Comparison of passenger vehicle braking distance when travelling on snow and asphalt at different velocities

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Abstract. The objective of this paper was to determine the braking distance of a passenger vehicle when traveling at the speeds of 30, 50 and 70 km/h, on low friction surfaces (snow, deep snow) and also on asphalt. A number of tests were conducted on different surfaces. The vehicle was accelerated and then braked completely. Based on the braking distance values obtained by GPS, the adhesion coefficient was calculated for each surface for every velocity value tested.

1. Introduction

In winter time, cars travel on different road surfaces influenced by the weather, causing modifications to the dynamic characteristics of the vehicle [1]. Statistic show that in the winter time, on icy roads, the injury risk is believed to be 20 times higher than in the summer where the road is dry [2]. Vehicle parameter will depend on various external parameters that intervene when driving in winter conditions unpredictable to the driver [3].

For the study, by using the GPS data, the vehicle velocity was obtained. Acceleration and distance travelled were determined analytically using the formulas [4]:

$$a = \frac{dV}{dt} \tag{1}$$

$$v = \frac{dS}{dt} \tag{2}$$

Where: V – velocity (m/s), a - acceleration (m/s2), S – distance (m), t – time (s)
Formula (3) defines the velocity in relation with the gravitational acceleration and adhesion coefficient [5]:

$$\left|\frac{dV}{dt}\right|_{\max} = g \cdot \varphi \tag{3}$$

Where: g – gravitational acceleration (m/s2) and φ – adhesion coefficient. To obtain the braking distance, the formula was used [6, 7]:

$$S_f = \frac{V_{\max}^2}{26 \cdot g \cdot \varphi} \tag{4}$$

In this relation, the velocity Vmax is in (km/h). The variation of the adhesion coefficient is given by the type of surface the wheel travels on. In the figure it is illustrated the value of the coefficient in regards to the substances that are between the wheel and the road [8].

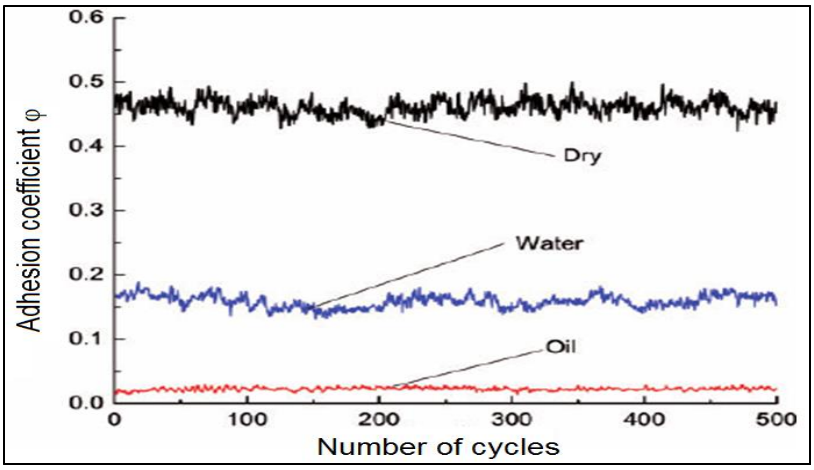

Figure 1. Adhesion coefficient variation.

Tire-road adhesion is a property of rubber that causes it to stick to other materials, as we see with adhesive tape. Adhesion is generally thought to be the result of momentary molecular bonding between the two surfaces [9].

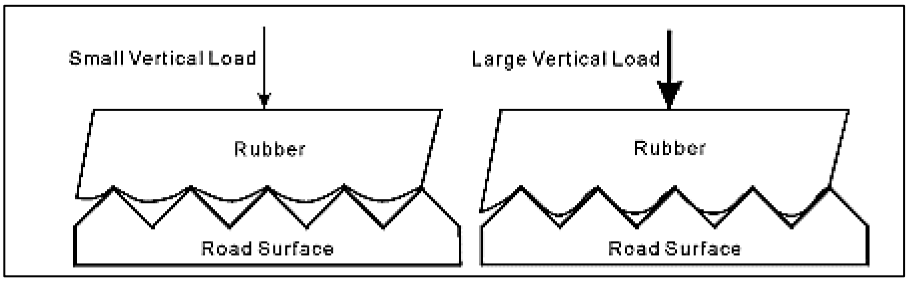

Figure 2. Example of how adhesion works.

When velocity is applied to a rubber slider on a rough surface it results in the deformation of the rubber by high points on the surface called irregularities or asperities. In the figure is shown how the rubber of the tire is dispersed when vertical load is applied along with the forward velocity [10].

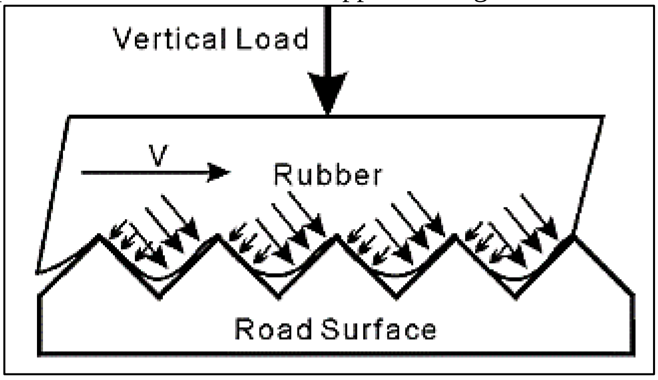

Figure 3. Adhesion influenced by velocity.

2. Methodology

The method used to determine the braking distance was the mean of experimental tests using a passenger vehicle. A controlled environment was established were the road was covered by snow, and another environment were the asphalt road was partially dry. The vehicle was accelerated at the desired velocities (30 km/h, 50 km/h and 70 km/h) then the brake was applied using the full available brake force. To study the key parameters of the vehicle during braking, a GPS system was mounted on the vehicle. By using the data from the GPS, the deceleration, distance, time and velocity parameters were obtained. For the vehicle, a standard sedan vehicle was used equipped with winter tires type Michelin Winter Sport 4D with the dimensions: 225/55 R16 92E M+S.

Figure 4. Tires used for the vehicle and measuring the snow on the road.

In the figure below the test scenario is presented. The vehicle is accelerated at the desired velocity and then the full brake force is applied until the vehicle comes to a complete stop.

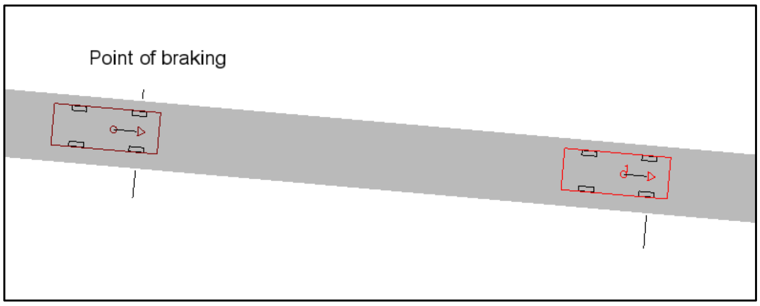

Figure 5. Testing scenario.

There are total of 7 tests conducted with the following velocities: 30 km/h, 50 km/h and 70 km/h on 2 types of surfaces: snow and asphalt. One extra test was conducted at 50 km/h on fresh snow.

3. Results

The primary results were the vehicle distance of braking for the different surfaces at the desired velocities. By studying the data provided by the GPS, the deceleration of the vehicle could be obtained and compared for each surface.

This reflects the braking force of the vehicle, meaning a higher deceleration value resulted in a higher adhesion coefficient between the tire and the road. Also by using the data from the GPS, the adhesion coefficient was accurately calculated for each surface and for each test. In the next two figures the GPS data is presented for the velocity of 30 km/h on snow and asphalt.

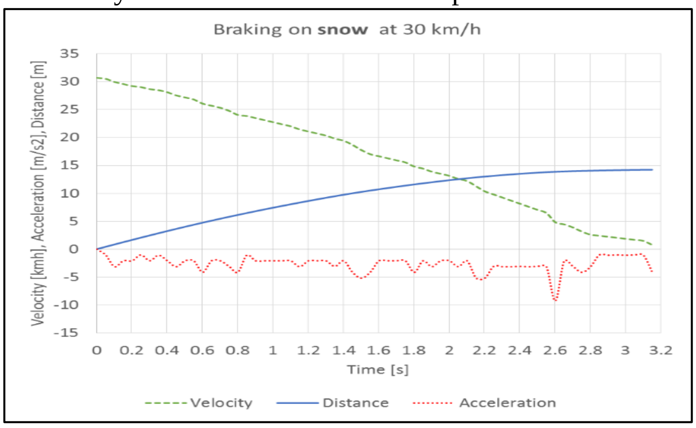

Figure 6. GPS data for 30 km/h on snow.

It can be observed that the distance travelled by the vehicle to completely stop it was 14 m in a period of 3.1 seconds and having a maximum deceleration of 9 m/s2 but with an average of 3-4 m/s2.

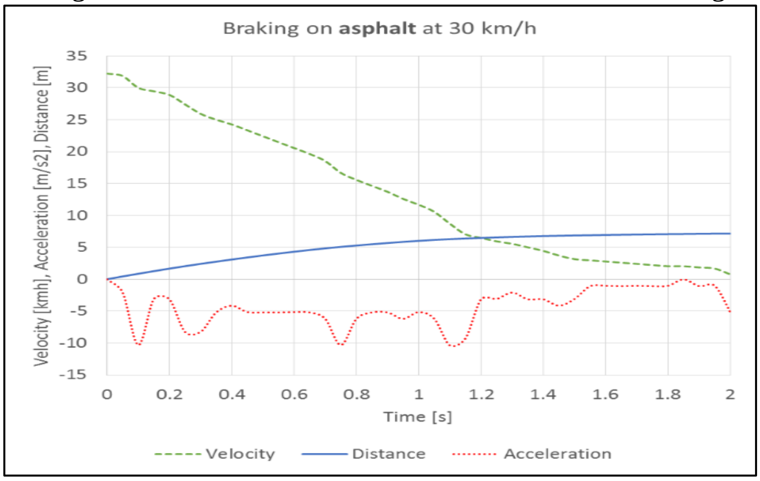

Figure 7. GPS data for 30 km/h on asphalt.

Compared to braking on snow, on asphalt the deceleration of the vehicle is higher, around 10 m/s2 and the duration of the braking phase shorter, 2 seconds compared to 3.1 s. The braking distance is a lot shorter as well, only 6 m. Next are three test at the velocity of 50 km/h on snow, fresh snow and asphalt done in the same conditions.

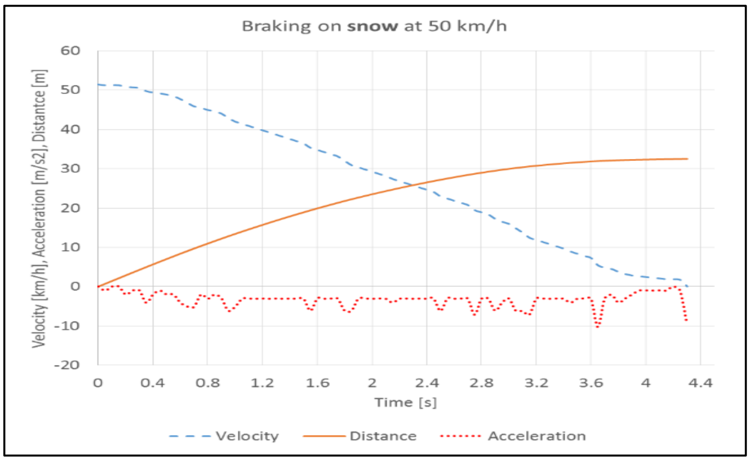

Figure 8. *GPS data for 50 km/h on snow*.

The deceleration in this case is similar to the 30 km/h test, with an average of 5-6 m/s2 and braking distance of 31 m in a period of 4.3 seconds.

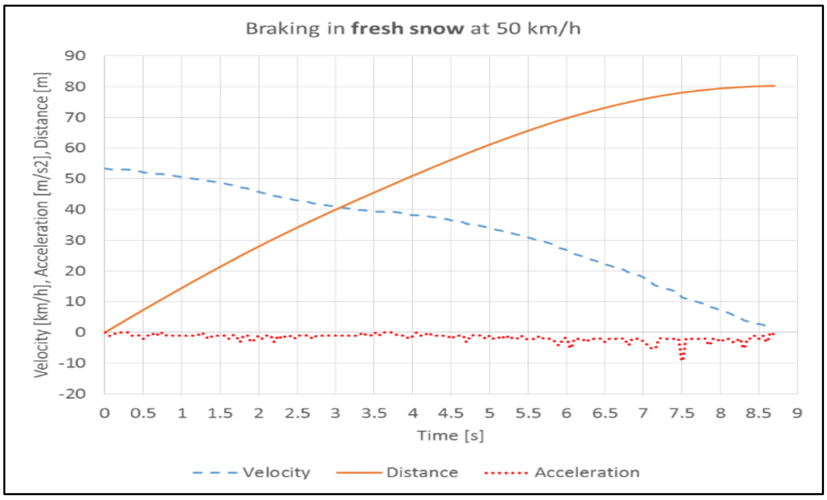

Figure 9. *GPS data for 50 km/h on fresh snow*.

In this case the braking distance increases dramatically compared to regular snow covered road, with a total travel distance of 80 m in a period of 8.5 s and a deceleration of 3 m/s2 on average.

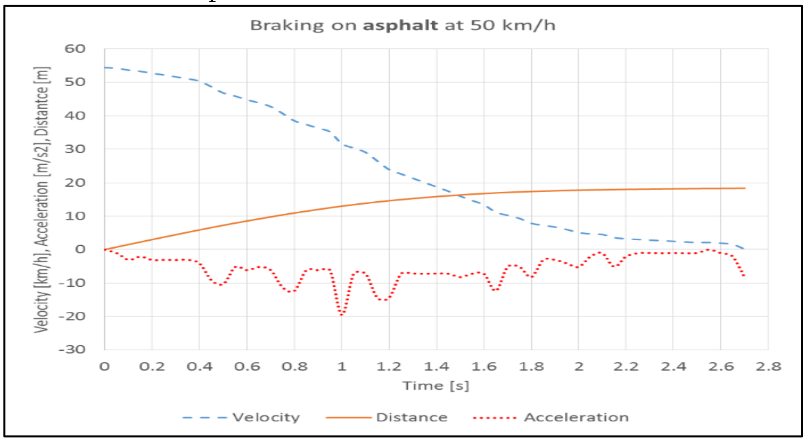

Figure 10. *GPS data for 50 km/h on asphalt*.

On asphalt the braking distance at 50 km/h was about 19 m in a period of 2.7 s and a deceleration of 10 m/s2 on average. In the last 2 tests, the velocity was increased at 70 km/h on 2 surfaces, snow and asphalt.

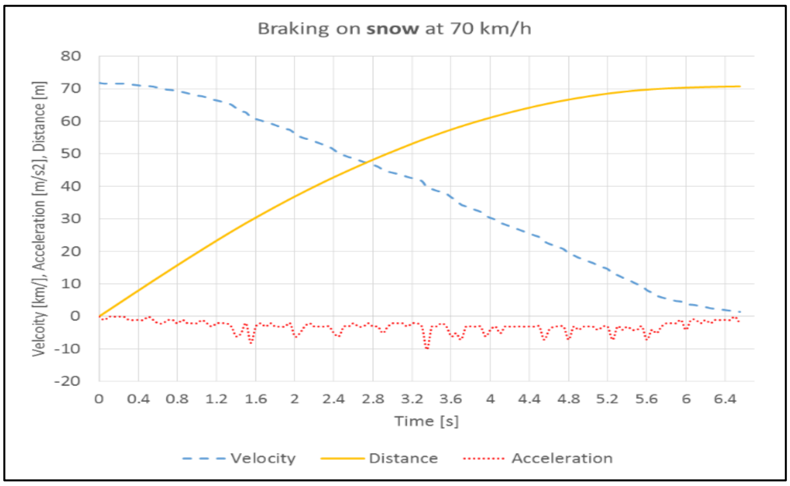

Figure 11. *GPS data for 70 km/h on snow*.

At this velocity, the braking distance on snow was about 70 m in a period of 6.4 s and an average deceleration of 6-7 m/s2.

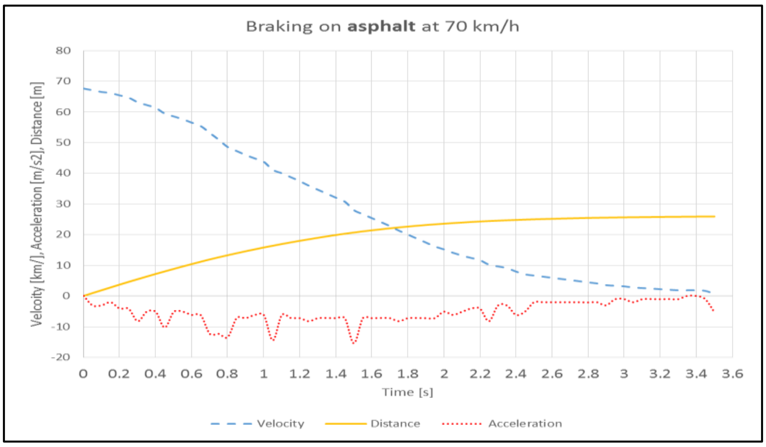

Figure 12. *GPS data for 70 km/h on asphalt*.

On asphalt the braking distance is considerably lower, with 26 m, achieved in a period of 3.5 s and an average deceleration of 11 m/s2. In table 1, a summary of the results are presented and also, using the formulas mention earlier, the adhesion coefficient predicted between the wheel and the road based on GPS data.

Table 1. Summary of the results.

Velocity [km/h]	Surface	Braking distance [m]	Adhesion coefficient
30	Asphalt	5	0.72
30	Snow	14	0.26
50	Asphalt	12	0.70
50	Snow	31	0.33
50	Fresh snow	66	0.16
70	Asphalt	20	0.68
70	Snow	70	0.3

It was found that there was a considerable difference between the regular snow and fresh snow. On fresh snow the adhesion coefficient calculated was 0.16 similar to ice, and in the case of snow, it had a value of 0.33. This difference doubles the braking distance from 31 m to 66 m. In the figure below, there is a graphical representation of the braking distance values and how can different surfaces affect these values.

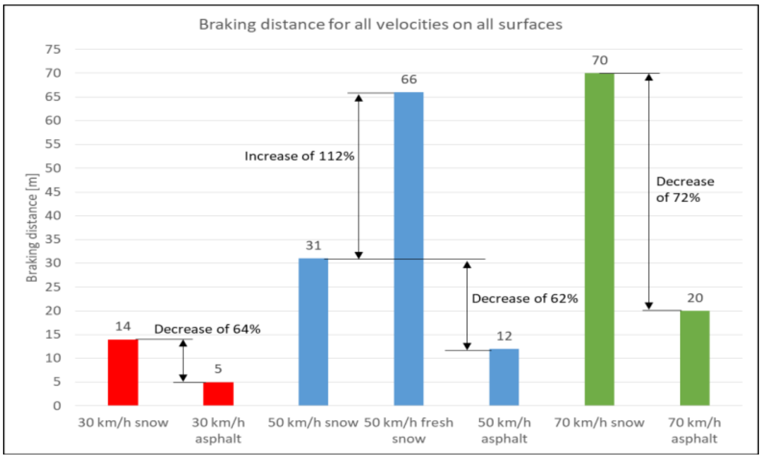

Figure 13. *Braking distances for all the tests*.

In can be observed that the greater the velocity is, the greater the braking distance increases. At lower velocities, at 30 km/h from snow to asphalt, the distance decreases by up to 64 % similar to higher velocity of 50 km/h where the difference is 62%. At 70 km/h from snow to asphalt, the distance decreases by up to 72%.

The huge difference is between snow and fresh snow, on fresh snow the braking distance increases by 112%, doubling it, increasing the chances of accidents.

4. Conclusions

The main conclusion was that the difference in braking distance between asphalt and snow was more than 60-70% increasing the chances of accidents. It was also found that there was a considerable difference between the fresh snow and regular snow. On the fresh snow, the adhesion coefficient was only 0.16, and in the case of shallow snow the coefficient had a value of 0.33. This difference doubles the braking distance of the vehicle.

5. References

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