Environmental Impacts and Fuel Efficiency of Road Pavements

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Executive Summary

Advantages of different road pavements from an environmental viewpoint and energy consumption have become an important part of the planning process for highway projects in many countries. In this report knowledge about fuel efficiency and greenhouse gas emission of different road pavements has been compiled.

Fuel economy and environmental emissions of road pavements at different stages

A method to get a good overview of the environmental impact of highways on the construction, maintenance and operation is to perform a LCA (Life Cycle Assessment). IVL, the independent Swedish Environmental Research Institute, has carried out a LCA study of roads in collaboration with NSRA, the National Swedish Road Administration. The study was performed for a 1 km long and 13 m wide road and included construction, maintenance and operation during 40 years.

The results of the IVL study show that the total energy consumption during construction, maintenance and operation (i.e. mainly traffic lights and lighting) of roads is lower for asphalt pavements than for concrete pavements. Also, the greenhouse gas emissions during construction, maintenance and operation are lower for asphalt pavements.

The Athena Sustainable Materials Institute in Canada has also performed a study on behalf of the Canadian Cement Industry about energy requirements and greenhouse gas emissions for concrete and asphalt pavements. In the Athena study the compared high traffic pavements were not equivalent from a design perspective. After a correction for pavement thickness the final results of the Athena study show that asphalt always has the lowest Green House Gas emission (GHG) and the lowest Global Warming Potential (GWP).

The energy consumption of the traffic itself on a road over its lifetime is of overwhelming importance. Depending on the traffic volume, the energy use for construction, maintenance and operation of the road is less than 2 to 5% of the energy used by the traffic itself. Therefore it is legitimate to focus on how different road pavement surfaces affect the fuel consumption of vehicles driving on it.

Factors impacting energy/fuel consumption for a vehicle

There are many factors that impact on the energy/fuel consumption for a vehicle. These factors can be divided into rolling resistance, air resistance, gradient resistance, inertia resistance and driveline losses. The factors are of different importance for different vehicles. About 12% of the fuel consumption for heavy trucks depends on the rolling resistance of the tyres. The importance of rolling resistance for fuel consumption is less for private cars than for heavy trucks especially at higher speeds.

Factors influencing the rolling resistance

The rolling resistance depends both on how the tyre is designed (tyre factors) and on different characteristics in the road pavement. Many different tyre factors influence the rolling resistance including the shape of the tyre, air pressure, the composition of the tyres and the ambient temperature.

The type of road pavement and its surface also influences the rolling resistance. Different surface characteristics (texture) give major impact on the rolling resistance but also the structural behaviour, such as bearing capacity and viscoelastic behaviour can influence the rolling resistance.

Impact of pavement surface characteristics

Published data on road surface effects on fuel consumption or rolling resistance have indicated significant influences of different textures. An experiment on the influence of road macro- and megatexture on fuel consumption has been performed by VTI in Sweden. The result of the study shows that fuel consumption for a passenger car varies over a range of approximately 11% from the smoothest to the roughest pavement tested. Fuel consumption on cement concrete is about the same as on dense asphalt concrete.

In another experiment in the Netherlands fuel consumption for passenger cars driving at constant speed on different types of pavements was studied. The results of the experiment show that fuel consumption varies up to 7% for different road surfaces (asphalt and concrete). The results also show from a statistical point of view that there is no significant difference in fuel consumption between asphalt and cement concrete road surfaces.

At WesTrack, an accelerated pavement test facility in Nevada, USA, fuel consumption for the driverless trucks used for pavement loading has been studied before and after major rehabilitation of the pavements. The data showed that rehabilitation reduced average IRI, International Roughness Index, by at least 10%. Under otherwise identical conditions, the trucks used 4.5% less fuel/km on smooth, post-rehabilitation pavement than on rough, pre-rehabilitation pavement.

Impact of structural behaviour: viscoelastic behaviour of asphalt pavement

In an experiment conducted by NRC, National Research Council, in Canada, the effect of pavement structure on fuel consumption for heavy trucks has been studied. The results of the study show that there seems to be some differences in fuel consumption for asphalt and concrete pavements. One of the three asphalt test sections had higher fuel consumption than the concrete section. In this asphalt section the fuel consumption was between 4 and 7% higher than on the concrete section. But contradictorily the other two asphalt sections had the same fuel consumption as the concrete section.

However, in the same NRC report a number of significant statistical limitations were mentioned. These included differences in surface roughness, large variation in air and pavement temperatures and short pavement test sections. Based on the limitations of the study, it is apparent that no valid conclusions can be drawn regarding fuel savings attributed to pavement type.

NPC, Netherlands Pavement Consultants have made a theoretical calculation of the maximum energy dissipation when driving on asphalt pavement and when driving on rigid cement concrete. In the calculation NPC used the linear visco-elastic multi-layer program VEROAD® developed at Delft University of Technology.

The conclusion in the NPC report is that the maximum increase of fuel consumption caused by the visco-elastic behaviour of asphalt pavement in comparison with rigid cement concrete pavement is:

- In the spring and autumn approximately 0.16%
- In the summer (worst case: extreme hot day) approximately 0.88%
- On a yearly average it is estimated that less than 0,05% extra fuel consumption may exist for truck driving on asphalt pavements.

Any possible difference is likely to be much less than 1%, which differs from the Canadian study. The results in the NPC report are also confirmed by another theoretical study carried out at LCPC, France. The scope of the study was the calculation of the rolling resistance of a rigid cylinder rolling on a homogeneous visco-elastic support. The result of this study shows that the rolling resistance calculated for a speed of 90 km per hour at 15°C is equal to the tangent of the angle of 0.00036, which represents a slope of 0.036% (i.e. almost negligible: 36 cm for 1 km).

Overall the surface roughness effects (approximately 5-10%) far outweigh any effect due to the viscoelastic behaviour (< 0.1%). Taking these aspects into consideration the total truck and passenger car population might easily result in an advantage in fuel consumption for asphalt pavements.

General conclusions

The results of the different studies show that there are a lot of factors that influence the energy consumption and greenhouse gas emission for roads. It is therefore very difficult to get conclusive results from field experiments and different studies yield conflicting conclusions.

It is clear that during construction, maintenance and operation of roads the energy consumption and the greenhouse gas emissions are lower for asphalt than for concrete pavements. But it is the traffic on the road that accounts for the major part (> 95 or 98% depending on traffic volume) of the total energy consumption and greenhouse gas emission, and here the differences between pavement types as such (asphalt or concrete) are not significant. More important for the fuel efficiency are pavements in good condition with good surface characteristics (texture and roughness). Optimal maintenance of the roads is therefore the means to limit fuel consumption and green house gas emission.

Besides energy consumption decision makers need also to consider several other factors in order to satisfy the multiple requirements of protecting the environment (limiting green house gas emission), saving energy, reducing traffic noise and ensuring good driving safety and comfort.