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ABSTRACT

Perpetual pavements are an important tool in building a sustainable highway pavement network. However, the method of measuring the sustainability is often a subject for debate. One method of looking at the sustainability is to look at the carbon footprint of a particular pavement structure. The carbon footprint is calculated from the greenhouse gasses produced during the construction of the road and its constituent materials. In this paper, we look at various methodologies used by authorities around the world to calculate the carbon footprint of a pavement structure. The carbon footprint for the initial construction and 50 year life cycle of typical flexible and rigid pavements as well as a flexible perpetual pavement are also calculated and presented.

INTRODUCTION

The concept of perpetual pavement was introduced in 2003 by the National Center for Asphalt Technology and the Asphalt Pavement Alliance. Dr. Dave Newcomb of the National Asphalt Pavement Association best explained the concept as follows:

> “A Perpetual Pavement is a hot mix asphalt pavement designed to last 50 years or more without major structural rehabilitation or reconstruction”

While the concept was introduced to look at sustainability of our highway network and to reduce impact on the travelling public, the subject of sustainability started to take on new meaning within the highway design fraternity. In addition, the heightened public awareness of global warming issues has also served to focus public attention on Green House Gas emissions.

GHG it typically measured in terms of carbon dioxide content even though GHG emissions take involve many other gasses. GHGs include carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and hydrofluorocarbon (HFC) leakage from air conditioning systems. Although not usually included, water vapour is the most abundant GHG.

GHG emissions are typically measured as part of an industrial process. However, in the last few years, the concept of carbon footprint and carbon neutral process has been gathering attention. It is now possible to when reserving an airline ticket on many airline web pages to click a button to pay to make your travel carbon neutral.

In this paper, we examine the carbon footprint of hot mix asphalt (HMA) and Portland cement concrete (PCC) pavement for typical residential, collector and freeway pavements in Ontario constructed of both HMA and PCC and compare the carbon footprint. In addition, we also look at the carbon footprint of an equivalent HMA freeway pavement built as a perpetual pavement. Both the carbon footprint of the initial construction and the carbon footprint of the maintenance activities over a 50 year lifecycle are evaluated and compared.

CARBON FOOTPRINT

Estimating the carbon footprint of a pavement can be a complicated procedure. There are many software programs available to evaluate the carbon footprint of highway construction. In 2008, the UK Highway trust defined a carbon footprint as "the total set of GHG (greenhouse gas) emissions caused directly and indirectly by an individual, organization, event or product".

There are many tools for calculating carbon footprint. The US EPA and Environment Canada both have online databases that enable individuals to calculate their personal carbon footprint. The University of California at Berkley developed the PaLATE, an Excel-based tool for life-cycle assessment (LCA) of environmental and economic effects of pavements and roads. The tool takes user input for the design, initial construction, maintenance, equipment use, and costs for a roadway, and provides outputs for the life-cycle environmental effects and costs. These tools are quite complex and involve evaluating many aspects of the construction and energy use, both on and off site.

These models were felt to be too complex for comparison purposes. It was decided for the purpose of this paper to evaluate carbon footprint based on the materials used to build typical pavement cross-sections. It was also decided to look for a tool that had been developed and used by an independent road authority to evaluate the carbon footprint of a road project.

THE MICKLEHAM ROAD PROJECT

State of Victoria in Australia undertook a carbon neutral twinning project on Mickleham Road. VicRoads has used the $13.3 million (Aus) Mickleham Road duplication as a pilot project to measure the carbon footprint of road construction, and identify ways to potentially reduce and offset the carbon emissions from roadwork. Information about the project can be found at the official web site – www.vicroads.vic.gov.au/environment.

This $16.3 million (Aus) State Government funded project extends the duplication of Mickleham Road for 2.4 km north from Barrymore Road to Somerton Road at Greenvale, providing two lanes in each direction. It builds on the benefits of duplication works completed in April 2007 south of Barrymore Road to Allanbrae Terrace at Attwood.

The pavement design of the new alignment consisted of 200 mm of HMA over 170 mm cement treated base over 410 mm engineered fill. The exiting paved section was milled for profile, padded and a single 70 mm overlay was placed. The project was completed in 2008.

Using an Excel based spreadsheet developed in-house, VicRoads calculated a carbon footprint of around 1,750 tonnes of CO_2. Ninety-seven percent of GHG emissions from embodied greenhouse gas emissions of materials (73 percent) and on-site transport (24 percent). The remainder came from transport of materials to site (2 percent) and on-site electricity (1 percent). VicRoad intends offset the GHG emissions generated by the project by planting 7,463 trees in Victoria's North West.

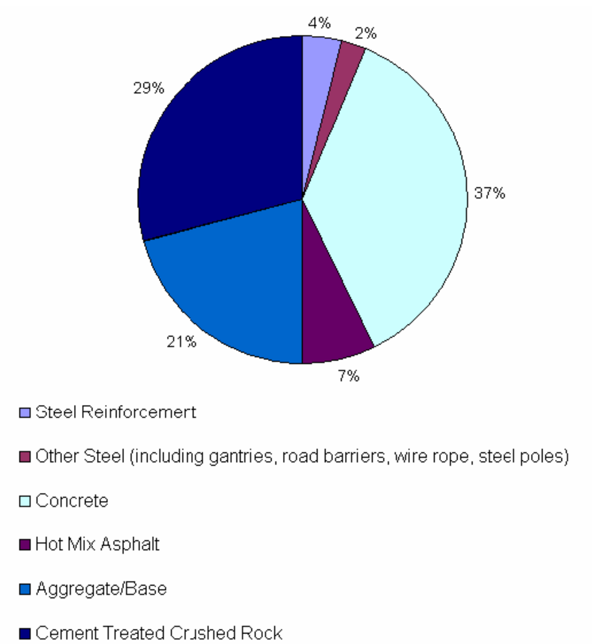

Figure 1 -- Distribution of GHG on the Mickleham Project

More information about this initiative and the spreadsheet used in the calculations is available on the VicRoads web site.

CARBON FOOTPRINT CALCULATIONS

For the purposes of comparing the carbon footprint of PCC and HMA pavements, it was decided to look only at the embodied greenhouse gas emissions of the materials, as this was the source of majority of the emissions calculated on the Mickleham Project.

In performing the carbon footprint calculations in this paper, we used the values for the Mickleham Project shown in Table 1.

TABLE 1

MATERIAL	CO_2 EMISSIONS (TONNES/TONNE)
Hot Mix Asphalt (at 5.0 percent asphalt cement)	0.0103
Granular A (crushed, screened and washed aggregate)	0.0080
Granular B (screened and washed aggregate)	0.0053
Portland Cement Concrete (at 32 MPa)	0.1073
Asphalt stabilized Open Graded Drainage Layer (at 1.8 percent asphalt cement)	0.0090

The first thing evident from this table is the difference in the values for the HMA and PCC. This can be explained by the chemical processes that occur in the production of Portland cement. For every 1,000 kg of Portland cement, approximately 650 kg of carbon dioxide is produced. Heating the aggregate and clay used to produce Portland cement to temperature of ~1,450°C in the kiln cause the disassociation of the limestone and the production of carbon dioxide.

It should be noted that the CO_2 equivalent of the carbon content of asphalt cement has not been included in the calculation. The purpose of the carbon footprint calculation is to calculate the GHG emissions of a product. The carbon in the asphalt cement will never be released into the atmosphere. It is neither consumed nor wasted in the process. The carbon has been sequestered in the form of an HMA pavement. In addition, 100 percent of the asphalt cement incorporated into HMA pavement can be recycled into new asphalt pavement by simply re-heating the material, thus reusing the energy invested initial production of the material. Currently in North America, about 80 percent of the pavement removed from the road is recycled into new HMA. The material not recycled is still not burned and thus the embodied carbon is never released into the atmosphere.

TYPICAL RESIDENTIAL PAVEMENT

Two pavement cross-sections chosen for analysis are shown on the following tables. The HMA pavement is based on common practice in Southern Ontario and is shown on Table 2A. The PCC pavement is taken from the Portland Cement Association's StreetPave program and is shown on Table 2B. Both pavements have a 7.5 m wide paved surface with curb and gutter. The PCC curb and underlying granular have not been included in the analysis, as they are common to both pavements.

TABLE 2A

HMA RESIDENTIAL PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
90	Mm	HMA	1,620	0.0103	16.7
150	Mm	Gran A	2,700	0.0080	21.6
300	Mm	Gran B	4,950	0.0053	26.2
			9,270		64.5

TABLE 2B

PCC RESIDENTIAL PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
145	Mm	PCC	2,610	0.1073	280.1
100	Mm	Gran A	1,800	0.0080	14.4
			4,410		294.5

The result of the calculation of the contribution of the materials to the carbon footprint of a one kilometre long section of the pavement is shown in Tables 2A and 2B. Based on these calculations, the HMA pavement is only 22 percent of the carbon footprint the PCC pavement.

It should be noted that these two pavements should not necessarily be considered to be equivalent. The PCC pavement would be considered to be quite lightly designed given the frost conditions encountered in southern Ontario (~650 Celsius degree days or about 1.2 m frost penetration for bare road).

TYPICAL COLLECTOR PAVEMENT

Two pavement cross-sections chosen for analysis are shown on the following tables. As with the previous example, the HMA pavement is based on common practice in Ontario (Table 3A). The PCC pavement is taken from the Portland Cement Association's StreetPave program (Table 3B). Both pavements have a 15 m wide paved surface with curb and gutter. The PCC curb and underlying granular have not been included in the analysis, as they are common to both pavements.

The result of the calculation of the contribution of the materials to the carbon footprint of a one kilometre long section of the pavement is shown in Tables 3A and 3B. Based on these calculations, the HMA pavement is only 25 percent of the carbon footprint the PCC pavement.

TABLE 3A

HMA COLLECTOR PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
130	Mm	HMA	4,680	0.0103	48.2
150	Mm	Gran A	5,400	0.0080	43.2
450	Mm	Gran B	14,850	0.0053	78.7
			24,930		170.1

TABLE 3B

PCC COLLECTOR PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
170	Mm	PCC	6,120	0.1073	656.7
100	Mm	Gran A	3,600	0.0080	28.8
			9,720		685.5

As with the residential pavements, these two pavements should not necessarily be considered to be equivalent. The PCC pavement would be considered to be quite lightly designed for Southern Ontario.

FREEWAY PAVEMENTS

For analyzing freeway pavements, it was decided to use the two pavement sections used by the Ontario Ministry of Transportation (MTO) in there Life Cycle Costing Analysis model. MTO introduced LCCA component into the alternative bid process in 1999. Both industries (HMA and PCC) funded the study in partnership with MTO. The LCCA model developed in the original study has been re-evaluated four times since 1999 to incorporate new technologies and changes in design process. In order to validate the model, MTO developed two idealized pavements that they considered to be equivalent. MTO also developed a typical maintenance program for each pavement type over a 50 year timeframe. It should be noted that these pavements were not site designed pavements but rather typical pavement sections for six lane divided highway in the MTO inventory.

These two pavements were analysed in a similar manner to the residential and collector pavements as shown below. Both pavements have a 16 m wide paved surface in each direction (3.25 m, 3.75 m and 3.75 m lane widths). There is an inside 1.5 m shoulder and an outside 3.75 m shoulder with median curb and gutter and granular rounding to the ditch on the outside. The HMA section is shown on Table 4A and the PCC section is shown on Table 4B.

The PCC curb and underlying granular have not been included in the analysis, as they are common to both pavements.

TABLE 4A

HMA FREEWAY PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
240	mm	HMA	12,384	0.0103	127.6
100	mm	OGDL	4,945	0.0090	44.5
150	mm	Gran A	7,740	0.0080	61.9
450	mm	Gran B	21,285	0.0053	112.8
			46,354		346.8

TABLE 4B

PCC FREEWAY PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
240	mm	PCC	12,384	0.1073	1,328.8
100	mm	OGDL	4,945	0.0090	44.5
300	mm	Gran A	15,480	0.0080	123.8
			32,809		1,497.1

The result of the calculation of the contribution of the materials to the carbon footprint of a one kilometre long section of the pavement is shown in Tables 4A and 4B. Based on these calculations, the HMA pavement is only 23 percent of the carbon footprint the PCC pavement.

LIFE CYCLE ANALYSIS

The carbon footprints of the residential and collector pavements were not looked at in terms of the life cycle carbon footprint due to the difficulty in providing a schedule of pavement treatments for these two classes of roads. The level of service desired for these road categories is very dependant on the jurisdiction. Instead, it was decided to look at a published life cycle maintenance program developed by an independent road authority.

As part of the LCCA study mentioned above, MTO developed a catalogue of activities over a 50 year maintenance period as shown on the Tables 5A and 5B for the HMA and PCC pavements, respectively. For each activity, only CO_2 content of the paving materials was examined. Crack sealing is shown but the contribution of carbon from the crack sealant has not been included as it could be argued that carbon has been sequestered.

TABLE 5A

HMA LIFE CYCLE ANALYSIS OF CARBON FOOTPRINT

YEARS AFTER INITIAL CONSTRUCTION	DESCRIPTION OF PAVEMENT TREATMENT	QUANTITY		TONNES
3	Rout and Seal Cracks	352	m	
9	Rout and Seal Cracks	938	m	
9	5 percent Mill and Patch 40 mm	1,075	m^2	103
15	Rout and Seal Cracks	1,760	m	
15	20 percent Mill and Patch 40 mm	4,300	m^2	413
19	Mill 90 mm Asphalt Pavement	21,500	m^2	
19	Superpave 19 mm - 50 mm	21,500	m^2	2,580
19	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
19	Tack Coat (2 Layers)	44,000	m^2	
22	Rout and Seal Cracks	352	m	
27	Rout and Seal Cracks	1,400	m	
27	10 percent Mill and Patch 40 mm	2,150	m^2	206
31	Mill 90 mm Asphalt Pavement	21,500	m^2	
31	Superpave 19 mm - 50 mm	21,500	m^2	2,580
31	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
31	Tack Coat (2 Layers)	44,000	m^2	
34	Rout and Seal Cracks	352	m	
38	Rout and Seal Cracks	1,400	m	
38	10 percent Mill and Patch 40 mm	2,150	m^2	206
42	Mill 90 mm Asphalt Pavement	21,500	m^2	
42	Superpave 19 mm - 50 mm	21,500	m^2	2,580
42	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
42	Tack Coat (2 Layers)	44,000	m^2	
45	Rout and Seal Cracks	352	m	
48	Rout and Seal Cracks	1,400	m	
	Total HMA over the 50 year lifecycle (tonnes)			14,861
	Total CO_2 from the HMA (factor of 0.0103 t/t) (tonnes)			153.1
	Total cracks sealed over a 50 year lifecycle (m)			8,306

TABLE 5B

PCC LIFE CYCLE ANALYSIS OF CARBON FOOTPRINT

YEARS AFTER INITIAL CONSTRUCTION	DESCRIPTION OF PAVEMENT TREATMENT	QUANTITY		TONNES
12	Reseal Joints (50 percent trans., 25 percent long.)	3,122	m	
18	Partial-depth PCC Patching	64	m^2	23
18	Full-depth PCC Patching	113	m^2	65
18	Texturize	21,500	m2	
18	Reseal Joints (100 percent trans., 50 percent long.)	6,244	m	
28	Partial-depth PCC Patching	213	m^2	77
28	Full-depth PCC Patching	376	m^2	217
28	Texturize full width	21,500	m^2	
28	Reseal Joints (100 percent trans., 100 percent long.)	7,244	m	
38	Tack Coat	45,000	m^2	
38	Superpave 19 mm - 50 mm	27,750	m^2	3,330
38	Superpave 12.5 mm FC2 - 40 mm	27,750	m^2	2,664
38	Granular A for rounding - 90 mm			1,323
41	70 percent Reseal (Composite)	5,071	m	
44	30 percent Reseal (Composite)	2,173	m	
	Total PCC over the 50 year lifecycle (tonnes)			381
	Total HMA over the 50 year lifecycle (tonnes)			5,994
	Total additional granular on the shoulders (tonnes)			1,323
	CO_2 from the PCC (factor of 0.1073 t/t) (tonnes)			40.9
	CO_2 from the HMA (factor of 0.0103 t/t) (tonnes)			67.1
	CO_2 from the HMA (factor of 0.0080 t/t) (tonnes)			10.6
	Total CO_2 of the section (tonnes)			113.2
	Total joints in PCC pavement sealed over a 50 year lifecycle (m)			16,610
	Total composite pavement cracks sealed over a 50 year lifecycle (m)			7,244

The results of the calculation of the contribution of the materials to the carbon footprint of a one kilometre long section of the pavement over a 50 year lifecycle is shown in Tables 5A and 5B. Based on these calculations, the HMA pavement is 135 percent of the carbon footprint the PCC pavement.

Although not relevant in terms of carbon footprint, it is interesting to note over the 50 year life cycle, there is almost 3 times the crack/joint sealing in the PCC pavement when compared to the HMA pavement.

Putting the together CO_2 footprint of the initial construction with the CO_2 footprint of the 50 year lifecycle for the MTO freeway pavement yields is shown on Table 6.

TABLE 6

TOTAL CARBON FOOTPRINT THE MTO FREEWAY PAVEMENTS
(TONNES OF CO_2/KM)

	HMA PAVEMENT	PCC PAVEMENT
Carbon Footprint of Initial Construction	346.8	1,497.1
Carbon Footprint from the Life Cycle Analysis	153.1	113.2
Total 50 year Carbon Footprint	499.9	1,610.4

As shown in the table, the total carbon footprint of the conventionally designed HMA pavement is only 31 percent of the total carbon footprint of the PCC pavement.

PERPETUAL HMA PAVEMENT

For the purposes of this paper, only the MTO freeway pavement was chosen for the perpetual pavement design. All the pavement sections presented in this paper are based on empirical pavement designs based on the classification of the roadway. The MTO freeway pavement used for the Ontario LCCA study is also not a site specific pavement but rather a pavement cross-section chosen to be typical for 6 lane divided highways in Ontario.

However, to design a perpetual pavement, it is necessary to have traffic and climatic details to design the pavement. To provide the necessary inputs, the pavement HMA freeway design section was back-analysed to find several alternatives for traffic and climate that would produce a pavement with the approximate overall thickness design used in the MTO LCCA study. The traffic alternatives were used as input into PerRoad v3.2 to develop a pavement that would be considered as a perpetual design. It should be noted that this design is not precise but rather one that approximated several alternative scenarios.

The final perpetual pavement design was chosen to have the same thickness of granulars and only the thickness of the HMA layer was changed. Based on this design methodology, the thickness of the HMA for the perpetual pavement used for this analysis was found to be 320 mm of hot mix compared to 240 mm of hot mix for the conventionally designed pavement. This represents an increased thickness of 33 percent. This HMA thickness increase was consistent with several other MTO perpetual pavement designs, particularly the Hwy 401 perpetual pavement near Woodstock which is currently under construction. The granular thickness were maintained for this pavement section and the hot mix thicknesses were 420 mm and 300 mm, respectively, of HMA over 750 mm of granulars.

The perpetual pavement design and the resultant carbon footprint calculations are given in Table 6.

TABLE 6

PERPETUAL HMA FREEWAY PAVEMENT			TONNES/KM	CO_2 (TONNES/TONNE)	CO_2 (TONNES/KM)
320	mm	PCC	16,512	0.0103	170.1
100	mm	OGDL	4,945	0.0090	44.5
150	mm	Gran A	7,740	0.0080	61.9
240	mm	Gran B	21,285	0.0053	112.8
			50,482		389.3

The resultant carbon footprint about 12 percent higher than the carbon footprint of the conventional pavement but is still only 26 percent of the carbon footprint of the PCC pavement.

For the life cycle carbon footprint, the MTO 50 year life cycle table was used with the exception that the HMA overlays at pavement at 19, 31 and 42 years were reduced to a single lift.

TABLE 7

HMA Life Cycle Analysis of Carbon Footprint

YEARS AFTER INITIAL CONSTRUCTION	DESCRIPTION OF PAVEMENT TREATMENT	QUANTITY		TONNES
3	Rout and Seal Cracks	352	m	
9	Rout and Seal Cracks	938	m	
9	5 percent Mill and Patch 40 mm	1,075	m^2	103
15	Rout and Seal Cracks	1,760	m	
15	20 percent Mill and Patch 40 mm	4,300	m^2	413
19	Mill 40 mm Asphalt Pavement	21,500	m^2	

TABLE 7

HMA Life Cycle Analysis of Carbon Footprint

YEARS AFTER INITIAL CONSTRUCTION	DESCRIPTION OF PAVEMENT TREATMENT	QUANTITY		TONNES
19	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
19	Tack Coat (1 Layer)	44,000	m^2	
22	Rout and Seal Cracks	352	m	
27	Rout and Seal Cracks	1,400	m	
27	10 percent Mill and Patch 40 mm	2,150	m^2	206
31	Mill 40 mm Asphalt Pavement	21,500	m^2	
31	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
31	Tack Coat (1 Layer)	44,000	m^2	
34	Rout and Seal Cracks	352	m	
38	Rout and Seal Cracks	1,400	m	
38	10 percent Mill and Patch 40 mm	2,150	m^2	206
42	Mill 40 mm Asphalt Pavement	21,500	m^2	
42	Superpave 12.5 mm FC2 - 40 mm	21,500	m^2	2,064
42	Tack Coat (1 Layer)	44,000	m^2	
45	Rout and Seal Cracks	352	m	
48	Rout and Seal Cracks	1,400	m	
	Total HMA over the 50 year lifecycle (tonnes)			7,121
	Total CO_2 from the HMA (factor of 0.0103 t/t) (tonnes)			73.3
	Total cracks sealed over a 50 year lifecycle (m)			8,306

The resultant carbon footprint over the 50 year life cycle is about 48 percent lower than the life cycle carbon footprint of the conventional pavement and 65 percent of the life cycle carbon footprint of the PCC pavement.

CONCLUSIONS

The calculations above lead to the summary shown in Table 8. Clearly, from the viewpoint of carbon footprint, the HMA pavement is more environmentally sustainable than is the PCC pavement.

TABLE 8

TOTAL CARBON FOOTPRINT THE MTO FREEWAY PAVEMENTS (TONNES OF CO_2/KM)

	HMA PERPETUAL PAVEMENT	HMA CONVENTIONAL PAVEMENT	PCC PAVEMENT
Carbon Footprint of Initial Construction	389.3	346.8	1,497.1
Carbon Footprint from the Life Cycle Analysis	73.3	153.1	113.2
Total 50 year Carbon Footprint	462.7	499.9	1,610.4
Comparison to PCC pavement	28.7%	31.0%	100%