ABSTRACT

The purpose of this paper is to demonstrate the differences in braking capability of the different types of tires through data collected from single variable testing. The only variable in these tests was the type of tire installed. Three different tire types; summer, all season, and winter, all of the same size, were tested in moderate ambient temperature on wet and dry asphalt surface with a single vehicle. The braking tests were conducted with ABS activated and deactivated for modulated and locked wheel friction comparison of the tire types.

Accident reconstructionists rely on accurate friction coefficients to calculate speeds from skid and yaw marks left at a collision scene. Maximum effort braking performance, whether locked wheel or ABS modulated, is influenced mainly by the road to tire interaction and is affected by the type of tire.

High performance, “Summer”, tires are increasingly available as Original Equipment Manufacturer fitment. These tires were once reserved for sports cars and European performance sedans. Today they are available as standard or optional equipment on domestic Sport Utility Vehicles and compact cars. Summer tires are not intended to be used when temperatures are near freezing or on snow and ice, necessitating the use of either all-season or winter tires for owners in areas that are susceptible to these roadway conditions.

The vehicle chosen for this testing is available from the manufacturer with either all-season or summer tires. The vehicle was left in an as manufactured condition for all tests, with the exception of tire changes and deactivating the Anti-Lock Brake System/Electronic Stability Control Electro-Hydraulic Control Unit for locked wheel tests. The vehicle was braked from a target speed of 45 MPH for all tests. A total of 72 tests were conducted on both wet and dry pavement conditions.

The results show differences not only between the tire types, but how each tire types’ friction varies between wet and dry asphalt and ABS modulated and locked wheel braking. The results report tire friction values higher than typically published numbers.

INTRODUCTION

One of the primary purposes for reconstructing crashes is to establish the initial speeds of the vehicles that are involved. Law enforcement agencies, traffic engineers and others often used the speeds to help plan remedial measures to improve vehicular safety on public roadways.

There are many methods crash reconstructionists use to calculate the energy dissipated in the various phases of a crash. The length of skids, yaws or other distances where the primary force imparted to a vehicle is through the tire-pavement interface is a very important component of the overall energy dissipation.

Often standard values are used for tire to roadway friction, and sometimes modified to account for specific conditions on the roadway. These standard values are useful, but vehicles today are fitted with a wide variety of different types of tires. This study is intended to test the braking performance of three types of tires to better establish the variances in friction values that should be incorporated into energy dissipation calculations.

Others [1] have conducted similar testing; however this series of tests is the first to use a modern, non-modified vehicle that is available with all-season and summer performance tires as
an OEM option. The ABS has been calibrated with both types of tires during development of the vehicle.

The goal of this study was to determine how friction coefficients change when the type of tire is changed on the same vehicle. To maintain the comparison of just the change in tires, other variables that can affect the friction at the tire/road interface were controlled.

The secondary goal of this study was to measure the friction values under different conditions. As real-world conditions change and vary, testing was conducted with both wet and dry pavement, and with and without anti-lock brakes. The test protocol was developed to minimize all other variables.

Three different categories of tires are tested and measured: Summer only high performance, grand touring all season, and winter snow tires. These three represent the spectrum of tire varieties commonly fitted to passenger vehicles. Each of these tire types has different characteristics in the three major components of a tire design: tread compound, carcass construction and their tread pattern.

Summer only high performance tires are built to withstand high friction forces and heat buildup. These tires are often used by vehicle enthusiasts for track days or in some cases, used in racing classes where street tires are mandatory. In some racing classes, minimum treadwear grades are also specified. Their tread compound is designed for a high level of hot tear strength at the anticipated temperatures of track use, often over 100°C.

The tread pattern of these tires contains large solid blocks of rubber which are often interconnected to enhance stability and minimize squirm (movement in the tread blocks). The thin sipes used in other types of tires are not used as they can promote squirm and tearing of the tread rubber. Often wet traction and hydroplaning performance is compromised to some degree in order to place a large amount of rubber contact area in the tire footprint. The tread pattern of the tires tested is shown in Photograph 1.

The tire carcass is made very stiff to reduce the distortion of the tire footprint when stressed under cornering at levels often greater than 1g. The stiff carcass also contributes to high speed performance by raising the speed of onset for standing waves. Severe cornering is often accompanied by high loads on the tire's shoulder, so extra reinforcement here in the carcass, tread pattern and compound is useful to extend tire lift.

Winter snow tires are the polar opposite of summer only high performance tires. Snow tires are intended for operation at low temperatures ranging from near freezing to very cold sub-zero (0F, −14C) conditions. Therefore their tread compound, tread pattern and carcass design is very different, as shown in Photograph 2.
high lateral forces and can remain soft to further enhance the tire footprint conforming to irregularities in the road surface.

Naturally a winter snow tire will not be expected to perform well in warm weather on aggressive pavement.

The all season tire tries to split the difference between the summer and winter tires. This tire has light siping of the tread blocks, an intermediate stiffness of the carcass to provide a firm but comfortable ride, and a tread pattern intended to produce good wet traction and resistance to hydroplaning with low noise. The tread pattern of an all season is shown in Photograph 3.

This test is the first in an intended series of tests to evaluate the traction characteristics under braking for the three types of tires. This first series was performed in warm summer conditions. A follow-up series of testing is expected to be performed under winter type conditions.

**TEST METHOD**

A 2012 BMW 328i sedan was tested on an asphalt surface. The vehicle brakes were stock and the odometer displayed about 6500 miles. The vehicle was accelerated to a target speed of 45 mph, with the speedometer indicated speed verified with a radar gun. When the target speed was reached, the driver fully applied the brakes and skid to a stop. The vehicle was equipped with a Vericom VC3000 performance testing computer. The Vericom uses a two channel accelerometer to record acceleration and a crystal clock for time. The microcontroller uses these sensors to show the deceleration and to calculate the velocity and distance versus time at 100 Hz sample rate.

The relationship between acceleration and velocity is the following simple equation of motion solved for velocity:

\[ a = \frac{V_e - V_i}{t} \]

where \( a \) is the acceleration, \( V_e \) is the end velocity, \( V_i \) is the initial velocity, and \( t \) is time interval for the calculation. The relationship between acceleration, velocity and distance is the following equation:

\[ X = \frac{V_e^2 - V_i^2}{2a} \]

where \( X \) is the distance. Used in the brake testing mode, the test was triggered by the start of deceleration. The unit was calibrated against gravity, and leveled at the start of each test. The Vericom was mounted to the center of the windshield, which is just forward of the vehicle center of gravity of the vehicle. The angle of the Vericom was adjusted for the test vehicle's pitch when braking before each test.

When the vehicle yaws, some of the deceleration rate longitudinally would be read the by lateral sensor reducing the measured deceleration rate. During the braking tests the driver made certain to keep the vehicle straight during the test. The vehicle is most susceptible to yaw during skid testing without ABS brakes on low friction surfaces.

Compared to other data measurement techniques such as GPS systems, skid sleds, and paint mark measurements, the Vericom is very accurate. Previous work in the literature described and tested different test data acquisition and analysis methods for coefficient of friction [2], but did not conclude any method of data analysis better than another. Our purpose was to compare tires, so repeatability was our main concern. The reported Vericom accuracy is 1% [3], and the author's experience in accelerometer testing indicated this to be a repeatable technology. Vericom testing results in less error than a torque transducer based test [4].

One test track was dry and another was wet before each test set. A 500 gallon roadway sprayer was used to saturate the road surface. The sprayer dispensed about 450 gallons of water over a 265 m² area prior to each series of 6 runs for a particular tire and brake modulation test. About 1.1 liters per square meter were applied to wet the road. This is the equivalent of about 1 millimeter of water.

Both road surfaces exhibited similar wear and were clean and nearly level (as shown in Photograph 4).

The air temperature was about 75°F and it was sunny. All tires used during this testing were an OEM size for the vehicle of 225/45R18, mounted to Moda MD11 aluminum rims, and were changed in a complete new sets of four. The winter snow tires were Bridgestone Blizzak WS70, the grand touring all-season tires were Michelin Primacy MXM4, and the summer only high performance were Michelin Pilot Sport PS2. Each tire tread is shown in Photographs 1, 2, 3.
Each set of tires were driven between 150 and 200 miles of a combination of highway, city, and rural driving cycles before testing to remove manufacturing chemicals that may prevent the tire from achieving maximum performance. Tire pressure was adjusted to the factory recommended setting prior to testing.

Photograph 4. Wet track test site

Table 1. Comparison of visible skid length measurement and Vericom calculated stopping distances for all dry surface locked wheel barking tests.

<table>
<thead>
<tr>
<th>Tire Type</th>
<th>Run #</th>
<th>Starting Speed (MPH)</th>
<th>Measured Skid Length (ft)</th>
<th>Vericom Computed Distance (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pilot PS2</td>
<td>1</td>
<td>46.2</td>
<td>95</td>
<td>106.7</td>
</tr>
<tr>
<td>(summer)</td>
<td>2</td>
<td>44.5</td>
<td>92.5</td>
<td>97.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>43.5</td>
<td>87</td>
<td>89.9</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>43.2</td>
<td>85.5</td>
<td>89.5</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>45.0</td>
<td>89.5</td>
<td>97.9</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>49.4</td>
<td>96</td>
<td>114.2</td>
</tr>
<tr>
<td>Primacy</td>
<td>1</td>
<td>49.0</td>
<td>96</td>
<td>106.1</td>
</tr>
<tr>
<td>(all-season)</td>
<td>2</td>
<td>42.5</td>
<td>78</td>
<td>83.3</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>43.3</td>
<td>79</td>
<td>87.0</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>44.4</td>
<td>84</td>
<td>90.2</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>43.8</td>
<td>82.5</td>
<td>90.6</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>47.4</td>
<td>95</td>
<td>105.3</td>
</tr>
<tr>
<td>Blizzak</td>
<td>1</td>
<td>47.6</td>
<td>93.1</td>
<td>92.5</td>
</tr>
<tr>
<td>(winter)</td>
<td>2</td>
<td>43.6</td>
<td>82.9</td>
<td>77.5</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>46.10</td>
<td>90.0</td>
<td>86.4</td>
</tr>
<tr>
<td></td>
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<tr>
<td></td>
<td>6</td>
<td>43.7</td>
<td>77.0</td>
<td>79.8</td>
</tr>
</tbody>
</table>

Testing progressed from wet to dry pavement with the anti-lock brake system active. Then the plug connection to the ABS/ASC control module was unfastened to disable the anti-lock brakes and stability control for testing on both roadway surfaces. We performed 6 tests of each condition; per tire, on wet then dry pavement, with and without ABS for a total of 72 tests.

At the conclusion of each test, the data from the Vericom VC3000 was recorded on a data sheet. This data included the vehicle speed at brake application, braking distance, time to brake, and average deceleration.

During the locked wheel testing an observer was stationed in the braking area to determine if all wheels locked during the maneuver.

The visible skid marks from the locked wheel dry asphalt tests were also measured and compared to the braking distances recorded by the Vericom VC3000 in Table 1. There was no discernable difference in the color or darkness of the skid marks left by the different tires. Differences in the pattern of the marks were noted due to the differing amount of voids in the tire treads.

RESULTS

The Vericom VC3000 data was processed with Vericom's proprietary Profile 3 software to generate charts of deceleration rate and vehicle speed versus time. The figures below show the deceleration and vehicle speed versus time for the 6 data samples collected for each tire, brake modulation type, and roadway condition.

In the figures below the left-hand axis is deceleration in units of g and the right-hand axis is speed in miles per hour (MPH).

Figure 1. PS2 tires, ABS modulated braking, dry asphalt

Figure 1 presents the deceleration data from the Michelin PS2 tire on dry asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.98g, with a range of 0.971g to 0.998g.
Figure 2 presents the deceleration data from the Michelin PS2 tire on dry asphalt with locked wheel braking. The deceleration data becomes noisy after 1.25 seconds during all of the runs due to the locked tire friction causing the rear suspension to enter into a resonant hop frequency. The hopping could be felt in the vehicle and is evident in videos taken during several tests. The average deceleration for the 6 tests was 0.70g with a range of 0.677g to 0.727g.

Figure 3 shows the deceleration versus time for the Michelin PS2 tire on wet asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.95g with a range of 0.927g to 0.967g.

Figure 4 presents the deceleration data from the Michelin PS2 tire on wet asphalt with locked wheel braking. The average deceleration for the 6 tests was 0.68g with a range of 0.657g to 0.700g.

Figure 5 presents the deceleration data from the Michelin Primacy MXM4 tire on dry asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.88g with a range of 0.868g to 0.889g.

Figure 6 presents the deceleration data from the Michelin Primacy MXM4 tire on dry asphalt with locked wheel braking. The average deceleration for the 6 tests was 0.73g with a range of 0.713g to 0.749g.

Figure 7 presents the deceleration data from the Michelin Primacy MXM4 tire on wet asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.85g with a range of 0.823 to 0.869g.
Figure 8 presents the deceleration data from the Michelin Primacy MXM4 tire on wet asphalt with locked wheel braking. The average deceleration for the 6 tests was 0.61g with a range of 0.595g to 0.612g.

Figure 9 presents the deceleration data from the Bridgestone Blizzak WS70 tire on dry asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.79g with a range of 0.767g to 0.798g.

Figure 10 presents the deceleration data from the Bridgestone Blizzak WS70 tire on dry asphalt with locked wheel braking. The average deceleration for the 6 tests was 0.83g with a range of 0.802g to 0.835g.

Figure 11 presents the deceleration data from the Bridgestone Blizzak WS70 tire on wet asphalt with ABS modulated braking. The average deceleration for the 6 tests was 0.72g with a range of 0.698g to 0.770g.

Figure 12 presents the deceleration data from the Bridgestone Blizzak WS70 tire on wet asphalt with locked wheel braking. The average deceleration for the 6 tests was 0.54g with a range of 0.488g to 0.580g.

Table 2 presents the average deceleration values for each 6 test run grouping. The data demonstrates that all tires, except the Blizzak on dry asphalt, produce higher tire friction during ABS modulated braking than during locked wheel braking.
The average deceleration rates were compared for each tire, both locked wheel and ABS modulated braking, between wet and dry asphalt. Table 3 lists the percent differences for these comparisons. It can be seen with ABS modulated braking the reduction in braking performance between dry and wet asphalt was less than 8% for all three tires. The locked wheel braking performance decreased markedly as the performance nature of the tire went down; the PS2 dropped by the same 3% as calculated with the ABS modulated braking while the Blizzak decreased by 35%.

The data for each tire was compared to calculate the difference in tire friction between ABS modulated and locked wheel braking on similar surface (wet or dry) and is listed in Table 4. The three tires displayed dramatically different losses of performance on dry asphalt, but on wet asphalt the tires displayed a consistent loss of performance.

**DISCUSSION**

The grand touring all-season tire tested is comparable to the tires used on police vehicles that are frequently used to
measure coefficients of friction at accident sites. Comparing
the performance data in these tests using that tire as a
baseline establishes the adjustments in braking coefficients
for summer and winter tires shown in Table 5. Positive
numbers in Table 4 indicate the need to use higher tire
coefficients of friction, negative numbers lower coefficients
of friction.

| Table 5. Tire friction adjustments by tire type for speed
  from skid calculations, for data based on all season tires. |
<table>
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<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Summer</td>
</tr>
<tr>
<td>Winter</td>
</tr>
</tbody>
</table>

The Blizzak WS70 was the only tire to show higher tire
friction during locked wheel braking than ABS modulated
braking, and only for the tests conducted on dry asphalt. It is
thought the characteristics of the tire created a false available
friction calculation in the ABS control unit.

The soft tread and high degree of tread siping allow for
greater rotational speed differential in the wheel and tire
system. Relative to the tread, the wheel is able to reduce
velocity at a greater rate. In other words, the wheel can momentarily slow down a great deal without sliding the tread.
This causes the ABS to believe the wheel is locking up when
it is just winding up within the wheel and tire system. This
phenomenon limits the effectiveness of the ABS to accurately
predict the amount of tire friction available, creating a
condition where the ABS is under-estimating the available
friction. The under estimating produces longer stopping
distances than could be attained given the actual tire friction
available.

The effect of the soft tread and high degree of siping could be
felt behind the wheel as well. During the “break-in” driving
with the Blizzaks, the vehicle felt less responsive and more
disconnected to the driver as compared to the other two tires.

The Blizzaks also displayed the greatest amount of tread
damage from the locked wheel tests.

The available tire friction is a key factor in determining a
vehicle’s braking capability in maximum effort stopping
distances.

Valid coefficients of friction are necessary to provide
accurate, reliable findings of vehicle speeds from skids. In the
testing described in this paper we have established
adjustments to published data to account for different types of
tires that may be on vehicles involved in collisions.

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