrete pavement on Highway 3.

Figure 4: Close-up of longitudinally grooved concrete pavement surface on the Highway 3.

OPSS.PROV 350 allows for optional diamond grinding of the concrete pavement surface to meet or exceed the specified smoothness requirements of the specification. For the Highway 3 project, the contractor opted to diamond grind the entire surface of the concrete pavement during the construction process to improve concrete pavement surface tolerance and smoothness before to owner acceptance testing. This process was completed prior to the final longitudinal grooving texture. The typical initial IRI value for the concrete pavement prior to diamond grinding was 1.0 m/km and higher. After diamond grinding the average IRI value was below 0.50 m/km. The slurry from the diamond grinding was collected in ready-mixed concrete trucks as shown in Figure 5 below and environmentally disposed of at the ready-mix concrete plant. This very smooth concrete pavement surface will help provide a longer pavement life due to reduced dynamic loads on the concrete panels. Additionally, the smoother surface will also improve heavy truck fuel efficiency due to reduced rolling resistance.

Figure 5: Diamond Grinding Operations with Ready-Mixed Concrete Truck collecting Slurry.

3.1 Decreased Potential for Hydroplaning

Hydroplaning occurs when a layer of water separates a vehicle's tires from the pavement surface, leading to a loss of steering and braking control. Several factors contribute to hydroplaning, including tire wear, driver speed and experience, and pavement surface characteristics. Since government agencies have limited control over tire conditions and driver experience, this discussion focuses on pavement surface characteristics, the area where agencies can exert influence.

All types of pavements whether gravel, asphalt or concrete have the potential for hydroplaning when it is raining, or water is present on the surface. However, concrete pavement, being a moldable material when first placed, can be textured to provide adequate friction characteristics and improved wet weather performance. As shown in Figure 6 form the American Concrete Pavement Association [6] Concrete Pavement Surface Texture document, texture created on the concrete surface is classified into two categories:

1) Microtexture – the fine-scale roughness contributed by the fine aggregate (sand) in the concrete matrix and provides the dry weather friction. This texture is created in the concrete surface by dragging burlap or astro-turf over the surface of the plastic concrete prior to applying the curing compound.

2) Macrotexture – the measurable striations or grooves formed in the plastic concrete by hand operated tining brooms or automated machines which provides the wet weather friction. Macrotexture may also be formed by cutting or sawing grooves into the hardened concrete surface.

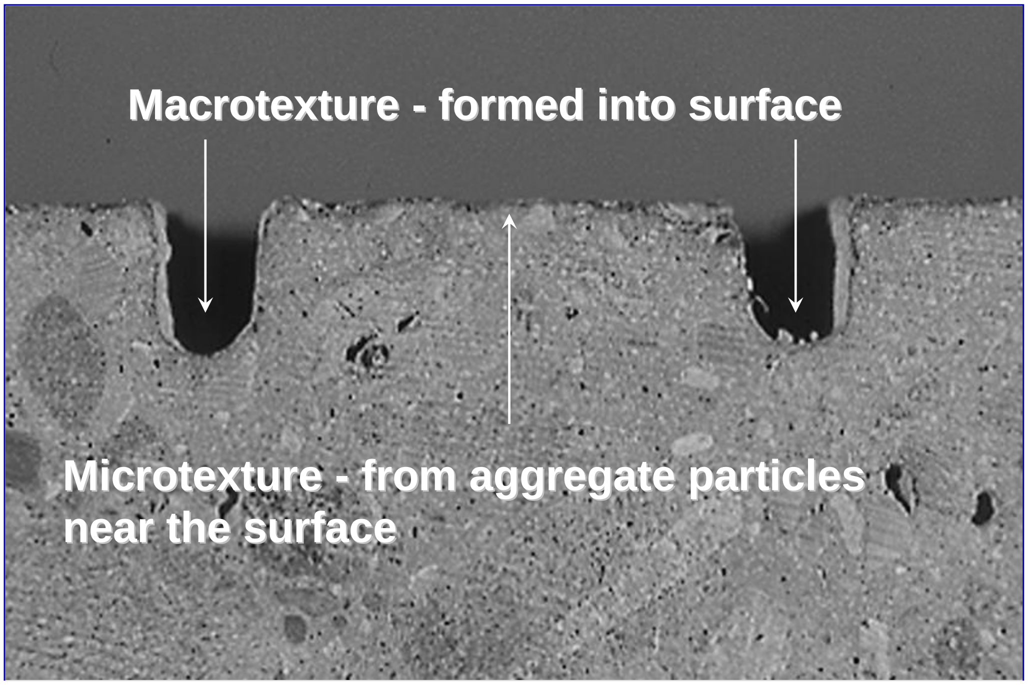


Figure 6: Close-up of Microtexture and Macrotexture on Concrete Pavement. [7]

As shown in Figure 7 from the Concrete Pavement Surface Texture document [7], macrotexture is the primary factor contributing to concrete pavement's superior performance in wet weather conditions. The grooves in the concrete pavement surface provide channels for water to escape from beneath the vehicle's tires, significantly reducing the potential for hydroplaning. Another factor contributing to concrete's excellent performance in wet conditions is its rigid structure, which prevents heavy vehicles from causing deformations such as ruts and washboarding in the pavement surface. Additionally, longitudinal grooving reduces splash and spray, making driving safer for vehicles in wet weather conditions.

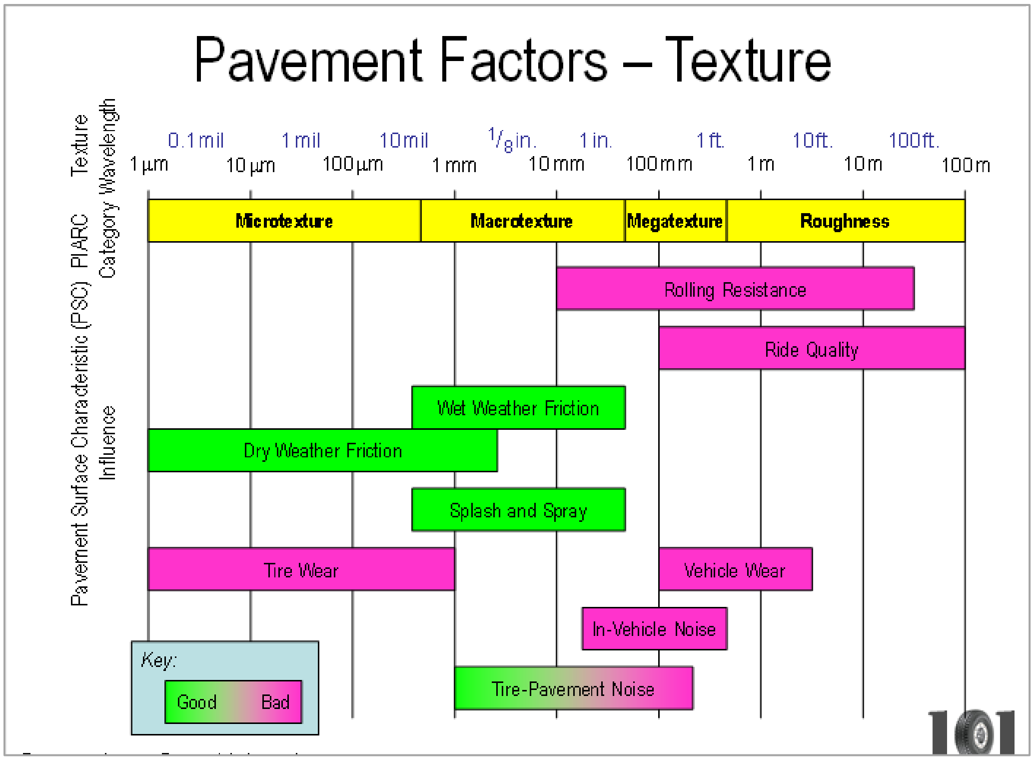


Figure 7: Effect of Texture on Pavement Surface Characteristics. (Source: Iowa State University)

3.2 Pavement Roughness Progression

As noted earlier in the report the Nova Scotia Department of Transportation and Public Works (NSTPW) [2] completed a 5-year study on an adjoining section of asphalt and concrete pavement built in 1994 on Highway 104 TransCanada Highway. The study, which concluded in 1999, showed both pavements performed well over the evaluation period. However, the concrete pavement section outperformed the adjoining asphalt pavement in both riding comfort and road smoothness.

Data from the comparative study by the NSTPW indicated that although the new asphalt pavement had a higher riding comfort index (RCI) initially, over time it deteriorated to a lower level than the adjoining concrete pavement. Figure 8 provides an illustration of how the RCI values changed over the 5-year evaluation period. The RCI reading at year five on the concrete pavement was 7.4 compared to 6.9 on the asphalt pavement. It is important to note that a higher the RCI value indicates a more comfortable ride.

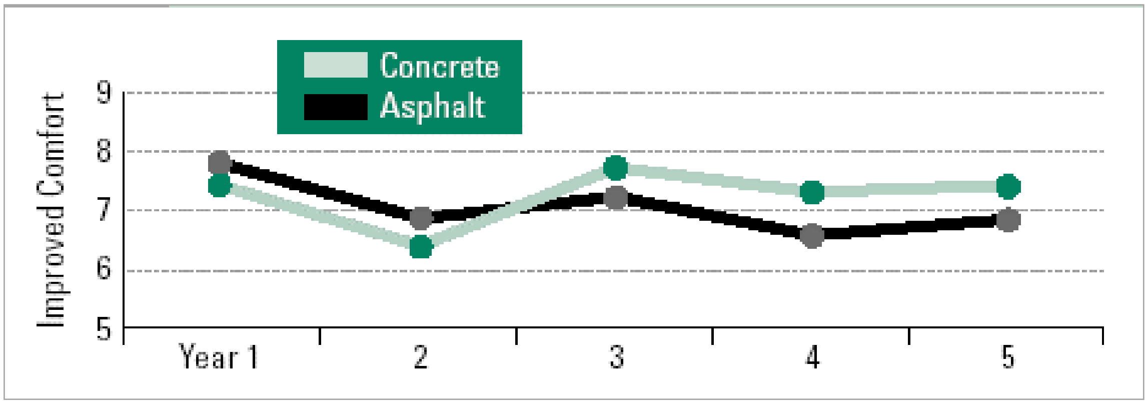


Figure 8: Comparison of Test Results of Riding Comfort Index. Source: Asphalt Concrete Pavement and Portland Cement Concrete Pavement, Highway 104, Cumberland County, Year 5 of 5 Year Study, October 1999. [2]

The NSTPW also measured the Profile Ride Index (PRI), a measure of pavement smoothness where higher numbers indicate increased roughness. Results from the first 5-years of the pavements' lives showed that the new concrete and new asphalt had approximately the same smoothness after one year. However, over the next four years, the concrete pavement maintained nearly its original smoothness, while the asphalt section exhibited increased roughness. Figure 9 illustrates the performance of the two pavement structures. Notably, the roughness of the asphalt pavement more than doubled that of the concrete pavement after five years of service, with readings of 6.8 mm/100 meters for the concrete versus 16.2 mm/100 meters for the asphalt.

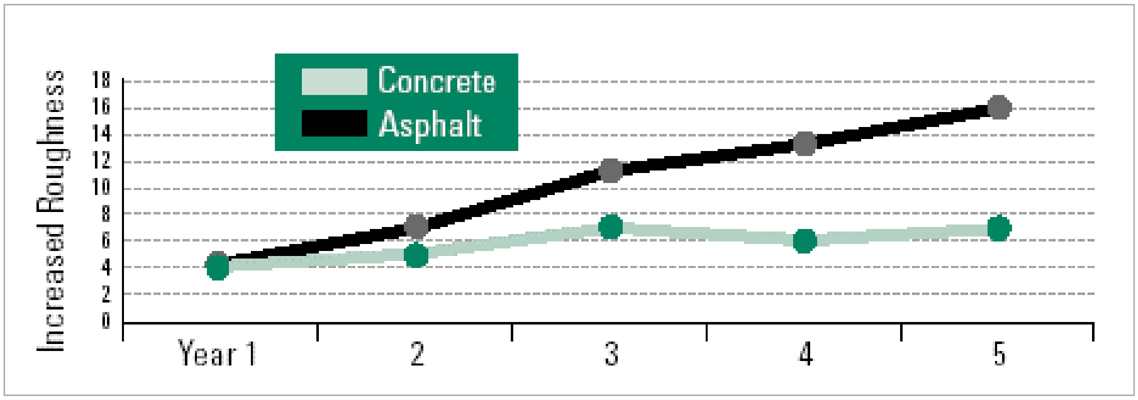


Figure 9: Comparison of Test Results of Profile Ride Index. [2]**4.0 Quiet Surface Texture**

In August 2022 MTO commissioned SLR Consulting (Canada) Ltd. to conduct a pavement noise study [8]. Table 1 below presents the overall measured sound intensity levels for several pavement sections in Ontario, including two asphalt control sections (Superpave 12.5 and SMA) and three types of concrete pavement textures (longitudinally grooved, longitudinally tined, and transversely tined). The study results show that the longitudinally grooved concrete pavement had a noise level equal to or better than the two asphalt control sections. The longitudinally tined concrete pavement was comparable to both SMA and Superpave 12.5 mixes, with the test section being within 1 dBA of the Superpave 12.5 section and 0.4 dBA of the SMA section. Noise levels for the transversely tined concrete pavement were notably higher than those for all the asphalt and longitudinally grooved and tined sections.

Table 1: Overall Measured Sound Intensity Levels for Roadways Tested in Ontario

			Sound Intensity Level (dBA) Average of Runs		
Section	**Highway**	**Type**	**Leading Edge**	**Trailing Edge**	**Pair Average**
1	Highway 402 - Sarnia	Concrete - Longitudinal Grooving	97.9	97.4	97.7
2	Highway 402 (control) - Sarnia	SP 12.5 FC 2	98.0	97.2	97.6
3	Highway 401 - Chatham	Concrete - Longitudinal Grooving	97.6	97.1	97.3
4	Highway 401 - Chatham	Concrete - Longitudinal tining	98.4	99.1	98.7
5	Highway 401 - Mississauga	Concrete - Longitudinal grooving - remediation	101.1	99.2	100.6
6	Highway 401 (control) - Campbellville	SMA 12.5	97.6	99.0	98.3
7	Highway 404 - Sharon	Concrete - Transverse tining	101.3	102.6	101.9

Section	**Highway**	**Type**	**Age (year)**	**OBSI (dBA)**
1	Highway 402 - Sarnia	Concrete - Longitudinal Grooving	2 (2020)	97.7
2	Highway 402 (control) - Sarnia	SP 12.5 FC 2	3 (2019)	97.6
3	Highway 401 - Chatham	Concrete - Longitudinal Grooving	4 (2018)	97.3
4	Highway 401 - Chatham	Concrete - Longitudinal tining	5 (2017)	98.7
5	Highway 401 - Mississauga	Concrete - Longitudinal grooving - remediation	3 (2019)	100.6
6	Highway 401 (control) - Campbellville	SMA 12.5	2 (2020)	98.3
7	Highway 404 - Sharon	Concrete - Transverse tining	8 (2014)	101.9

Source: On-Board Sound Intensity Pavement Noise, Longitudinal Grooving, Tining & Transverse Tining with Control Sections [8]

Table 2 below compares the noise level increase in pavement noise relative to the quietest longitudinally grooved section of concrete pavement. According to this table, the SuperPave 12.5 FC2 had a 3.5% higher noise level while the SMA was 12.2% higher. The longitudinally tined section was 17.5% louder than the longitudinal grooved section while the transversed tined section was 69.8% higher.

Table 2: Comparison of Noise Increase of Pavement Type Compared to Longitudinally Tined

Pavement Type	Noise level (dB)	Noise Increase (%)
Concrete - Longitudinal Grooving	97.3	0%
SuperPave 12.5 FC 2	97.6	3.5%
SMA 12.5	98.3	12.2%
Concrete - Longitudinal Tining	98.7	17.5%
Concrete - Transverse Tining	101.9	69.8%

Based on the MTO Noise study the Highway 3 concrete pavement should have a noise level equal to or slightly better than SuperPave 12.5 FC2 and SMA asphalt pavements.

5.0 Other Sustainable Benefits of Concrete Pavement

Figure 10 below illustrates the various benefits of using a concrete pavement on roads. This paper details several of these benefits including lower carbon footprint due to using Portland limestone cement (PLC), urban heat island effect, superior light reflectance, better fuel economy, and the potential for CO_2 sequestration.

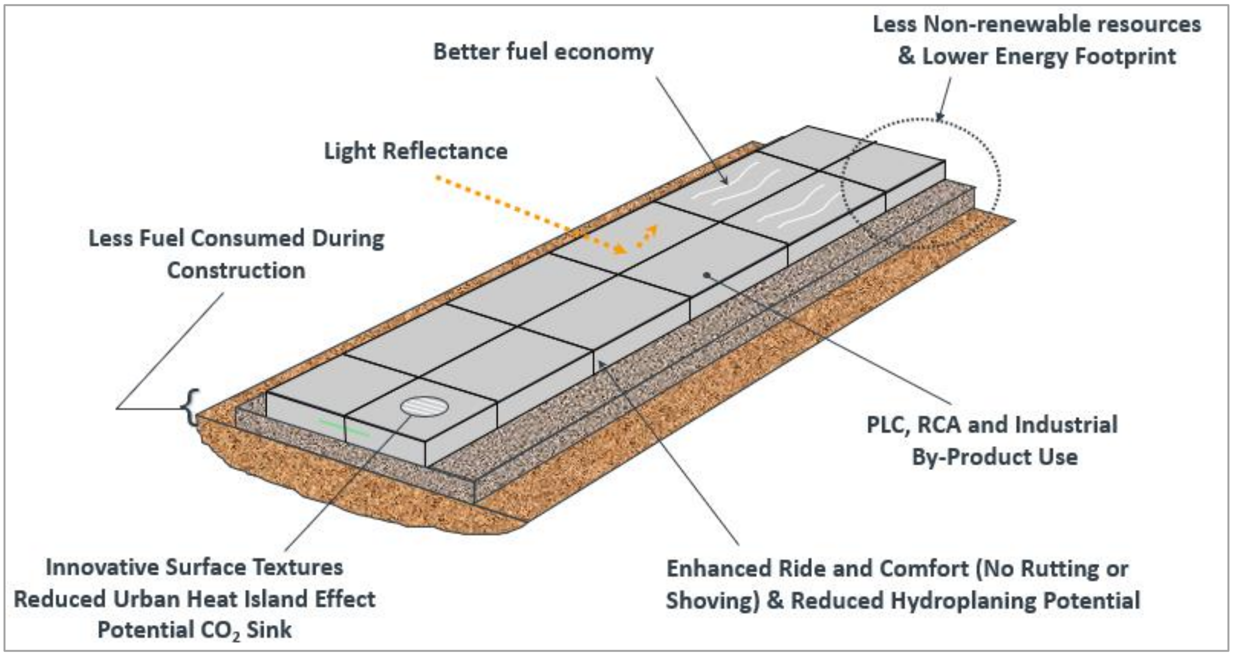


Figure 10: Benefits of Using Concrete Pavement.

5.1 Use of Portland Limestone Cement and Higher SCM Amounts

The majority of concrete's carbon footprint, 80 to 85 %, is due to the production of clinker in the cement kilns. Extremely high temperatures, around 1,500 degrees Celsius, are required to create the clinker, which is used to make cement. Fossil fuels are burned to generate these high temperatures, accounting for approximately one-third of the clinker's carbon footprint, known as combustion emissions. The remaining two-thirds of CO2 emissions, known as process emissions, occur when CO2 is driven off the limestone during heating. Minimizing the amount of clinker used in cement helps reduce the carbon footprint of concrete.

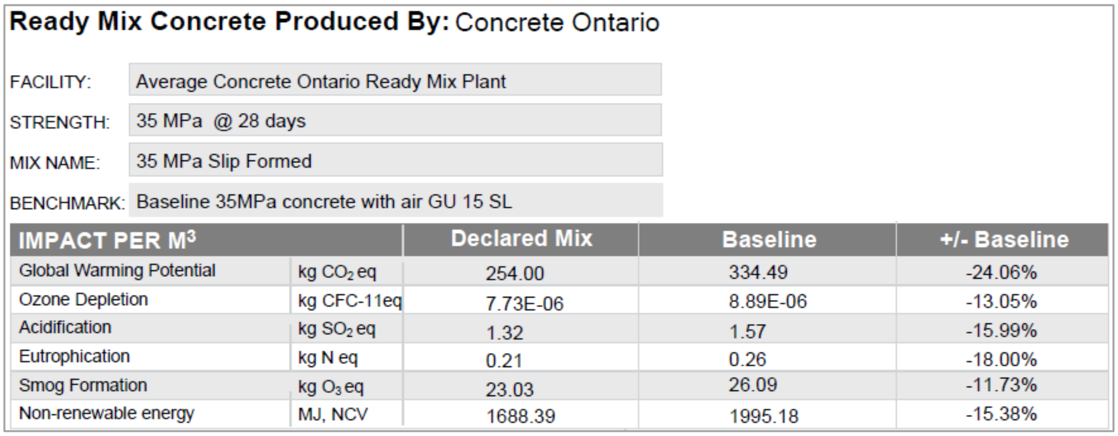
One effective way to reduce the carbon footprint of concrete products is to use Portland limestone cement (PLC). This cement, known as general use limestone (GUL) cement, has up to 15% interground limestone in it compared to general use (GU) cement which has up to 5 % interground limestone. Consequently, the carbon footprint of the GUL cement is reduced by approximately 10 %. For more information on PLC cements refer to the Cement Association of Canada's Technical Summary document [9].

Another way to reduce concrete's carbon footprint is by producing blended cements with supplementary cementitious materials (SCMs) that replace a percentage of the clinker or by using SCMs in the ready-mixed concrete mix to reduce the amount of cement being used. Maximizing the use of SCMs in a concrete mix or in a blended cement provides a lower carbon concrete.

To demonstrate the effect of using GUL and SCMs in a concrete mix on its carbon footprint, this paper presents the CO2 savings realized when using concrete produced with GUL cement compared to GU cement, along with two different levels of SCM substitution. For this comparison, we refer to the Athena Sustainable Materials Institute's Concrete Ontario Member Industry-Wide Environmental Product Declaration (EPD) for Ready-Mixed Concrete, verified by ASTM International [10]. This document includes EPDs for over 125 mix designs for various concrete strengths, both with and without air entrainment. Another useful tool is the Concrete Ontario CO2 calculator developed by Athena for EPD calculations.

Table 3 and 4 below show the results from the Concrete Ontario EPD calculator, comparing the baseline 35 MPa GU mix with 15 % slag to two lower-carbon mixes. Table 3 displays the global warming potential (GWP) for the actual project concrete mix design - GUL cement with 25 % slag. The calculator shows the GWP reduction or CO$_2$ reduction compared to the baseline mix design was 24 %. Table 4 shows the GWP results if the contractor had of used the allowable 30 % slag in the concrete mix based on MTO's maximum allowable slag limit. The GWP reduction or CO$_2$ savings using the higher level of slag in the concrete mix design would have been 27 %, which is 3 % better than the actual mix used by the contractor.

Table 3: Global Warming Potential Calculation for GUL and 25 % Slag Mix Design (Actual Mix Design)



Ready Mix Concrete Produced By: Concrete Ontario

FACILITY: Average Concrete Ontario Ready Mix Plant

STRENGTH: 35 MPa @ 28 days

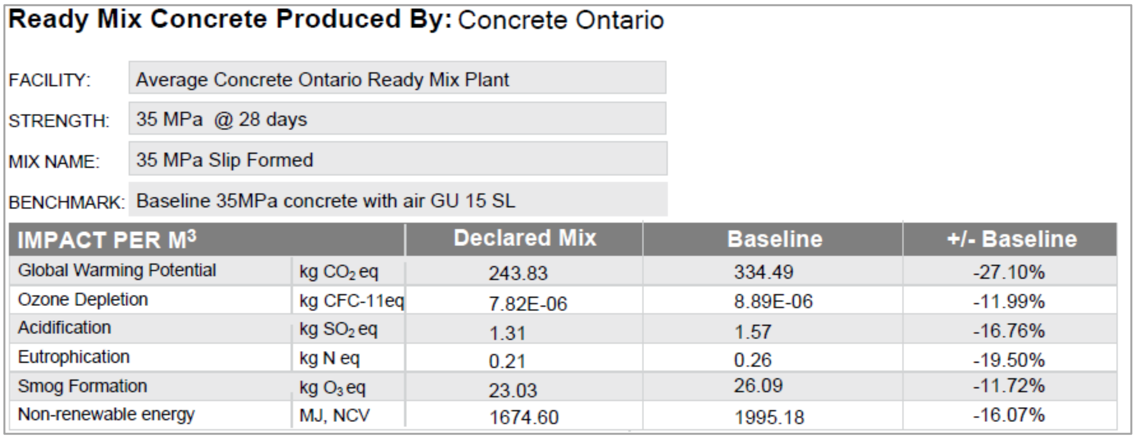
MIX NAME: 35 MPa Slip Formed

BENCHMARK: Baseline 35MPa concrete with air GU 15 SL

IMPACT PER M^3		Declared Mix	Baseline	+/- Baseline
Global Warming Potential	kg CO$_2$ eq	254.00	334.49	-24.06%
Ozone Depletion	kg CFC-11eq	7.73E-06	8.89E-06	-13.05%
Acidification	kg SO$_2$ eq	1.32	1.57	-15.99%
Eutrophication	kg N eq	0.21	0.26	-18.00%
Smog Formation	kg O$_3$ eq	23.03	26.09	-11.73%
Non-renewable energy	MJ, NCV	1688.39	1995.18	-15.38%

Source: Concrete Ontario CO_2 calculator

Table 4: Global Warming Potential Calculation for GUL and 30 % Slag Mix Design



Ready Mix Concrete Produced By: Concrete Ontario

FACILITY: Average Concrete Ontario Ready Mix Plant
STRENGTH: 35 MPa @ 28 days
MIX NAME: 35 MPa Slip Formed
BENCHMARK: Baseline 35MPa concrete with air GU 15 SL

IMPACT PER M^3		Declared Mix	Baseline	+/- Baseline
Global Warming Potential	kg CO_2 eq	243.83	334.49	-27.10%
Ozone Depletion	kg CFC-11eq	7.82E-06	8.89E-06	-11.99%
Acidification	kg SO_2 eq	1.31	1.57	-16.76%
Eutrophication	kg N eq	0.21	0.26	-19.50%
Smog Formation	kg O_3 eq	23.03	26.09	-11.72%
Non-renewable energy	MJ, NCV	1674.60	1995.18	-16.07%

Source: Concrete Ontario CO_2 calculator

Using the Concrete Ontario Member Industry-Wide Environmental Product Declaration (EPD) for Ready-Mixed Concrete document the total CO_2 savings for the project can be calculated based on the industry average EPDs. Table 5 below shows the CO_2 savings achieved on the Highway 3 project for both the actual mix design at 25% slag and potential savings when using 30% slag. The actual mix used for the Highway 3 concrete pavement had a 24% reduction in CO_2 compared to the baseline mix for a 35 MPa concrete. If the contractor used the maximum allowable slag percentage by MTO (i.e. 30%) the CO_2 reduction for the project would have been 27%.

Table 5: CO_2 Reductions Calculations for Highway 3 Using Concrete Ontario's Industry Average EPD's

	Mix: 35 MPa with air 25% Slag		
A1	Volume	15242	m³
A2	EPD Baseline from report	334.49	kg CO_2/m^3
A3	Concrete Placed (GUL 25% SL)	254	kg CO_2/m^3
A4	CO_2e Baseline (A1 * A2)	5098	tonnes CO_2
A5	CO_2e Project (A1 * A3)	3871	tonnes CO_2
A6	GHG Reduction (A4 - A5)	1227	tonnes CO_2
A7	**CO_2 Reduction (A6 / A4)**	**24%**	

	Mix: 35 MPa with air 30% Slag		
A1	Volume	15242	m³
A2	EPD Baseline from report	334.49	kg CO_2/m^3
A3	Concrete Placed (GUL 25% SL)	243.83	kg CO_2/m^3
A4	CO_2e Baseline (A1 * A2)	5098	tonnes CO_2
A5	CO_2e Project (A1 * A3)	3716	tonnes CO_2
A6	GHG Reduction (A4 - A5)	1382	tonnes CO_2
A7	**CO_2 Reduction (A6 / A4)**	**27%**	

5.2 Reduced Carbon Dioxide Emissions from Operating on Concrete Pavement

Differences in fuel consumption as a function of pavement structure is an important consideration for users and government agencies. It is well known that heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection absorbs part of the vehicles rolling energy that would otherwise propel the vehicle forward. The National Research Council of Canada (NRC) conducted three phases of studies comparing the fuel consumption of heavy vehicles operating on concrete and asphalt pavements in Ontario and Quebec. The Phase II and III fuel studies [11] [12] looked at the fuel savings from travelling on concrete pavement compared to asphalt for tanker semi-trailer and van semi-trailer, respectively. The studies showed the truck fuel savings ranged from 0.8 to 6.9 % savings when operating on a concrete pavement compared to asphalt pavements. [13]

The MIT Concrete Sustainability Hub undertook research on pavement vehicle interaction [14] [15] and found that stiffer pavements could reduce vehicle fuel consumption by as much as 3 percent. The study also noted that the asphalt pavement would need to be 60 % thicker than a concrete pavement to achieve the same stiffness. Figure 11 below compares pavement deflection on concrete versus asphalt, demonstrating the reduced deflection on concrete pavements. The figure also shows that pavement roughness has an even greater impact on fuel consumption. The average IRI of Highway 3 was below 0.5 m/km, indicating that this section of highway will result in lower truck fuel consumption than most highways.

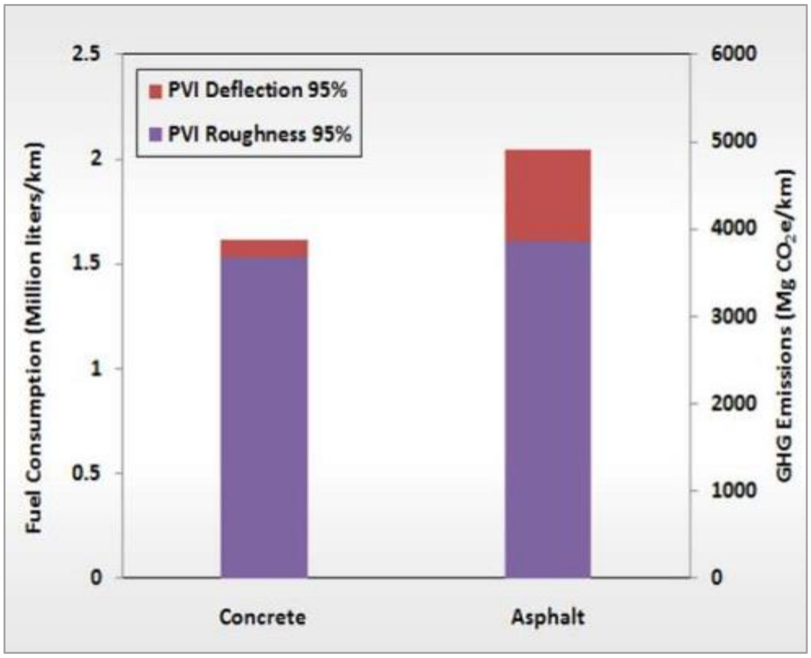


Figure 11: Vehicle Fuel Economy MIT Study. [16]

Table 6 identifies the yearly potential fuel saving and associated cost, CO_2 Equivalent, NOx, SO_2 savings over a year period for the 8 km section of concrete pavement on Highway 3. The savings are based on the following assumptions: heavy truck fuel efficiency of 43 litres / 100 km; diesel fuel cost of $1.596 / litres; and highway section carrying 2,500 trucks per day. The multipliers for carbon dioxide, nitrogen oxides, sulphur dioxide are as follows: CO_2 equivalent (2,758 g/L), NO_x (31.22 g/L) and SO_2 (3.95 g/L).

Table 6: Yearly Savings in $, CO_2 Equivalent, NO_X, SO_2 for Highway 3

Fuel Savings	**Savings (%)**	**Equivalent Fuel (litres)**	**Value of Fuel Saved**	**$CO_{2\ Eq.}$ (tonnes)**	**NO_X (Kg)**	**SO_2 (Kg)**
Minimum	0.80%	25,112	$40,080	69.3	784	99.2
Average	3.85%	120,852	$192,880	333.3	3,773	477.4
Maximum	6.90%	216,951	$345,680	598.4	6,773	857

Note: CO_2Equivalent calculations include carbon dioxide, methane and nitrous oxide. CO_2 = carbon dioxide, NO_X = nitrogen oxides, SO_2 = sulphur dioxide.

Based on the evidence presented above, it is clear that operating tractor-trailers on Portland Cement Concrete Pavement (PCCP) versus Asphalt Concrete Pavement (ACP) results in significant greenhouse gas (GHG) savings, leading to fewer pollutants being emitted into the environment. Additionally, the reduced fuel consumption lowers operating costs for trucking firms, which can potentially reduce the cost of goods for consumers.

5.3 Superior Nighttime Visibility

An earlier paper on concrete pavement sustainability by Tim Smith [13] noted concrete pavement's light reflective surface not only provides a pavement surface that minimizes heat island effect in urban areas but also enhances nighttime visibility in urban and rural environments. This is accomplished due to the light coloured (high albedo) surface of concrete pavement. Table 7 below from that same paper shows the albedo (solar reflectance) ratings for various pavement types. As shown in the table concrete pavement has superior albedo to ACP in both new and weathered conditions: concrete pavement (0.35 – 0.40 new PCCP and 0.20 – 0.30 weathered concrete) and asphalt (0.05 -1.0 new ACP and 0.10 – 0.15 weathered ACP).

Table 7: Albedo for Various Pavement Types [17]

Pavement Type	Albedos (solar reflectance)
Asphalt	0.05-0.10 (new) 0.10-0.15 (weathered)
Gray Portland Cement Concrete	0.35-0.40 (new) 0.20-0.30 (weathered)
White Portland Cement Concrete	0.70-0.80 (new) 0.40-0.60 (weathered)

5.4 Concrete as Potential Carbon Sink

Carbon dioxide sequestration is another climate change mitigation advantage of concrete. It has long been known concrete absorbs CO_2 over its life, but little was known about this potential. According to the Cement Association of Canada Concrete Zero [18] document, "Research conducted at IVL, the Swedish Environmental Research Institute finds an average of 20% of the CO_2 calcination emissions (i.e., process emissions from clinker production) can be permanently sequestered when a concrete structure has been built. Another 2% of calcination emissions can be permanently sequestered when the concrete structure is demolished. Another 1% of calcination emissions are considered permanently sequestered if the demolished concrete is reused as an aggregate."

Concrete pavement is often diamond-ground later in its life to help restore skid resistance. When diamond grinding is performed, a fresh surface of concrete is exposed, which will absorb more carbon dioxide.

6.0 Conclusion

The concrete pavement constructed on Highway 3 in the Windsor Essex area of Ontario exemplifies next-generation concrete pavement. It was built with exceptional smoothness, achieving an average IRI value under 0.5 m/km. This smoothness will contribute to a longer lifespan for the pavement due to reduced dynamic loading on the concrete slabs. The longitudinal grooving texture will not only decrease the potential for hydroplaning, splash, and spray but also provide a quieter surface equal to or better than asphalt. Specifying higher quality aggregate ensures the long-term durability of the pavement's skid resistance, adding another benefit to this concrete pavement. The high albedo concrete surface also offers better nighttime visibility and reduces the heat island effect. Lastly, the use of PLC and higher quantities of slag in constructing a low-carbon concrete pavement minimizes the CO_2 footprint, making this truly a sustainable pavement.

7.0 References

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