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FUEL SAVINGS OF HEAVY TRUCKS ON CONCRETE PAVEMENT

SR351

KEYWORDS

asphalt pavement, fuel savings, fuel study, heavy vehicles, portland cement concrete pavement, road roughness, and truck fuel consumption

ABSTRACT

This report summarizes research measuring heavy truck fuel consumption on three highway pavements, under a variety of test conditions. Research variables to determine fuel consumption included pavement structure, pavement roughness, vehicle configuration, vehicle speed, vehicle load, and ambient temperature. Results of the study focus on the fuel consumption performance on portland cement concrete pavement (concrete) compared to asphalt concrete pavement (asphalt). Conclusions are provided with respect to the effect temperature, road roughness, road grade, and vehicle weight have on fuel consumption. The data shows there are potentially significant differences between the concrete and asphalt pavements for the heaviest and fastest test conditions.

REFERENCE

Fuel Savings of Heavy Trucks on Concrete Pavement, SR351, Portland Cement Association, Skokie, Illinois, USA, 2001, 8 pages.

FUEL SAVINGS OF HEAVY TRUCKS ON CONCRETE PAVEMENT

A report prepared for the Cement Association of Canada indicates fuel consumption of heavy trucks on concrete pavements is significantly reduced compared to asphalt pavements when the heavy trucks are traveling at higher speeds. (Heavy trucks are defined as weighing 17,100 to 39,700 kg (37,700 to 87,500 lb). Fuel consumption over all temperature ranges for heavy trucks traveling on the asphalt pavements increased by an average of 11%, 8%, and 6% for speeds of 100, 75, and 60 km/h (62, 47, and 37 mph), respectively.

TESTING AND PARAMETERS

The study was undertaken by the National Research Council of Canada, Centre for Surface Transportation Technology (NRC-CSTT)[1] and was conducted for the Cement Association of Canada, formerly the Canadian Portland Cement Association. The purpose of the report was to evaluate the connection between heavy truck fuel consumption and pavement structure. Pavement structures included concrete, asphalt, and composite concrete/asphalt overlay highways. The effects of pavement roughness, vehicle configuration, speed, vehicle load, and ambient temperature were taken into account for each pavement type and are summarized in Table 1. The study differs from previous research in that it attempted to hold all input variables constant while changing the structure of the pavement.

[1] Taylor, Gordon, Marsh, Philip, and Oxelgren, Eric, "Effect of Pavement Surface Type On Fuel Consumption," National Research Council of Canada, Centre for Surface Transportation Technology, Report No. CSTT-HWV-CTR-041, Ottawa, Ontario, PCA R&D Serial No. 2437, August 2000, 129 pages.

Table 1. Test Variable Matrix

Variable	Number of Conditions	Conditions
Pavement Structures	3	Concrete** -Highway 440 in Laval, QC -Highway 40* in Vaudreuil,QC Asphalt -Highway 417 near Casselman, ON -Highway 25 near Laval, QC -Highway 40* in Vaudreuil, QC Composite (Asphalt/Concrete)-Highway 401 near, Lancaster, ON
Pavement Roughness	2	IRI <1.5, IRI> = 1.5***
Vehicle Types	3	3 axle straight truck, 5-axle tractor semi-trailer, 7-axleB-train
Load	3	Empty, Half-full, Full†
Speed	3	100, 75, 60 km/h,(62, 47, 37 mph)
Seasons	4	Spring, Summer, Fall, Winter
Temperature	4	<-5, -5 to 10, 10 to 25, >25 °C (<23, 23 to 50, 50 to 77, >77 °F)
Test Directions	2	Bi-directional

Notes: * A fourth concrete and asphalt site was added for Fall and Winter tests - Highway 40 near Vaudreuil, QC.
** Throughout the report the terms concrete and asphalt refer to portland cement concrete and asphalt concrete respectively.
*** IRI - International Roughness Index. A high IRI indicates a rougher pavement.
† Empty is 17,100 kg (37,700 lb); Half-full is 28,400 kg (62,600 lb); Full is 39,700 kg (87,500 lb).

Previously, fuel consumption was back-calculated using fuel weight difference methods after the tests were completed. This study employed the use of a computer linked directly to engine output which enabled engineers to measure real-time engine data of which one component was fuel flow. This allowed the use of shorter test sections so that grade as well as other external variables could be held constant more effectively.

Overall the study realized two major benefits of constructing pavements from concrete rather than asphalt. First, the results indicate that concrete pavements reduce fuel consumption of heavy trucks when compared to asphalt pavements. Second, the IRI[2] values were less affected by seasonal changes on the concrete pavement relative to the asphalt pavement. This means IRI values on concrete pavements were found to be more stable throughout the year.

FUEL CONSUMPTION

The results from the study indicate that fuel consumption of heavy trucks is greater on asphalt pavements. Heavy vehicles cause greater deflection on flexible pavements than on rigid pavements. This increased deflection of the pavement absorbs part of the vehicle energy that would otherwise be available to propel the vehicle. Thus, the hypothesis can be made that more energy, and therefore more fuel, is required to drive on flexible pavements.[3] Concrete's rigid design reduces road deflection and corresponding fuel consumption.

[2] The International Roughness Index (IRI) is a measure of a pavement's average vertical elevation changes. Measurements are taken under each wheel path and averaged over a 50 m (160 ft) distance interval. Higher IRI values indicate rougher pavement.

[3] Zaniewski, J.P., *Effect of Pavement Surface Type on Fuel Consumption,* SR289, Portland Cement Association, Skokie, Illinois, 1989.

Of the five pavements analyzed, this trend was most prevalent between the bituminous asphalt pavement on Highway 417 and the concrete pavement on Highway 440. The largest differences occurred for fully loaded tractor semi–trailers at all test speeds as shown in Table 2. The average fuel consumption on the asphalt pavements was 11%, 8%, and 6% higher relative to concrete pavements for speeds of 100, 75, and 60 km/h (62, 47, and 37 mph) respectively. For all other pavements, trends were less consistent and differences between fuel savings on asphalt and concrete pavements were less, but nonetheless visible.

Table 2a. Fuel Consumption Results For Fully Loaded Trucks (SI units)

Load	Full		Full		Full	
Speed (km/h)	100		75		60	
Pavement	Asphalt	Concrete	Ashpalt	Concrete	Ashpalt	Concrete
Temp °C	Estimated L/100 km					
-20	50	45	40	37	35	34
-10	48	43	38	36	34	32
0	46	41	37	34	32	30
10	44	39	35	33	31	29
20	41	37	34	31	29	27
30	39	35	32	30	28	26
40	37	33	31	28	26	24
Temp °C	% Difference from Concrete					
-20	12.2%		6.6%		5.9%	
-10	11.9%		6.9%		6.0%	
0	11.6%		7.2%		6.1%	
10	11.3%		7.6%		6.3%	
20	11.0%		7.9%		6.4%	
30	10.6%		8.3%		6.6%	
40	10.2%		8.8%		6.9%	

Note: A positive percentage difference means a higher fuel usage on asphalt.

Table 2b. Fuel Consumption Results For Fully Loaded Trucks (US units)

Load	Full		Full		Full	
Speed (mph)	62		47		37	
Pavement	Ashpalt	Concrete	Ashpalt	Concrete	Asphalt	Concrete
Temp °F	Estimated gal/100 mile					
-4	21	19	17	16	15	14
14	20	18	16	15	14	14
32	20	17	16	14	14	13
50	19	17	15	14	13	12
68	17	16	14	13	12	11
86	17	15	14	13	12	11
104	16	14	13	12	11	10
Temp °F	% Difference from Concrete					
-4	12.2%		6.6%		5.9%	
14	11.9%		6.9%		6.0%	
32	11.6%		7.2%		6.1%	
50	11.3%		7.6%		6.3%	
68	11.0%		7.9%		6.4%	
86	10.6%		8.3%		6.6%	
104	10.2%		8.8%		6.9%	

Note: A positive percentage difference means a higher fuel usage on asphalt.

PAVEMENT SMOOTHNESS

Another important finding of the report was a consistent reduction in fuel consumption of about 10% for vehicles traveling on very smooth roads. A very smooth road was defined as having an average IRI value less than or equal to 1.0. Although the connection between fuel consumption and pavement roughness was not as clear for pavements with an IRI above 1.0, a definite reduction was observed in every case where pavements had an average IRI value of 1.0 or less. This reduction of fuel consumption was independent of pavement type.

A difference in pavement roughness between asphalt and concrete pavements was observed during seasonal changes. For this evaluation the pavements were separated into smooth (IRI ≤2.0) and rough (IRI >2.0) conditions. Table 3 categorizes pavements into groups of smooth (IRI values up to 2.0) and rough (IRI values of 2.7 and greater). Note that an IRI of 1.0 or less is a very smooth road. Although the rough pavements experienced little change in roughness throughout the year, the smooth pavement sections experienced the highest amount of seasonal change as shown in Table 3.

Of all the smooth test sections evaluated, the Highway 440 concrete IRI values were the most stable throughout the year, while the Highway 417 asphalt IRI values increased as much as 63% in the winter. This implies that smooth concrete pavements should maintain lower IRI values throughout the year than asphalt pavements. Therefore the increase in roughness of the asphalt pavements experienced during the winter months could increase the fuel consumption of heavy trucks on these roads as compared to the more stable concrete pavements.

Table 3. Effects of Pavement and Season on IRI* (Smoothness)

	IRI (average of two directions)				% Change from Fall IRI			
Smooth	Spring	Summer	Fall	Winter	Spring	Summer	Fall	Winter
417 Asphalt	1.1	1.1	1.1	1.8	1%	-1%		63%
40 Asphalt			1.5	2.0				33%
25 Asphalt	1.4	1.2	1.4	1.5	2%	-13%		10%
440 Concrete	1.5		1.4	1.4	4%			-1%
40 Concrete			1.1	1.3				20%
401 Composite	1.1	1.2	1.2	1.3	-7%	-3%		4%
Rough	Spring	Summer	Fall	Winter				
417 Asphalt	3.9	3.8	4.1	3.9	-6%	-7%		-4%
440 Concrete	3.1		3.1	3.1	-2%			-2%
401 Composite	2.9	2.9	3.0	2.7	-2%	-3%		-10%

* IRI - International Roughness Index. A high IRI indicates a rougher pavement.

Although the lower fuel consumption observed for heavy trucks traveling on concrete pavement versus asphalt pavement verify the findings of other studies on the topic, it is important to point out the limitations of the data. Due to the sample size, only qualitative differences in fuel consumption can be seen. Additional data are required to verify a statistically accurate difference between the pavement groups.

SUMMARY

Results of the study show that compared to asphalt pavements, the fuel consumption of heavy trucks is lower on concrete pavements. Trucks traveling on concrete pavements were shown to improve fuel consumption on average by as much as 11% over all temperature ranges. In addition, the IRI values of concrete pavements were found to be less affected by seasonal changes than asphalt pavements which could also lead to lower fuel consumption.

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