Production of Cleaner Hot Mix Asphalt (CHMA) in Canada

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Abstract

The production of sustainable asphalt mixtures is a challenge for the asphalt industry as a whole. However, new technologies such as Warm-Mix Asphalt (WMA) appear to produce more environmental friendly asphalt mixtures, helping meet this challenge of sustainability. There are still many obstacles in developing this technology, though, such as making the required modifications to asphalt mixing plants, cost of mix production and the long-term performance of WMA. Currently, WMA is produced and evaluated using the same mixture design and performance tests as Hot-Mix Asphalt (HMA), but it seems that the current mixture design methods should be improved by evaluating the Environmental Polluting Potentials (EPPs) of materials in the asphalt mixture. In this paper, the effects of aggregate sources were studied as regards the parameters proposed as indicators for EPPs of materials as correlates to the production of HMA in Canada, as a case study. The results clearly indicated that Cleaner Hot-Mix Asphalt (CHMA) can be produced irrespective of asphalt binder, aggregate and industrial fuel types in the mixing plants. The results also showed that the total amount of saved fuel, based on the EPP of materials, is equivalent to the amount required energy to energize anywhere from4000 to 14503 Canadian households per annum, indicating a significant amount of energy saving without any modification to the asphalt mixing plants.

1. Introduction

A variety of different materials –such as aggregate materials, cement, asphalt binder, and industrial fuel – are required to produce the pavements. Despite these variances, it is expedient that all pavement types, including asphalt, cement concrete and concrete block pavements, should act harmoniously in sustainable development. It is with this goal in mind that pavement experts have made a constant effort to develop new technologies for production of more sustainable pavements. For example, one such technology is warm-mix asphalt (WMA). There are various additives to produce WMA, with different mechanisms, one of which is Sasobit®. Canadian researchers studied the effects of Sasobit® on rheological properties of asphalt binders [1]. Aurilioet al. [2] carried out a trial study on WMA incorporating Sasobit®. In this trial study, the mixing temperature of asphalt mixture and range of compaction temperatures were 130°C and approximately 90–110°C, respectively, while the ambient temperature fluctuated from 3 to 10°C. Paving crews reported no observed fumes as the mix was laid down and compacted, and that the mix was ready to work, and neither shoving nor pushing of the mat was verified during compaction. Fuel requirement was reduced by 30% by the use of WMA on Victoria Street; this reduction was the main motivation for using WMA in cold climates.

Although WMA can lead to producing more sustainable asphalt mixtures, it may require some modifications in the asphalt plants. Consequently, it may impose additional costs in the paving projects; yet it is necessary to produce sustainable pavements which are simultaneously affordable in order to encourage their use by both the asphalt industries and customers.
Additionally, since Canada is an energy-intensive country, the energy sector is a vital section of the economy of Canada in terms of trade, investment, income generation and employment [3]; as such, an effective energy policy is necessary to produce more energy-efficient asphalt mixtures. It should also be noted that developing an effective energy policy in pavement construction is

impossible without sufficient knowledge of energy consumption and emission analysis of important specifications of pavement material. It is with this in mind that Jamshidi et al. [4] suggested the use of specific heat capacity (C) of aggregate materials as environmental polluting potentials (EPPs). The use of a C coefficient in the aggregate selection source would upgrade Superpave™, an integrated system incorporating performance-based and asphalt binder rheological characteristics with design service conditions through its control of rutting, intermediate and low temperature cracking; furthermore, the method offers the potential to assess the EPP and environmental friendliness of the materials sources [4,5]. Jamshidi [6] also studied the effects of specific heat capacity, in terms of total energy consumption, exergy and greenhouse gas (GHG) emissions, for different countries in various continents, such as Australia, Canada, China and the United States. This paper briefly presents the results of energy analysis and GHG emission for production of cleaner Hot-Mix Asphalt (CHMA) for Canada.

2. Materials and Methods

The supposed aggregate type is granite,and the gradation is an unimportant factor for computing fuel requirement and GHG emission. Table 1 presents the aggregate's properties. These values are selected in order to show the effects of a C coefficient of the materials in energy consumption and GHG emission.

Table 1: Properties of Aggregate at 25°C

Aggregate Type	Specific gravity	Specific heat capacity(C)	Source	Reference
	gr/cm^3	J/kg˚C		Kuad Quarry
Granite	2.650	790	1	
	2.620	1188	2	[7]

Two asphalt binder types were chosen, PG 64 and PG 76. The asphalt binders often have no significant effects on total energy consumption of asphalt mixture since they make up only 4% to 6% of the total mass of the asphalt mixture. In this study, it was supposed that optimum binder content is 5%. Table 2 shows the rheological properties of the asphalt binders.

Table 2: Rheological Properties of Asphalt Binders

Asphalt binder		PG64		PG76
Aging State	Test Properties	Value		Value
Unaged (origin state)	Viscosity at 135ºC (mPa.s)	465		2587.50
	G*/sinδ at 64ºC (kPa)	1.23	at 76ºC (kPa)	1.51
	Specific Heat Capacity J/kg°C	920		2093
Short-term-aged	G*/sinδ (kPa) at 64ºC	2.68	at 76ºC (kPa)	3.07
Long-term-aged	G*sinδ at 25ºC (kPa)	2958.75		1649.7

The total number of mixture productions of asphalt mix in Canada is 30 million per annum [8]. This amount of total asphalt mixture was selected for use in this study. Therefore, total aggregate and total asphalt binder mass are 28,500,000 tons ($0.95*30*10^6$) and 1,500,000 ton ($0.05*30*10^6$), respectively.

It is also supposed that the industrial fuel utilized in the asphalt mixing plants is natural gas. The ambient temperature of the environment was assumed to be 25°C. The amount of required heat energy, fuel requirements and GHG emissions were computed for hot-mix asphalts produced at 160 and 180°C for PG 64 and PG 76, respectively. Although the assumed materials in this study may not have the same specifications as materials that are available in Canada, the main objective of this study is to study the role of materials in energy consumption and GHG emission in asphalt mix production in a case study of national-scale.

The amount of required heat energy, fuel requirement and GHG emissions were computed using user-friendly computational software developed by Jamshidi [6], called EFEAS (Energy, Fuel and Emission Analyzing Software). The outputs of software are the energy and fuel requirements, and GHG, CO_2, CH_4 and N_2O, emitted to heat materials from ambient temperatures to the mixing points of the asphalt mixtures.

3. Discussion

Table 3 shows amount of energy, fuel requirements and GHG emissions for asphalt mixtures produced using PG 64 and PG 76 binders. According to Table 3, the required heat energy to produce the asphalt mixtures containing aggregate from source 2 is significantly higher than source 1, irrespective of binder type. The reason behind this difference is that, although the specific gravity values of the aggregates from different sources are very much similar to each other, as shown in Table 1, their specific heat capacities widely differ. A higher specific heat capacity means that more energy is required to raise its temperature.

Table 3: Required Heat Energy and Value of Fuel for Heating PG 64 Binder and Aggregates for Total HMA Production in Canada

Source	Binder type	Q_T* (TJ)	Fuel requirements	GHG		
				CO_2 (Ton)	N_2O (Ton)	CH_4 (Ton)
1	PG 64	3701	$9.7*10^7$	195487	116	290
2		5472	$1.4*10^8$	289015	171	429
1	PG 76	4603	$1.20*10^8$	243141	144	361
2		6677	$1.74*10^8$	352686	209	523

*: Total required heat energy to heat aggregate and asphalt binder

For example, Table 3 shows that amount of natural gas required to produce HMA using aggregate from source 1 is $9.7*10^7 m^3$, while producing the same asphalt mixture using aggregate from source 2 requires $1.4 *10^8 m^3$, which is 44.30% higher than that of the aggregate from source 1. Consequently, the amount of GHG emissions from producing asphalt mixtures using aggregate source 2 is much higher than those of source 1. Therefore, aggregate from source 1 is more energy-efficient and sustainable, compared to that of source 2, in terms of fuel requirement and GHG emissions; this is due to a lower C coefficient. Although the C coefficient shows significant effects on energy consumption, Canadian researchers found no distinct relationships between air void and the amount of course aggregate in HMA for different aggregate sources [9]. In another research, the Canadian researchers also found that there was no relationship between the C coefficient and the engineering properties of HMA in terms of the resilient modulus, mix density, Marshall stability and flow [10].

In addition, high GHG emissions due to the use of aggregate with high a C coefficient can lead to an increase in carbon tax for the asphalt mixing plants. As a result, the total cost of paving projects may increase. Furthermore, the following problems may emerge in different phases of the life cycle of the asphalt pavement, due to theuse of aggregate with a high C coefficient:

- Pavement Construction
  In the phase of pavement construction, more fuel consumption is required and more GHGs are emitted. In addition, more time is required to heat up aggregate in the mixing plant. Consequently, equipment may become fatigued faster in the mixing plant, do to increased operation levels.

- Pavement utility
  Due to a high specific heat capacity, more heat energy is absorbed by aggregate particles. After mixing, the released heat is absorbed by the asphalt binder coating the aggregate particles. Therefore, the asphalt binder becomes stiffer, due to higher aging. Consequently, more failures can be found, due to this higher aging. Meanwhile, the released heat can generate extra stresses in the internal structure of asphalt mix that are not predicted in mixture design and structural design of pavement. This can even lead to premature failures, and therefore, the costs of utility of pavements increases further.

- Pavement Recycling

Due to high stiffness of asphalt mixture constructed using high C coefficient, more energy is required to remove the old pavements. Therefore, the machinery of asphalt recycling can become more fatigued more quickly, and operational costs increase.

As a result, use of aggregate with a high C coefficient can create many problems which may be avoided during process of pavement material selection and construction. That is why Jamshidi et. al. [4] recommended the C coefficient as EPP in the Superpave™ mix design method.

An alternative to reduce the requirements of both heat energy and fuel, as well as GHG emissions, is the use of a high specific heat capacity aggregate is replaced with the same aggregate type, but possessing of a lower specific heat capacity. For instance, a fraction of granite aggregate with specific heat capacity, source 2, in a mixture is suggested to be replaced by another granite aggregate possessing a lower specific heat capacity, source 1. In other words, the optimum aggregate mixture is a blend of two aggregates from the same aggregate type, but each with different specific heat capacity values. Table 4 shows the aggregate blends recommended in producing asphalt mixture.

Table 4: Aggregate Blends Incorporating one Type of Aggregate with Different C Coefficients

Asphalt Blend	Percentage from source 1	Percentage from source 2
A	0	100
B	25	75
C	50	50
D	75	25
E	100	0

Table 5 clearly shows that the amount of energy and fuel requirement, as well as GHG emissions, is reduced by using the aggregate blends proposed in Table 4. It can be seen that the fuel requirement and GHG emissions decrease as the amount of aggregate with low specific heat capacity increases – irrespective of binder types. This indicates that a combination of the aggregates with low and high C coefficients can also reduce fuel consumption significantly. Therefore, use of low-C- coefficient aggregate is a proposed strategy to promote sustainability of HMA without any modification to theexisting technology of asphalt mixing plants.

Table 5: Required heat energy and value of fuel for Heating Binder and Aggregate Blends for Total HMA Production in Canada

Asphalt Mixture	Binder Type	Q_T(TJ)	Fuel Requirement (m^3)	GHG		
				CO_2 (Ton)	N_2O (Ton)	CH_4 (Ton)
A	PG 64	5472	$1.4*10^8$	289015	171	429
B		4900	$1.28*10^8$	265633	158	394
C		4470	$1.17*10^8$	242251	144	359
D		4040	$1.05*10^8$	218869	130	325
E		3701	$9.7*10^7$	195487	116	290
A	PG 76	6677	$1.74*10^8$	352686	209	523
B		5970	$1.56*10^8$	325299	193	482
C		5470	$1.43*10^8$	302295	179	448
D		4970	$1.30*10^8$	297913	161	401
E		4603	$1.20*10^8$	243141	144	361

It is obvious that the effects of an aggregate with a low C coefficient on long-term performance of HMA should be evaluated in more detail in terms of fatigue, rutting, aging and moisture sensitivity. Furthermore, the costs and environmental loadings of low-C-coefficient aggregatesusage should be investigated in the life cycle of pavements using rating systems such as Life Cost Analysis (LCA) and Leadership in Energy and Environmental Design (LEED).

Effects of the use of aggregate with a low C coefficient is more readily apparent when the amount of energy saved is evaluated in terms of household energy consumption per annum. Annual Energy Consumption of aHousehold is 143 GJ per in Canada [11]. Figure 1 illustrates the effects of the amount of energy saved due to use of a low-C-coefficient aggregate. Figure 1 also shows the number of Canadian households be energized per annum using the energy saved by using a low-C-coefficient aggregate in HMA production. It is clear that the number of refueled households increases as the amount of low-C-coefficient increases, irrespective of asphalt type, which indicates significant improvement in energy efficiency on a national scale.

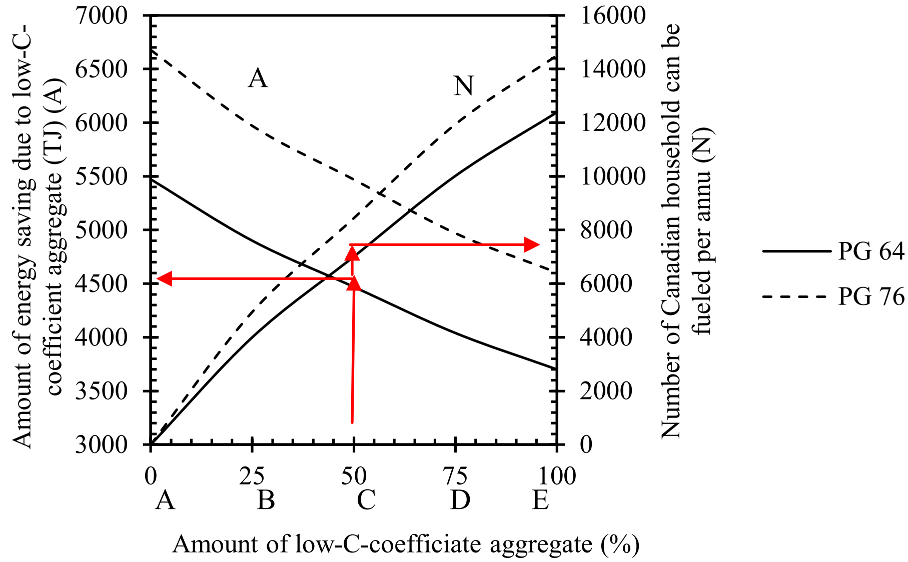

Figure 1: Relationship between Amount of Low-C-coefficient Aggregate and Energy Saving and Number of Fueled Canadian Households per Annum.

This can serve as a sharp justification for environmental policy makers and energy planning experts to promote the development of greater sustainability of HMA on a large scale. Analysis of energy savings based on the provision of annual household energy would encourage asphalt industries to save more energy and subsequently reduces the energy cost in asphalt mixing plants, stimulating economic growth and conforming to the Kyoto protocol limit on GHG emissions.

4. Conclusion

This study was just an example intended to measure the potential effects of aggregate energy absorbance in terms of a C coefficient in HMA production in Canada. The results strongly indicated that a more energy-efficient and cleaner HMA (CHMA) can be obtained by selecting aggregate sources with minimum required heat energies. Aggregate potentials should be measured in the terms of the C coefficient in order to select the best aggregate source. The C coefficient of aggregates is a good criterion for evaluating the energy requirements and the GHG emissions of asphalt mixes as EPP. A lower specific heat capacity can reduce the fuel requirements and GHG emissions by up to the 44.30%. Blends of aggregates with high and low specific heat capacities were evaluated as an alternative to produce more environmentally friendly HMA. Amount of energy saved through the use of low-C-coefficient aggregates in HMA production is considerable. The amount of energy saved is enough to energize anywhere from 4000 to 14503 Canadian households. This energy saving is obtained without any modification to the current technology of asphalt mixing plants. In conclusion, energy policy makers and engineers can adopt the use of low-C-coefficient aggregate as a strategy to produce much more sustainable HMA or CHMA in Canada.

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