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MIT Research: Life Cycle Assessment of Concrete Pavements

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Life cycle assessment (LCA) offers a comprehensive approach to evaluating and improving the environmental impacts of concrete pavements. Recent research at the Massachusetts Institute of Technology (MIT) explores and advances key areas relevant to the field of pavement LCA: methodology, benchmarking and impact reduction.

Methodology

The U.S. roadway system is a complex web of approximately 2.6 million miles of public roadways upon which approximately three trillion vehicle miles are traveled every year. U.S. EPA indicates that road transport contributes the most green house gas (GHG) emissions of any transport mode. Additionally, construction and maintenance of these roadways consume energy and resources. For these reasons, there is a growing desire to identify opportunities to reduce GHG emissions during construction, operation and maintenance of roadways.

MIT researchers employed standardized LCA methodology to assess the environmental impact of concrete pavements to encompass the entire life cycle—materials, construction, use, maintenance and end-of-life (See Figure 1). This allowed researchers to quantify cumulative environmental impacts and provide ways to reduce GHG emissions.

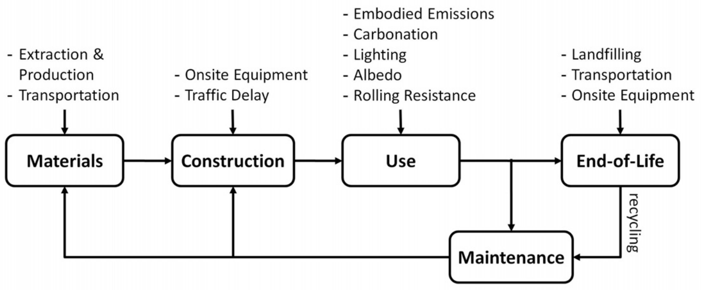

Figure 1. Suggested System Boundaries (including life cycle phases and components) for Pavement LCA.

Benchmarking

The LCA methodology was applied to benchmark 12 pavement designs based on FHWA roadway classifications ranging from rural local roads to urban interstates (See Table 1). The designs were developed using *1993 AASHTO Method for the Design of Pavement Structures* to capture the current state of practice used by most government agencies. Global Warming Potential (GWP), measured in terms of carbon dioxide equivalents (CO_2e), were determined for each life cycle phase for the 12 pavement designs to quantify the relative importance of each life cycle phase and identify specific strategies to reduce GWP of concrete pavements.

Rural	Interstate	Principal Arterial	Minor Arterial	Major Collector	Minor Collector	Local
AADT* (vehicles/day)	22,074	6,414	3,084	1,219	574	177
AADTT** (trucks/day)	4,415	706	308	85	40	12
Lanes	4	2	2	2	2	2
Conc. Thickness, in (mm)	11.5 (292)	8.0 (203)	7.5 (191)	6.0 (152)	5.0 (127)	4.0 (102)
Base Thickness, in (mm)	6 (152)	6 (152)	6 (152)	6 (152)	0 (0)	0 (0)
Steel dowel diam. In (mm)	1.5 (38)	1.25 (32)	-	-	-	-

Urban	Interstate	Freeway	Principal Arterial	Minor Arterial	Collector	Local
AADT* (vehicles/day)	79,789	54,809	19,631	9,729	4,221	980
AADTT** (trucks/day)	6,303	2,152	785	389	169	39
Lanes	6	4	4	2	2	2
Conc. Thickness, in (mm)	12.0 (305)	11.0 (279)	8.5 (216)	7.0 (178)	6.5 (165)	5.0 (127)
Base Thickness, in (mm)	6 (152)	6 (152)	6 (152)	6 (152)	0 (0)	0 (0)
Steel dowel diam. In (mm)	1.5 (38)	1.5 (38)	1.25 (32)	1.25 (32)	-	-

*AADT = annual average daily traffic (two way); **AADTT = Annual average daily truck traffic (two way)

Table 1. Benchmark pavement designs evaluated by MIT based upon FWHA Roadway Classifications (thickness

Impacts

Results from the research indicate:

- GWP of concrete pavements ranged from 600 tons CO_2e/mi (340 Mg CO_2e/km) on rural local roads to 11,000 tons CO_2e/mi (6,300 Mg CO_2e/km) on urban interstates;

- GHG emissions from cement production are the largest contributor—45% for urban interstates to 72% for rural local roads; and
- For 9 of 12 pavement designs, the second largest contributor to GWP is fuel consumed from roughness.

Impact Reductions

There are a number of potential GHG emissions reduction strategies for concrete pavements that were explored and LCA provides guidance for future environmental improvements. Notable conclusions include:

- GWP could be reduced by 15% for urban interstates to 36% for local roads by increasing fly ash in concrete from 10% to 30%;
- Increase albedo reduces the urban heat island effect resulting in up to 43% reduction in GWP for rural local roads;
- Carbonation through crushing and stockpiling concrete for one year sequestered 28% of initial CO_2 released;
- Reducing roughness through extra pavement rehabilitations reduces GWP by 13% for urban interstates but increases GWP for rural local roads by 10%; and
- Implementing all four strategies could decrease GWP from 38% for urban interstates to 58% for urban local roads (see Figure 2).

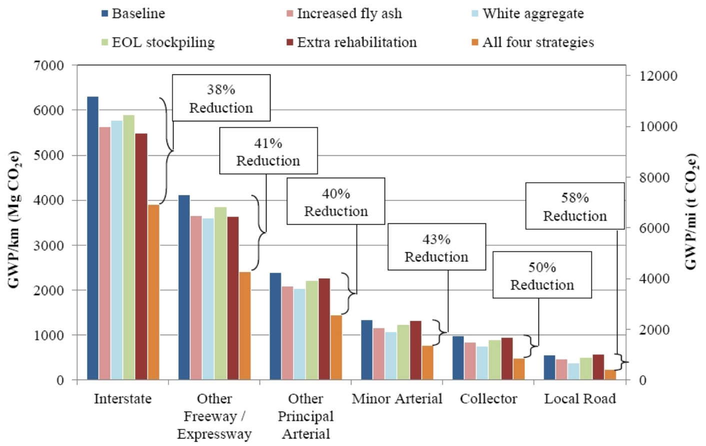

Figure 2. GWP reduction strategies for urban roadways.

Another way to decrease GWP is to provide more cost effective pavement designs using state-of-the-art design methodologies. For example, utilizing *AASHTO Mechanistic Empirical Pavement Design Guide (MEPDG)* in lieu of *1993 AASHTO Design Guide* could reduce GWP by up to 17% for rural interstates.

Pavement Vehicle Interaction

Pavement-vehicle interaction (PVI) describes the effect of pavement properties on vehicle fuel consumption. The effect of PVI on fuel consumption over a full life cycle can be significant. Roughness and deflection are the main contributors to higher fuel consumption (see Figure 3).

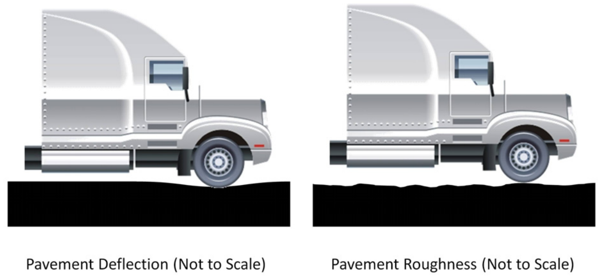
Pavement Deflection (Not to Scale)
Pavement Roughness (Not to Scale)

Figure 3. Pavement-vehicle interaction

MIT developed a mechanistic model to draw a relationship between pavement deflection and fuel consumption. It validated the model by comparing results to existing field data. The mechanistic model calculates that an asphalt pavement would need to be 1.6 times thicker than an equivalent concrete pavement to achieve the same fuel consumption.

More Information

The full report titled *Methods, Impacts, and Opportunities in the Concrete Pavement Life Cycle* can be downloaded from the MIT Concrete Sustainability Hub Web site at http://web.mit.edu/cshub. The Concrete Sustainability Hub is a research center at MIT that was established by the Ready Mixed Concrete (RMC) Research & Education Foundation and the Portland Cement Association (PCA). Both organizations are committing significant effort and resources with the goal of accelerating emerging breakthroughs in concrete science and engineering and transferring that science into practice. NRMCA is providing technical input and helping transfer the research into practice.

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