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RESEARCH ON THE BRAKING DECELERATION OF A PASSENGER CAR EQUIPPED WITH TIRES FOR DIFFERENT WEATHER CONDITIONS UNDER VARIOUS ROAD STATES

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Abstract:

The present study focuses on the experimental determination of the braking deceleration of a passenger car equipped with all-weather tires during emergency braking. The study evaluates the impact of the anti-lock braking system (ABS) under different road surface conditions. The experimental measurements are carried out using a braking deceleration measuring device ENERGO-SM 4.0, which is used to compare the indicators during normal operation of ABS and forced deactivation of the system.

The test automobile is an Opel Zafira A. It is chosen due to its considerable popularity in the passenger car segment and its representativeness for the typical consumer. To achieve completeness in the testing process, the experiments are carried out with two main types of tires - summer and winter - in the context of a variety of road surface conditions, both dry and wet.

The results of the conducted experiments demonstrate significant variations in braking deceleration, depending on the type of tires and road conditions. With ABS operating normally, the vehicle shows a significantly longer braking deceleration on wet surfaces compared to emergency braking without the system's assistance. In wet asphalt situations, ABS exhibits a distinctive ability to maintain vehicle traction and controllability, while deactivating the system results in loss of control and lower braking deceleration values.

The obtained results provide important data that can serve as a basis for further studies and recommendations regarding the optimization of braking systems, especially considering the dynamic road conditions and the variety of tires available on the market.

1. INTRODUCTION

Modern active safety systems play a key role in reducing the risk of road traffic accidents by providing better control and stability of the vehicle in critical situations [3, 7]. The Anti-lock Braking System (ABS) is one of the most widely used technologies designed to prevent wheel lock-up during braking, thereby maintaining traction with the road surface and ensuring vehicle maneuverability [9]. However, the effectiveness of ABS depends on numerous factors, including the type of road surface, weather conditions, driving speed, and the type of tires fitted to the vehicle.

The present study focuses on the experimental determination of the deceleration and braking distance of a passenger car during emergency braking under various road conditions. Using precise measuring equipment, the influence of ABS on braking performance is analyzed, considering different combinations of tires and road surfaces. The results obtained provide valuable insights for optimizing braking systems and adapting them to the dynamic conditions of the road environment [3, 7].

Deceleration is a key parameter in evaluating the braking performance of a passenger car. It represents the rate at which the vehicle's speed decreases and is typically measured in meters per second squared (m/s²). High deceleration is an indicator of the efficiency of the braking system, which must quickly and reliably reduce the vehicle's speed to a complete stop. Deceleration is a critical metric for assessing the braking performance of a passenger car. Effective braking not only ensures safety and control but also supports the integration of modern technologies and compliance with regulatory standards [5]. Careful investigation and optimization of deceleration are essential for the development of safer and more reliable vehicles.

Studies on braking performance often involve measuring deceleration and braking time at various speeds. Deceleration is defined as the change in the vehicle's speed during braking and is a key indicator of the braking system's efficiency [1].

ABS has proven its effectiveness on various road surfaces, including wet and snowy roads. According to numerous studies, the system is particularly beneficial when driving in conditions of reduced visibility and slippery surfaces, where the risk of wheel lock-up is higher [6, 9].

To record the investigated vehicle parameters, it is necessary to use modern and precise equipment that ensures accurate results. In this study, a non-contact system for measuring the speed and distance of moving vehicles, EnergoSM 4.0 (**Fig. 4**), developed by the company ENERGOTEST, was used.

2. METHODOLOGY

The methodology of the experimental research involves measuring the deceleration of a passenger car during emergency braking on various road surfaces with different coefficients of friction. The experiments were conducted during the summer season, at an ambient air temperature of approximately 25 degrees Celsius and an asphalt surface temperature of 20 degrees Celsius. The tests were carried out on a test track (**Fig. 1**) located in the town of Smolyan, covered with an asphalt surface. The experiments were performed on a straight and level section of the track under different road conditions: dry pavement and wet pavement. The passenger car was initially equipped with summer tires, and subsequently, under the same conditions, it was tested with winter tires.

Fig. 1 A test track with an asphalt surface.

For the experiment, a passenger car was used. The test vehicle was an Opel Zafira A, selected due to its significant popularity in the passenger car segment and its representativeness for the typical user. To ensure the comprehensiveness of the testing process, the experiments were conducted with two main types of tires - summer and winter - under different road surface conditions, both dry and wet.

Fig. 2 Passenger car OPEL ZAFIRA A with summer tires.

2. 1. OPEL ZAFIRA A, MANUFACTURED IN 2005 (FIG. 2), EQUIPPED WITH SUMMER TIRES, BRAND “MICHELIN” SIZE 205/55 R16 91V, WITH A MEASURED TREAD DEPTH OF 6 MM.

The experiments with the specified vehicle, which is standardly equipped with an active safety system (ABS), were conducted on a straight and level section of the track at various driving speeds. The experiment included tests at speeds of 30, 40, 50, and 60 km/h. Additionally, under the same conditions, tests were performed with the ABS system forcibly deactivated.

2. 2. OPEL ZAFIRA A, MANUFACTURED IN 2005 (FIG. 3), EQUIPPED WITH WINTER TIRES, BRAND "KUMHO," SIZE 195/65 R15, WITH A MEASURED TREAD DEPTH OF 8 MM.

Fig. 3 Passenger car OPEL ZAFIRA A with winter tires.

In this study, a non-contact system for measuring the speed and acceleration of moving vehicles, EnergoSM 4.0 (**Fig. 4**), developed by the company ENERGOTEST, was used [10].

The maximum deceleration was measured by the “Energo-SM 4.0” decelerometer from the moment the brake was engaged (the start of deceleration increase) until the vehicle came to a complete stop. The results of the conducted experiments were processed using the software “ESM2: EnergoSM decelerometer windows software” Ver. 2.0.5, which provides graphical representation of the measured parameters over time and also displays the vehicle’s speed.

Fig. 4 Decelerometer “Energo-SM 4.0”.

Key Features of the Device:

Non-Contact Measurement: The Energo-SM 4.0 uses non-contact measurement technologies, ensuring more accurate and stable results compared to traditional methods. It is suitable for measurements on both closed tracks and real road conditions.

High Precision: The system is designed to deliver high measurement accuracy, which is critical for research and development in the field of automotive safety and dynamics. The precision of the measurements is essential for the validity of experimental data and for drawing reliable conclusions.

Speed and Deceleration Measurement: The EnergoSM 4.0 provides the ability to measure the current speed of the vehicle and its deceleration with high accuracy. The system can record the vehicle’s accelerations and decelerations in real time, which is useful for analyzing braking performance and other dynamic characteristics.

Applications:

Brake System Testing: The system is used for experimental studies of braking system efficiency, providing data on deceleration and stopping time at various speeds and conditions.

Dynamic Vehicle Analysis: The system is utilized for analyzing the dynamic characteristics of vehicles, including acceleration, deceleration, and behavior during various maneuvers.

The Energo-SM 4.0 accelerometer is a modern tool for precise measurement and analysis of the dynamic characteristics of vehicles, making it highly valuable in the field of automotive research and development.

3. EXPERIMENTAL RESULTS

The maximum deceleration was measured by the "Energo-SM 4.0" decelerometer from the moment the brake was engaged. The results of the conducted experiments were processed using the software "ESM2: EnergoSM decelerometer windows software" Ver. 2.0.5, which provides graphical representation of the measured parameters over time (**Fig. 5**). Additionally, it allows for the visualization of the vehicle's speed (**Fig. 6**).

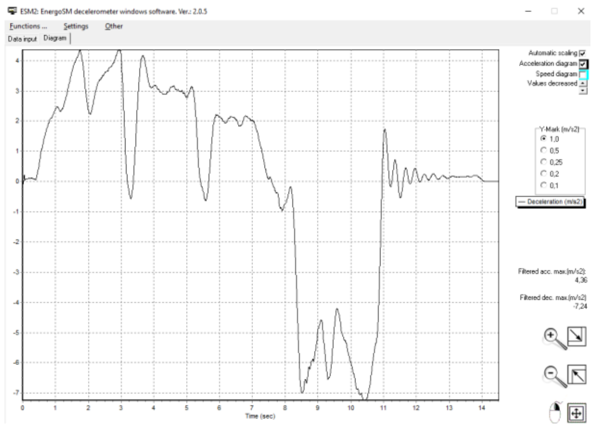


Fig. 5 Graphics from "Energo SM 4.0", processed with "ESM2" software, showing the braking deceleration in m/s^2.

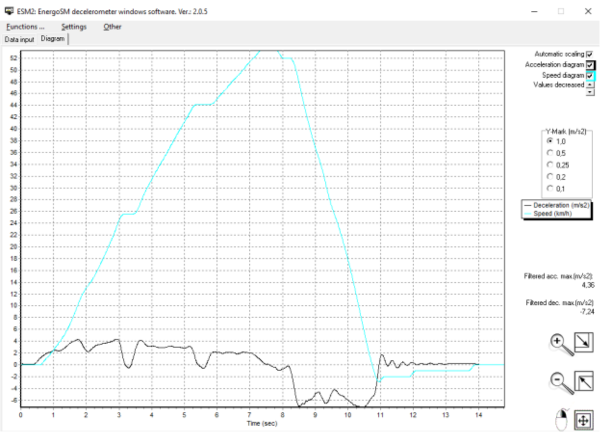
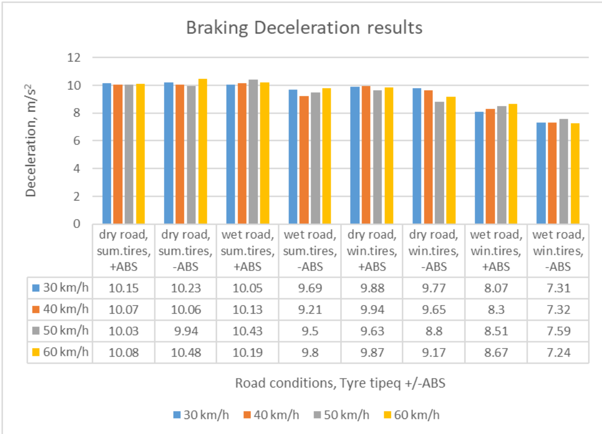


Fig. 6 Graphics from "Energo-SM 4.0", processed with "ESM2" software, showing the braking deceleration in m/s^2 and additionally the speed in km/h.

The results of the experimental study are presented both graphically and in tabular form in **Fig. 7** and **Fig. 8**.

3. 1. STUDY OF THE BRAKING DECELERATION OF TKE OPEL ZAFIRA A.

The graph in **Fig. 7** illustrates the deceleration results (in m/s²) under different road conditions, tire types, and the presence or absence of ABS (Antilock Braking System). The data is categorized by speed (30, 40, 50, and 60 km/h) and demonstrates how various factors influence braking performance.



	dry road, sum.tires, +ABS	dry road, sum.tires, -ABS	wet road, sum.tires, +ABS	wet road, sum.tires, -ABS	dry road, win.tires, +ABS	dry road, win.tires, -ABS	wet road, win.tires, +ABS	wet road, win.tires, -ABS
30 km/h	10.15	10.23	10.05	9.69	9.88	9.77	8.07	7.31
40 km/h	10.07	10.06	10.13	9.21	9.94	9.65	8.3	7.32
50 km/h	10.03	9.94	10.43	9.5	9.63	8.8	8.51	7.59
60 km/h	10.08	10.48	10.19	9.8	9.87	9.17	8.67	7.24

Fig. 7 Variation in Deceleration of the OPEL ZAFIRA A Based on Road Surface, Tire Type, ABS Presence, and Vehicle Speed.

Key Observations:

Dry road with summer tires:

With ABS, deceleration is the highest (approximately 10.15–10.08 m/s² across different speeds). Without ABS, deceleration is slightly higher (10.23 - 10.48 m/s²), indicating that ABS is not a critical factor on dry surfaces.

Wet road with summer tires:

With ABS, deceleration is lower (9.69 - 10.43 m/s²), showing reduced braking efficiency compared to dry conditions. Without ABS, deceleration is even lower (9.21 - 9.8 m/s²), emphasizing the importance of ABS in wet conditions.

Dry road with winter tires:

With ABS, deceleration is relatively high (9.88 - 9.87 m/s²) but lower than with summer tires. Without ABS, deceleration is slightly lower (9.94 - 9.63 m/s²), indicating that winter tires are not optimal for dry conditions.

Wet road with winter tires:

With ABS, deceleration is significantly lower (8.07 - 8.67 m/s²), highlighting the limited efficien-

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cy of winter tires on wet surfaces. Without ABS, deceleration is the lowest (7.24 - 7.59 m/s²), underscoring the poor performance of winter tires without ABS on wet roads.

Conclusions:

Summer tires provide better deceleration on both dry and wet surfaces compared to winter tires.

ABS plays a crucial role in improving deceleration, especially on wet surfaces.

Winter tires are less effective in summer conditions, particularly on wet roads.

3. 2. STUDY OF THE BRAKING DISTANCE OF THE OPEL ZAFIRA A.

The graph in **Fig. 8** presents the results of the experiment measuring the braking distance (in meters) under various road conditions, tire types (summer and winter), the presence or absence of ABS (Anti-lock Braking System), and different speeds (30, 40, 50 and 60 km/h).

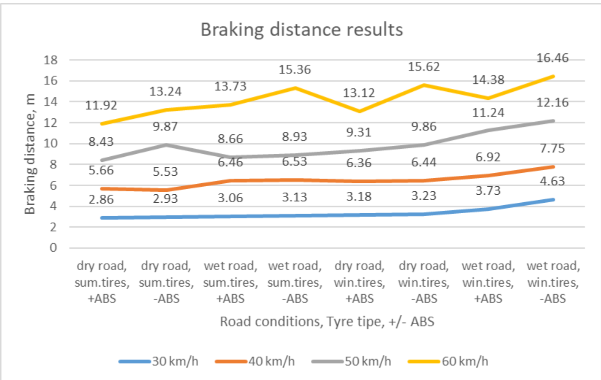

Fig. 8 Variation in Braking Distance of the OPEL ZAFIRA A Based on Road Surface, Tire Type, ABS Presence, and Vehicle Speed.

Key Observations:

Dry road with summer tires:

With ABS, the braking distance is the shortest across all speeds (e.g., 2.86 m at 30 km/h and 11.92 m at 60 km/h). Without ABS, the braking distance is slightly longer (e.g., 2.93 m at 30 km/h and 13.24 m at 60 km/h), indicating minimal influence of ABS on dry surfaces.

Wet road with summer tires:

With ABS, the braking distance is longer compared to dry conditions (e.g., 3.06 m at 30 km/h and 13.73 m at 60 km/h). Without ABS, the braking distance increases further (e.g., 3.13 m at 30 km/h and 15.36 m at 60 km/h), highlighting the importance of ABS in wet conditions.

Dry road with winter tires:

With ABS, the braking distance is longer compared to summer tires (e.g. 3.18 m at 30 km/h and 13.12 m at 60 km/h). Without ABS, the braking distance is even longer (e.g. 3.23 m at 30 km/h and 15.62 m at 60 km/h), showing that winter tires are not optimal for dry conditions.

Wet road with winter tires:

With ABS, the braking distance is significantly longer (e.g. 3.73 m at 30 km/h and 14.38 m at 60 km/h), indicating the limited efficiency of winter tires on wet surfaces. Without ABS, the braking distance is the longest of all scenarios (e.g. 4.63 m at 30 km/h and 16.46 m at 60 km/h), emphasizing the poor performance of winter tires without ABS on wet roads.

Conclusions:

Summer tires provide a shorter braking distance on both dry and wet surfaces compared to winter tires.

ABS significantly improves braking distance, especially on wet surfaces, with the most noticeable difference observed when using winter tires.

Winter tires are less effective in summer conditions, particularly on wet roads, where the braking distance is the longest.

These results underscore the importance of selecting the appropriate tires for the season and road conditions, as well as the critical role of ABS in ensuring safety.

4. COMMENTS AND CONCLUSIONS

The present study provides valuable insights into the effectiveness of the Anti-lock Braking System (ABS) under various road conditions and with different types of tires. Based on the conducted experiments, the following key conclusions can be drawn:

- Effectiveness of ABS on Wet Surfaces

The ABS system demonstrates significant advantages on wet and slippery road surfaces. When ABS is functioning properly, better traction and vehicle control are observed, reducing the risk of wheel lock-up and loss of control. This is particularly critical during emergency braking, where reaction time and vehicle stability are essential.

ABS significantly improves braking distance, especially on wet surfaces. The difference in braking distance between ABS and non-ABS scenarios is most pronounced when using winter tires on wet roads.

On dry surfaces, the difference between ABS and non-ABS braking is minimal, indicating that ABS is more effective under low-traction conditions.

Wet surfaces substantially increase braking distance, particularly when using winter tires without ABS. This is a critical safety factor that requires heightened caution when driving in rainy conditions.

- Impact of Tire Type on Deceleration

Summer tires exhibit better performance on both dry and wet surfaces compared to winter tires. This is especially evident at higher speeds, where the braking distance with winter tires is significantly longer.

Winter tires are optimized for cold conditions and snow, but their efficiency decreases considerably on wet surfaces and at summer temperatures.

- Role of ABS at Different Speeds

At various speeds, the ABS system delivers consistent results, providing shorter braking distances and better traction compared to a deactivated system.

As speed increases, braking distance grows significantly, regardless of tire type or ABS presence. This highlights the importance of adjusting speed to match road conditions.

- Importance of Precise Measurements

The use of modern measuring equipment, such as the Energo-SM 4.0 decelerometer, is crucial for ensuring the accuracy of results. This technology enables detailed analysis of the vehicle's dynamic characteristics and provides reliable data for evaluating braking system performance.

- Recommendations for Future Research

The results obtained in this study can serve as a foundation for further research aimed at optimizing ABS systems and adapting them to various road and weather conditions.

Future studies could also explore the impact of additional factors, such as tire wear and different types of road surfaces, on braking performance.

These findings emphasize the importance of selecting appropriate tires for the season and road conditions, as well as the critical role of ABS in enhancing safety, particularly on wet and slippery surfaces.

5. CONCLUSION

The study confirms the critical role of the ABS system in enhancing road safety. The results clearly demonstrate that ABS significantly improves vehicle control and traction during emergency braking, particularly on wet and slippery surfaces. The type of tires also has a substantial impact on the effectiveness of the braking system, highlighting the importance of selecting the appropriate tires based on road and weather conditions. Summer tires are most suitable for dry and wet conditions in warm temperatures, while winter tires should only be used in cold conditions, snow, or ice. Using winter tires in summer or on wet surfaces significantly increases braking distance and reduces safety.

This study provides valuable insights into the optimization of braking systems and their adaptation to the dynamic conditions of the road environment. It also emphasizes the importance of modern measurement and analysis technologies, which contribute to a better understanding of vehicle behavior during emergency braking. These findings can be utilized to develop new strategies for improving the active safety of vehicles, which is essential for reducing road accidents and enhancing traffic safety.

REFERENCES

[1] Lyubenov, D. (2012). Experimental Determination of Vehicle Deceleration on a Special Surface. Scientific Papers of the University of Ruse, 51, Series 4.

[2] Lyubenov D. (2011). Research of the stopping distance for different road conditions. III International conference – Transport problems 2011, Katowice, Poland, pp. 199-205.

[3] Liu, X., Ma, Ch., Jiang, Y., Zhang, L., Xue Y. (2021). Research on Anti-lock Braking System of Electro-mechanical Braking Vehicle Based on Feature Extraction. Journal of Physics: Conference Series, 1982, 2nd International Conference on Artificial Intelligence

and Information Systems (ICAIIS 2021), May 2021, art. no. 012001.

[4] Koylu, H. & Tural, E. (2021). Experimental study on braking and stability performance during low speed braking with ABS under critical road conditions. Engineering Science and Technology, 24 (5), pp. 1224-1238.

[5] Toshev, N. & Minchev, R. (2023). Increasing the Safety of the Car, Science Series Innovative STEM Education, Institute of Mathematics and Informatics – Bulgarian Academy of Sciences, pp. 153-162.

[6] Kumar, D., Sharma, S. & Singh, S. (2020). A Review Paper on Anti-lock Braking System (ABS) and Its Advancement. International Journal of Management, Technology and Engineering, pp. 2249-7455.

[7] Zhao, Z. & Fan, X. (2020). Review of Vehicle Active Safety Systems and Their Coordinated Control. Recent Patents on Mechanical Engineering, 14 (1), pp. 4–17.

[8] Erd, A., Jaśkiewicz, M., Koralewski, G., Rutkowski, D. and Stokłosa, J. (2018). Experimental research of effectiveness of brakes in passenger cars under selected conditions. XI International Science-Technical Conference Automotive Safety, Žastá, Slovakia, pp. 1-5.

[9] Lukyanchuk, A. D. (2012). Vehicle Safety. In BNTU eBooks.

https://rep.bntu.by/handle/data/3745.

[10] User manual Decelerometer for vehicles ENERGOTEST Energo-SM 4.0