National Center for Asphalt Technology
NCAT
at AUBURN UNIVERSITY

Synthesis of the Effects of Pavement Properties on Tire Rolling Resistance

RESEARCH SYNOPSIS–NCAT REPORT 11-05

Problem Statement

Interest in improving vehicle fuel economy has increased as costs of energy resources continue to rise and the public becomes more environmentally conscientious. Fuel economy is affected by factors such as vehicle aerodynamics, engine efficiency, drivetrain losses and rolling resistance of tires on pavements.

Objective

The main objective of this study was to investigate the influence of pavement type (i.e., asphalt and concrete) on the rolling resistance of vehicle tires by reviewing existing literature. It was also important to research the influence of specific pavement properties such as stiffness and surface texture on rolling resistance. Existing methods of measuring rolling resistance and quantifying the influence of these properties were also investigated.

Background

Vehicle rolling resistance is the force required to keep a tire moving. The force comes from friction losses at the rolling interface due to some slip, friction in the bearings (internal), aerodynamic drag (although some researchers may not consider this rolling resistance) and energy losses due to deformation of the tire rubber. If the tire is moving at a constant speed, the rolling resistance force will balance with the traction force between the road and the tire. The torque driving the tire then balances with the torque created by the traction force. A wheel rolling with no slip against a smooth, level and rigid surface would have no rolling resistance.

Factors that affect rolling resistance are the material composition of the tire, the geometry of the tire, the road composition, and the roughness of both the tire and the road. Air temperature, vehicle speed and inflation pressure of the tire will also affect rolling resistance. At a constant velocity, the amount of fuel a vehicle consumes is determined by rolling resistance in addition to internal friction and air drag.

Literature Review: Key Findings

Approximately two dozen recent publications that investigated the effect of pavement properties on rolling resistance were reviewed for this synthesis. These studies evaluated the effects of properties such as pavement stiffness, smoothness and texture. The following is a summary of the findings.

Effect of Pavement Properties on Rolling Resistance
In pavement engineering, pavement surface geometries such as texture and roughness are classified by wavelength scales. The smallest scale is microtexture, which applies to wavelengths less than 0.5 mm. Microtexture deals with the texture of aggregate particles on the pavement surface and affects skid resistances. Wavelengths in the range of 0.5 to 50 mm are considered macrotexture. This is the general surface relief of the pavement that is visible to the naked eye.

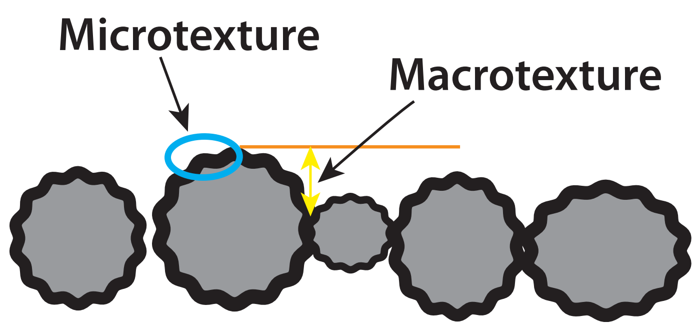

Figure 1 Schematic of the effect of aggregate on different scales of texture.

Pavement roughness, typically with wavelengths greater than 0.5 meters, is generally cited throughout the literature as the pavement characteristic having the greatest influence on rolling resistance. This wavelength range causes significant deformation of the tire as well as shocks that induce vibrations and energy loss.

To determine the smoothness of asphalt compared Portland cement concrete (PCC) pavements, one study conducted for the Ontario Ministry of Transportation in 2007 measured the texture of two pavements using the standard International Roughness Index (IRI). The initial IRI of the asphalt pavement assessed in the research was 0.83 m/km, while the average IRI of the PCC pavement was 1.34 m/km, showing that the asphalt pavement was initially smoother than the PCC pavement.

Several studies related pavement smoothness directly to fuel consumption; for example, one looked at how changing the IRI influences fuel economy. A study conducted in Denmark suggested that reducing the IRI of a roadway by just 6 percent can reduce fuel consumption by 1.8 to 2.7 percent. Others showed that driving on smoother pavements can increase fuel economy by as much as 4 to 4.5 percent.

The literature also indicated that a surface texture spectrum that minimizes rolling resistance and maximizes friction may be optimal. Not only does maximizing friction improve driver control of a vehicle, more friction will also keep the tire surface from slipping against the road. Slippage decreases rolling resistance because it dissipates energy.

Overall, the literature review indicated that a smoother road can decrease fuel consumption by decreasing the vibrations of the tire and suspension. However, pavement deformation and energy loss will vary based on the scale of roughness, vehicle speed and vehicle type. Pavement deforms when it comes in contact with the tire and, therefore, dissipates some energy.

While one study suggested that a stiffer pavement may be best for this reason, other references concluded that most deformation and energy loss is associated with tire rather than with pavement deflection.

Experimental Methods for Measuring Rolling Resistance

Researchers have used three methods to measure the rolling resistance of tires and pavement conditions: bench (laboratory) tests, vehicle-based methods, and towed trailer methods. A common laboratory method for assessing tires' influence of rolling resistance involves a drum tire dynamometer, which measures forces during free rolling (no torque) at the tire hub. The hydraulic dynamic test is another laboratory method in which a wheel is vibrated to match a measured road profile, and the temperature change of the shock absorber is measured to determine the energy lost in suspension. Vehicle-based methods use techniques such as fuel consumption calculations, the coast-down method and placing force transducers in the vehicle. However, these methods are not completely effective in measuring rolling resistance since other sources of energy loss such as air drag and internal friction exist in a moving vehicle. Thus, it is difficult to isolate the portion of energy loss that results from rolling resistance.

Towed trailers, on the other hand, have been devised to isolate the forces measured for rolling resistance from the powertrain and minimize air drag. One reference used a trailer device that measured the deflection of a beam suspending the tire. The coefficient of rolling resistance was determined from the deflection angle.

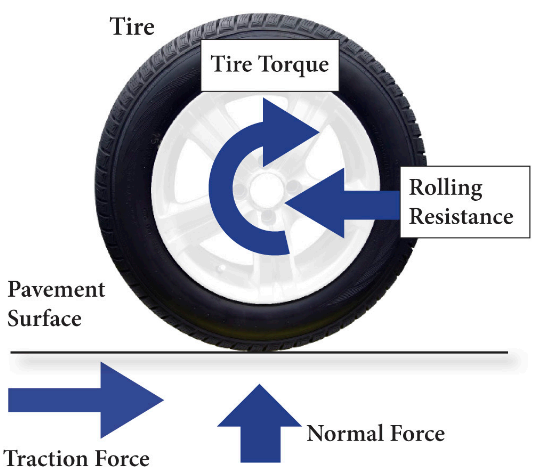

Figure 2 Schematic of the forces affecting a tire interacting with a road.

Maintaining Smooth Pavements

While most state agencies already have smoothness requirements for asphalt and concrete pavements, additional roadway design and construction criteria could be developed to improve smoothness. The cost to implement new standards could be repaid in fuel savings. The greatest challenge to developing a fuel-efficient pavement network would be maintaining the smoothness of pavement structures. Over time, both asphalt and concrete pavements exhibit changes in smoothness and texture. However, utilizing perpetual pavement design concepts would help state agencies maintain smoothness standards.

Potential Cost Benefits

A Denmark study conducted to determine the true cost-benefit of reducing pavement rolling resistance showed that the average fuel savings greatly outweighed roadway rehabilitation costs to build and maintain smoother pavements. The study estimated that it would cost $637,463,862 to repave 3,717 km of roadways, but the country would save 3.3 percent in fuel costs. Throughout 15 years, Denmark would save almost $3.78 billion dollars, including rehabilitation costs.

Conclusions and Recommendations

Pavement roughness and texture are key characteristics that affect rolling resistance, with large-scale roughness being the most important. The following additional conclusions and recommendations can be drawn from this literature review:

- Pavement stiffness does not appear to have a significant effect on the rolling resistance or fuel economy.
- Rolling resistance on concrete or asphalt pavements with the same surface texture should be almost identical.
- Improvements in pavement roughness could directly improve fuel efficiency by about 2 to 6 percent. However, it should be noted that fuel efficiency is also influenced by factors such as tire type and speed, in addition to energy losses not related to tire rolling resistance.
- Additional studies on rolling resistance under controlled conditions are suggested. An isolated trailer containing a rolling tire appears to be the best option for further evaluating the effects of pavement characteristics on rolling resistance. This trailer could be pulled over various pavement types at different speeds and loads, and the pavement surface profiles could be characterized using methods such as the IRI and spectral methods. Pavement texture, roughness and stiffness could be measured using an inertial profiler and falling-weight deflectometer (FWD).
- A comprehensive socioeconomic analysis should be conducted for the U.S. to determine the costs and benefits of using pavements with less rolling resistance.

Acknowledgements and Disclaimer

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