[1.]**Andreea–Catalina CRISTESCU**, [1.]**Ilie FILIP**, [1.]**George IPATE**, [1.]**Gheorghe VOICU**,
[2.]**Lucretia POPA**, [2.]**Vasilica STEFAN**, [2.]**Catalin PERSU**

A CORELATTION BETWEEN THE COEFFICIENT OF FRICTION AND BRAKING DISTANCE AND TIME

[1.]Faculty of Biotechnical Systems Engineering, University Politehnica of Bucharest / ROMANIA;
[2.]National Institute of Research – Development for Machines and Installations Designed for Agriculture and Food Industry – INMA Bucharest / ROMANIA

Abstract: This article examines the correlation between the coefficient of friction and braking distance/time. Through comprehensive experiments and data collection, it was observed that as the coefficient of friction between a vehicle's tires and the road surface increased, the distance and time required for braking decreased proportionately. Factors such as tire state, road conditions, and vehicle weight, and braking system efficiency were considered. This correlation emphasizes the pivotal role of friction in vehicular safety, warranting further research and technological advancements in this domain.
Keywords: coefficient of friction, braking distance, breaking time

1. INTRODUCTION

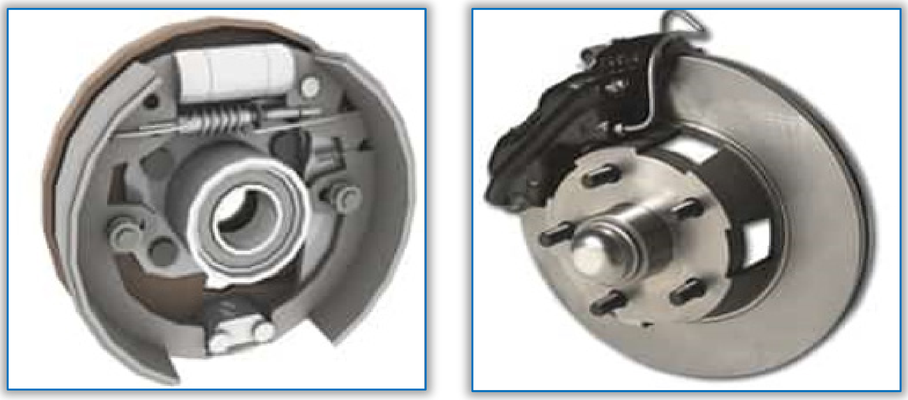
The primary focus of analysing the braking system is to elevate its efficacy, given the modern advancements and the current state of braking technologies that offer consistent and secure halting capabilities, even at elevated speeds. Integrating ferrite magnets into the disc braking mechanism augments the halting strength of the vehicle.

This enhancement leads to notable reductions in both the time and distance required to come to a full stop. High–velocity vehicles, including cars and motorcycles, predominantly employ this braking methodology to ensure dependable and steady deceleration *(Filip & Cristescu, Tribological Behavior of Friction Materials of a Disk-Brake Pad Braking System Affected by Stru*ctural Changes—A Review, 2022).

As the emphasis on passenger safety intensifies, the effectiveness of the braking system has grown crucial for vehicle producers and occupants alike. Though lowering the friction coefficient can mitigate the squeal in the braking mechanism, it concurrently compromises its operational efficiency *(Baba, Hamid, Soid, & Omar, 2018)*.

Contemporary vehicles come outfitted with one of two distinct braking mechanisms: either disc brakes or drum brakes (See Fig. 1). Their design is tailored to suit a range of operational environments, with a particular focus on managing heat dispersion within the brakes (T*alati & Jalalifar, 2*009).

Today, a majority of vehicles come fitted with pad–equipped disc brakes on their front axles (See Fig. 1 a). Yet, a notable portion still employs drum brakes for the rear axle. Consequently, the standard braking setup in vehicles often involves disc brakes at the front and either drum or disc types at the back, complemented by a linkage system connecting the calipers to the master and auxiliary cylinders *(How To Differentiate Braking Systems In Automobiles?, 2021)*.



(a) (b)

Figure 1 – Car Breaking system (How To Differentiate Braking Systems In Automobiles?, 2021)
a) Breaking system with drums; b) breaking system with disk/pad

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When a vehicle brakes, its kinetic energy is transformed into heat energy. The temperature at the contact point between the brake pads and disc, alongside alterations in speed, greatly influences the friction coefficient. This is because, as sliding speed and temperature increase, the friction coefficient tends to decrease. Any braking system undergoes wear, especially when the friction coefficient experiences notable reductions due to temperature variations *(Sabri & Fauza, 2018; Parczewski, 2013)*.

Excessive heat during braking can lead to issues like brake deterioration, accelerated wear, brake fluid vaporization, bearing malfunctions, thermal fractures, and heat–induced oscillations.

Optimal brake pads should maintain consistent friction across all operational situations, preventing brake decline irrespective of heat levels. For optimal braking efficacy, the material composition of the brakes should be tailored to provide stable friction coefficients, minimized wear, and limited noise, across a broad spectrum of braking scenarios (*Filip & Cristescu, Experimental Study of the Correlation between the Wear and the Braking System Efficiency of a Vehicle, 2023)*.

Yin and colleagues *(Yin, et al., 2018)* undertook an analysis of the braking mechanism and its testing methodologies, pinpointing five crucial parameters that dictate a vehicle's braking capabilities. These encompass the friction coefficient between tire and road, the vehicle's weight, the exertion level of the driver, the brake command infrastructure, and the friction coefficient between the brake pads and disc during deceleration.

Expanding on this, studies by Rashid *(Rashid, 2014) and Sharip (Sharip, 2013)* explored the efficiency of brake discs under severe conditions. Their conclusions emphasize the need for brake discs to exhibit superior thermal transfer, robust thermal conductivity, formidable mechanical durability, heightened friction resilience, resistance to thermal shocks, and excellent frictional traits. Additionally, in terms of wear, weight, and the ease of tweaking brake system components *(Nussbaum, 2016)*, the variations should remain minimal, hinging heavily on the design chosen. Regulations governing braking systems undergo constant revisions, pushing for ever–growing performance standards, as pointed out by Volkov and his team *(Volkov, et al., 2021)*.

This has catalysed a wave of research *(Nussbaum, 2016; Bao, Liu, Yin, & Liu, 2015)* aimed at enhancing the dependability and effectiveness of braking mechanisms *(Filip & Cristescu, Tribological Behavior of Friction Materials of a Disk-Brake Pad Braking System Affected by Structural Changes—A Review, 2022)*.

The connection between a tire's tread and the roadway plays a crucial role in determining how quickly a wheel can come to a stop.

The adherence factor (k) relates the deceleration force to the wheel's vertical weight. Similarly, the friction coefficient (μ) emerges when surfaces glide across each other. Yet, to maximize deceleration resistance, it's essential that the wheel continues to turn until it comes to a complete stop. Table 1, describes the grip factors for various road surfaces *(Childs & Peter, 2014)*:

Table 1. Coefficients of friction for various road surfaces *(Childs & Peter, 2014)*

Material	Weather Conditions	Coefficient of friction
Cement, coarse asphalt	Dry	0,8
Asphalt, polished bitumen.	Dry	0,6
Concrete, coarse asphalt.	Wet	0,5
Asphalt	Wet	0,4
Asphalt, bitumen	Wet	0,3
Asphalt, bitumen	Greasy	0,25
Crushed bitumen, compacted sno.	Greasy	0,2
Crushed bitumen, compacted snow	Dry	0,15
Ice	Wet	0,1

In light of the existing body of literature, myriad theories have been postulated to elucidate the intricacies of vehicular dynamics. Yet, one can argue that there remains a lacuna in the comprehensive understanding of the interplay between certain factors. Specifically, the friction coefficient, a critical determinant in vehicular motion, has not been thoroughly examined in the context of its influence on braking distance and time.

The current research article endeavours to bridge this gap by undertaking a meticulous investigation into the nuanced impact of the friction coefficient. By employing rigorous methodologies and drawing from empirical data, we aim to ascertain its consequential effects within the milieu of congested road traffic. Ascertaining this relationship is not merely an academic exercise; it bears significant practical implications.

A deeper comprehension of this dynamic can pave the way for enhanced traffic safety protocols, inform the design of next–generation braking systems, and potentially inspire infrastructure modifications tailored to the demands of contemporary road conditions.

2. MATERIALS AND METHODS

As the coefficient of friction plays a pivotal role in vehicular dynamics and safety, greatly influencing braking performance, tire wear, and overall vehicular stability, to rigorously ascertain the coefficient of friction under varied conditions, a meticulous and systematic approach is crucial.

The ensuing procedures are designed to determine this coefficient at a uniform speed of 30 km/h. Notably, this study spans two distinct terrains: a well–maintained asphalt road and a cemented road. Evaluating the coefficient of friction on both surfaces ensures a holistic understanding, offering insights into how different road conditions can impact the coefficient of friction.

The procedures detailed below have been crafted to methodically evaluate how quickly and effectively a vehicle can come to a complete stop from a consistent speed of 30 km/h, in two different road conditions. By maintaining this speed with the assistance of an autopilot and marking a specific initiation point for braking, controlled environment was created. This ensures repeatability and accuracy in the results, focusing on both the braking time and distance.

- Speed Acquisition: The vehicle was initially accelerated until a target speed of 30 km/h was achieved. This speed was verified using the vehicle's speedometer, from diagnosis menu (Fig. 2.) and corroborated with an external speed measuring device to ensure accuracy.
- Maintaining the Speed: Once the desired speed of 30 km/h was attained, the vehicle's autopilot system was engaged. This feature ensured that the vehicle consistently maintained the predetermined speed without any fluctuations. The autopilot's efficiency in maintaining this constant speed was crucial to guaranteeing the consistency of our trials.
- Braking Initiation Point: A predefined mark on the road served as the braking initiation point. As soon as the vehicle reached this mark, the braking procedure began.
- Braking Sequence: Upon reaching the braking mark, the brake pedal was firmly and uniformly depressed. The exact moment of pedal depression was taken as the starting point for our time measurements.
- Time Measurement: A stopwatch, synchronized with the braking initiation, was used to measure the time taken from the moment the brake was applied until the vehicle came to a complete stop. Multiple trials were conducted to ensure consistency and accuracy in the recorded times.
- Distance Measurement: After the vehicle had come to a complete halt, the distance from the braking initiation point to the vehicle's final resting position was measured. This provided braking distance. For enhanced precision, this measurement was repeated across several trials, and an average was derived to account for any minor variations.

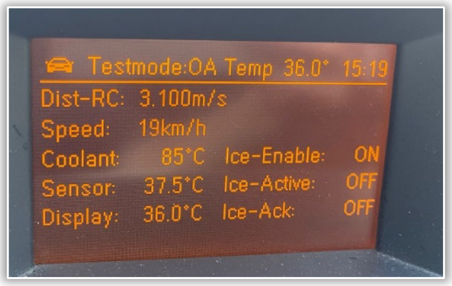

Figure 2 – Vehicle diagnose menu used for measuring the speed

After acquiring all the date, the coefficient of friction was determined for each given speed, applying the equations associated with uniform acceleration:

$$s = u \times t + \frac{1}{2} \times a \times t^2 \quad (1)$$

where:

s = braking distance
u = initial speed
t = braking time
a = acceleration

From which the acceleration formula results:

$$a = \frac{2(s - u \times t)}{t^2} \quad (2)$$

An considering that a=μ×g, the coefficient of friction can be determined by using the following formula:

$$\mu = \frac{a}{g} \tag{3}$$

3. RESULTS

Multiple breaking tests had been conducted for a speed of 30km/h. Using formulas (1–3), the coefficient of friction was determined. The results for the breaking distance, breaking time and coefficient of friction, are displayed in Table 2. In figure 3, the graphic that displays the evolution of the COF, depending on time, speed and breaking distance can be observed. The parameters are determined for asphalted road.

Table 2. Braking time, distance, and coefficient of friction for 30 km/h – asphalt road

Speed (km/h	30	30	30	30	31	31	30
Breaking distance (m)	3.5	3.64	3.69	3.55	3.6	3.72	3.37
Braking time (s)	1.7	1.88	1.98	1.75	1.84	1.85	1.77
Coefficient of friction	0.75	0.695	0.667	0.734	0.706	0.728	0.696

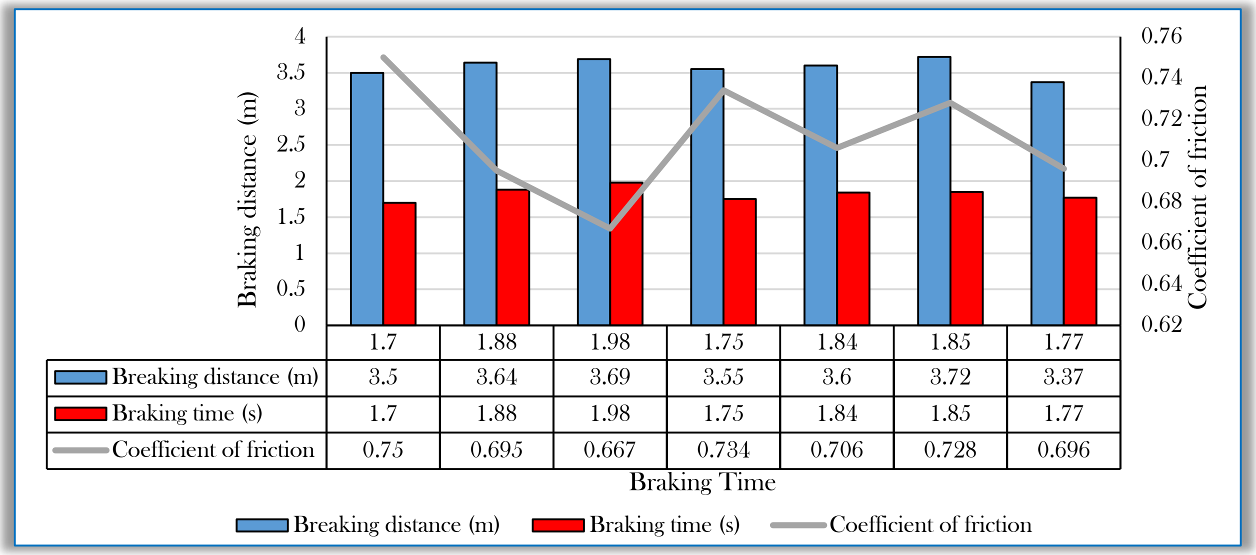

Figure 3 – Coefficient of friction depending on speed, time and breaking distance – asphalt road

In table 3, the measure breaking distance, breaking time, and coefficient of friction for cemented road are displayed. Fig 4 presents the evolution of the coefficient of friction depending on the breaking time and distance.

Table 3. Braking time, distance, and coefficient of friction for 30 km/h – cemented road

Speed (km/h	30	30	30	30	31	31	30
Breaking distance (m)	6.5	5.98	6.76	6.23	6.57	6.34	6.24
Braking time (s)	3.4	3.1	3.65	3.2	3.4	3.18	3.2
Coefficient of friction	0.386	0.421	0.361	0.407	0.383	0.405	0.406

As previously, the COF had been calculated using equations (1–3) and the breaking distance/time determined experimentally.

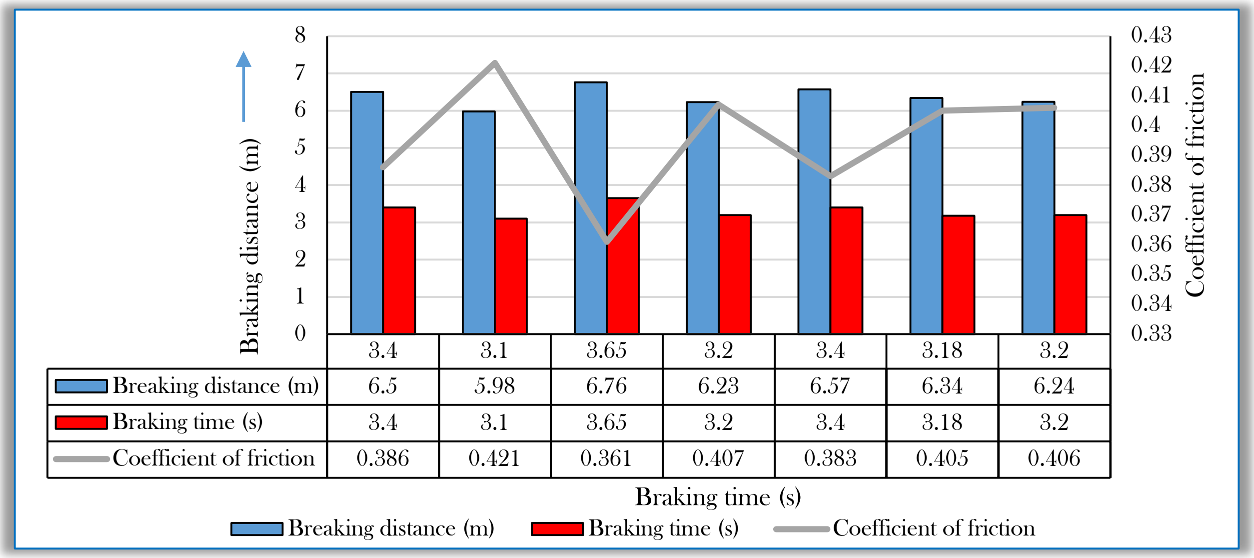

Figure 4 – Coefficient of friction depending on speed, time and breaking distance – cemented road.

In fig. 5, the distinction between the coefficients of friction for asphalt and cemented roads is markedly evident. The asphalt, a widely used material for roadway construction, often offers a higher coefficient of friction compared to cemented surfaces.

This difference in friction coefficients directly impacts a vehicle's braking performance. As displayed in the chart, vehicles traversing asphalt surfaces tend to experience more resistance during braking, thereby shortening stopping distances and times.

Conversely, cemented roads, due to their smoother surface and distinct material properties, generally present a lower coefficient of friction, potentially leading to longer braking distances under similar conditions. It is essential for drivers to be aware of these differences as they navigate varying road surfaces, ensuring optimal safety measures are in place.

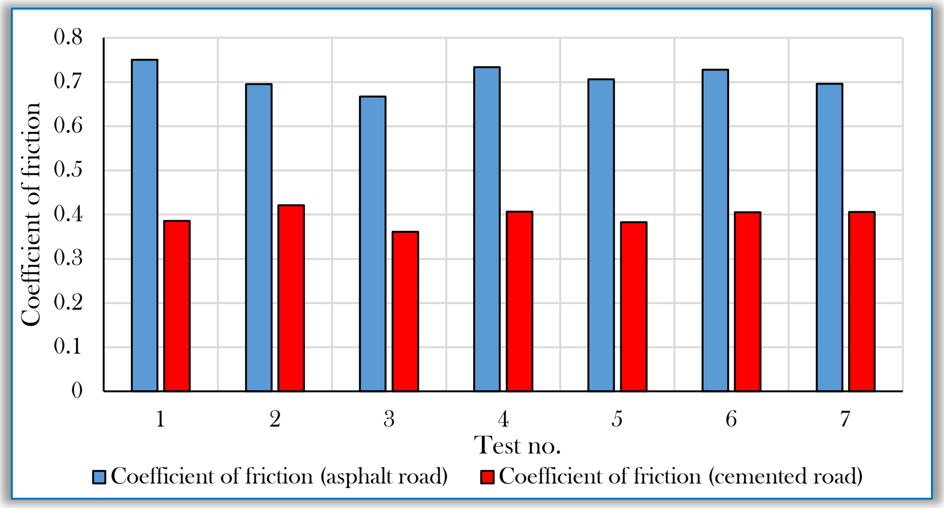

Figure 5 – Differences between the coefficient of friction on asphalt vs cemented road

4. CONCLUSIONS

In summarizing our findings, the correlation between the coefficient of friction and both braking time and distance is paramount.

This study has highlighted the significant variance in braking performance on differing road surfaces, namely asphalt and cemented roads. From a tribological standpoint, the frictional interaction between the tire and the road surface plays a crucial role in the braking efficiency of a vehicle. As demonstrated, asphalt surfaces, with their inherently higher coefficient of friction, facilitate reduced braking distances and times compared to smoother cemented roads.

This distinction becomes particularly vital in the context of intense traffic scenarios. A slight change in the coefficient of friction can dramatically alter the response time required to prevent collisions or navigate abrupt stops. In densely populated traffic areas, understanding these nuances can mean the difference between safe transit and potential mishaps.

Moreover, as we move into an era of evolving transportation systems and increasing vehicular complexities, the tribological implications in braking systems become even more significant.

By fully comprehending the relationship between the coefficient of friction and braking efficacy, we can better design, educate, and implement safety measures suitable for diverse road conditions. Thus, the coefficient of friction is not merely a numerical value but a pivotal component that influences vehicular safety and traffic management.

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