

Analysis of the influence of some factors on the temperature distribution and tire durability

Vu Hai Quan^{1*}, Tran Quang Tam¹, Nguyen Trong Duc², Le Hong Quan¹, Tran Phuc Hoa¹ and Kirill Evgenievich Karpukhin³

¹ Faculty of Automotive Technology, School of Mechanical and Automotive Engineering, Hanoi University of Industry, **Vietnam**

² Moscow Automobile and Road Construction State Technical University, **Russia Federation**

³ Russian State Scientific Research Center "NAMI" (Central scientific research automobile and automotive engines institute), **Russia Federation**

*Corresponding Author: quanvh@hau.edu.vn

Received: 11 October 2025; *Revised:* 12 January 2026; *Accepted:* 18 January 2026

<https://doi.org/10.58712/ie.v3i1.41>

Abstract: Increasing vehicle operating speeds place greater thermal and mechanical demands on automotive tires, making the assessment of tire behavior under varying speed conditions essential for safety and durability. This study investigates the effects of speed, load, and inflation pressure on the temperature distribution and durability of the Bridgestone ECOPIA EP150 tire using numerical simulation in Ansys Workbench. The results indicate that the shoulder region exhibits the highest temperature, which rises with increasing vehicle speed. Inflation pressure and vertical load significantly influence the contact area and stress distribution. An inflation pressure of 34 psi is identified as optimal, limiting localized heat generation and maintaining tire durability under realistic operating conditions. The findings provide practical guidance for tire selection and usage, particularly in tropical climates, and support improved safety and operational efficiency. Furthermore, the simulation-based approach demonstrates the effectiveness of numerical analysis as a predictive tool for evaluating tire performance under complex operating conditions, reducing reliance on extensive experimental testing.

Keywords: temperature tire; pressure; velocity; tire-road; structure tire

1. Introduction

In recent years, the number of automobiles in circulation worldwide has continuously increased, with more than 93.5 million vehicles produced in 2023 alone, primarily in North America, Japan, and the European Union [1]. This rapid growth has been accompanied by increasingly stringent requirements for vehicle safety, stability, and fuel efficiency. Among vehicle subsystems, tires are the only components in direct contact with the road surface and therefore play a decisive role in load transfer, steering control, and braking performance. During operation, frictional interaction between the tire and the road generates heat, and the surface temperature may exceed 80 °C, which accelerates material degradation and increases the risk of pressure loss or tire failure [2].

Previous studies have demonstrated that elevated road surface temperatures, particularly under high-speed driving or hot weather conditions, strongly influence tire thermal behavior and service life. Non-uniform temperature distribution within the tire structure leads to rubber deformation and reduced traction, especially during cornering and emergency braking [3]. These effects are further intensified in tropical regions, where road surface temperatures can exceed 60 °C for extended periods, creating severe thermal operating conditions for passenger car tires.

Although tire thermal and mechanical behaviors have been widely investigated, most existing studies have addressed these aspects independently or under simplified operating scenarios [4], [5], [6], [7], [8]. Many investigations focus on average temperature evolution or isolate the influence of a single parameter, such as vehicle speed, load, or inflation pressure [9], [10], [11]. As a result, the combined effects of these parameters on localized temperature distribution and durability-related responses, particularly the formation of thermal hotspots in critical regions such as the tire shoulder, remain insufficiently understood under realistic driving conditions.

Against this background, a comprehensive evaluation of the Bridgestone ECOPIA EP150 tire under coupled thermal and mechanical loading is required. As a fuel-efficient tire designed for everyday passenger vehicles, its performance must be assessed under operating conditions representative of real-world use. Accordingly, this study investigates the joint influence of vehicle speed, load, and inflation pressure on localized temperature distribution, contact area, and stress characteristics using a three-dimensional numerical model. By emphasizing localized heat accumulation rather than global averages, the present work provides deeper insight into tire thermo-mechanical behavior and offers practical guidance for tire pressure selection, operation, and maintenance, particularly in high-temperature or tropical climate environments.

2. Material and methods

2.1 Theoretical basis

To evaluate the impact of temperature on the tire's thermal performance, it is necessary to simulate the heat transfer process at the tire surface as the vehicle operates over different speed ranges. The calculation of the heat transfer coefficient begins with determining the Reynolds number (Re) [12], which reflects the airflow regime around the tire. This coefficient is defined by Equation (1).

$$Re = \frac{\rho v L}{\mu} = \frac{v L}{\nu} \quad (1)$$

The Nusselt number (Nu) is calculated using the Dittus-Boelter equation, which is specifically applicable to turbulent flow conditions ($Re > 4000$).

$$Nu = 0.023 Re^{0.8} Pr^n \quad (2)$$

This equation is effectively applied within Equations (3) and (4).

$$0.6 \leq Pr \leq 160 \quad (3)$$

$$Re \geq 10000 \quad (4)$$

From the Nusselt number, the convective heat transfer coefficient can be determined in Equation (5).

$$h = \frac{Nu \cdot k}{L} \quad (5)$$

2.2 Model building

In this study, the simulation model is based on the geometric specifications of the Bridgestone ECOPIA EP150 tire, as illustrated in Figure 1(a). Key technical parameters of the tire are summarized in Table 1.

Table 1. Bridgestone ECOPIA EP150 tire specifications [13]

Tire size	205/55R16
Rim size	16 inches
Tire construction	Radial
Load index	91 – 615 Kg
Speed rating	V – 240 km/h

The geometric model was carefully constructed and systematically checked [14], [15], [16], [17] to eliminate geometric inconsistencies prior to numerical analysis. Meshing was then performed using the Coupled Field Transient solver in Ansys Workbench 2025. A predominantly hexahedral mesh was selected, as this mesh type is well-suited for capturing coupled thermal and mechanical responses in rubber-based tire structures with improved numerical stability [18]. The global element size was set to 10 mm, yielding approximately 18,484 elements and 63,880 nodes. To accurately represent regions with high stress and heat concentration, local mesh refinement was applied in the tire–road contact zone and shoulder areas (Figure 1b).

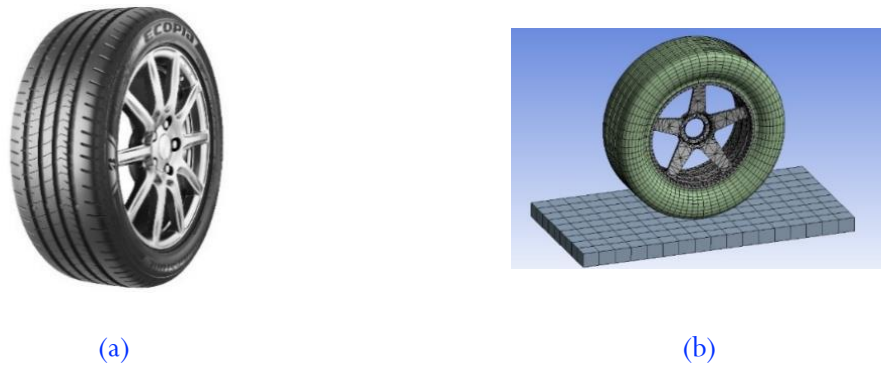


Figure 1. (a) Bridgestone ECOPIA EP150 tire [13], (b) Local mesh refined tire

The adequacy of the selected mesh was evaluated through a mesh independence assessment by comparing temperature and stress results obtained from both coarser and finer mesh configurations. The observed variations in key response parameters were within acceptable limits, confirming that the adopted mesh provides a reliable compromise between computational efficiency and numerical accuracy. Moreover, the chosen meshing approach is consistent with previously published tire thermo-mechanical simulation studies that successfully employed hexahedral meshes with similar element sizes.

2.3 Simulation process

The simulation procedure and methodological framework were established using well-documented approaches from previous tire-related studies. In particular, existing research on tire–road heat transfer provided the basis for defining thermal boundary conditions and convective heat transfer modeling, while earlier numerical and experimental investigations on automotive wheel and tire components informed the treatment of material behavior, stress distribution, and durability-related responses. Additional studies were consulted to support the selection of simulation parameters and ensure methodological consistency under realistic operating conditions [19], [20], [21], [22]. Following the geometric design and meshing stages, the numerical model was completed by applying boundary conditions including material properties, contact interaction between the tire and the road surface, applied load, inflation pressure, and rotational motion [23], [24]. Vehicle speed was explicitly

defined as a key research variable and implemented by prescribing different tire rotational speeds corresponding to vehicle velocities of 60, 80, and 90 km/h. This formulation enabled a systematic evaluation of the influence of vehicle speed on transient temperature distribution and the coupled thermo-mechanical response of the Bridgestone Ecopia EP150 tire under representative real-world operating conditions (Figure 2).

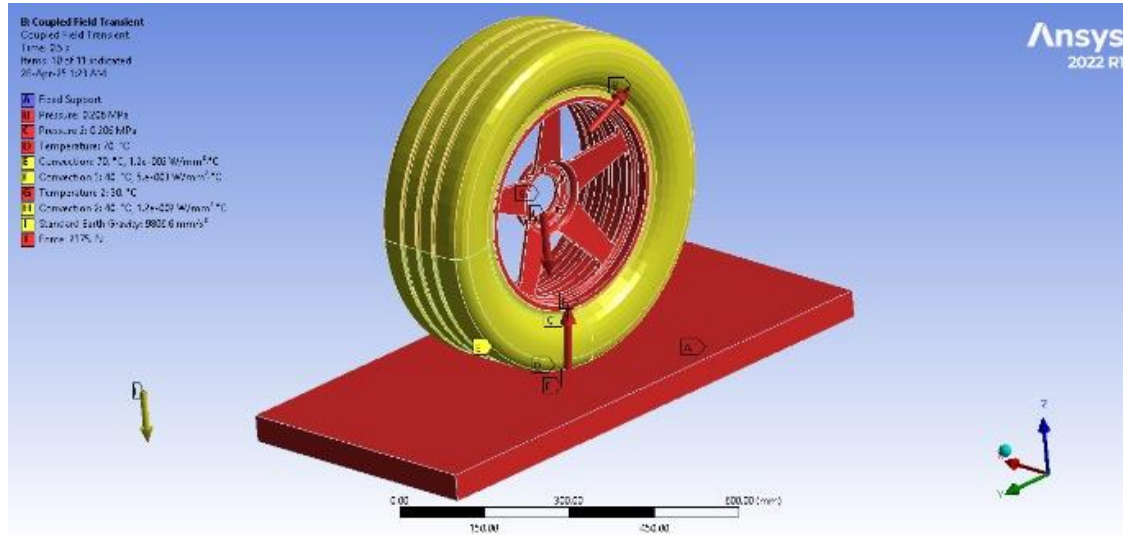
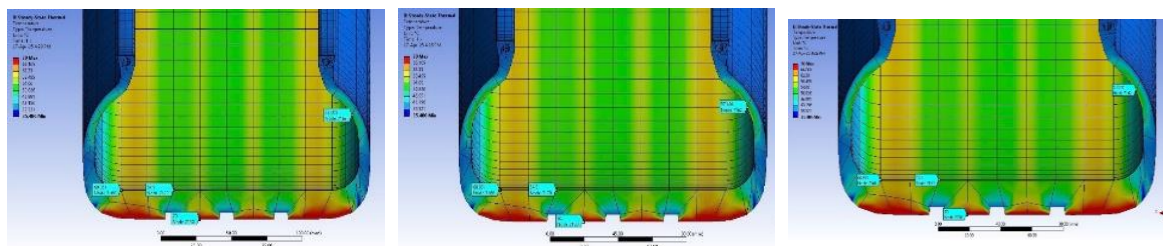


Figure 2. Boundary condition setup in the simulation model

3. Results and discussion

3.1 Effect of speed on tire temperature

The analysis results indicate that the shoulder region of the tire, which includes node 7162, experiences the highest temperature during the simulation. In contrast, the temperature at the center of the tread is significantly lower than that of the shoulder, as indicated by the green color on the thermal map. As the vehicle speed increases, the shoulder area gradually transitions from yellow to dark red, indicating a substantial rise in temperature. Conversely, the central region of the road maintains a relatively stable temperature.



a) 60 km/h

b) 80 km/h

c) 90 km/h

Figure 3. Temperature distribution of the tire across varying speeds

The results from three test scenarios show variations in temperature at different nodes of the model, as illustrated in Figure 4.

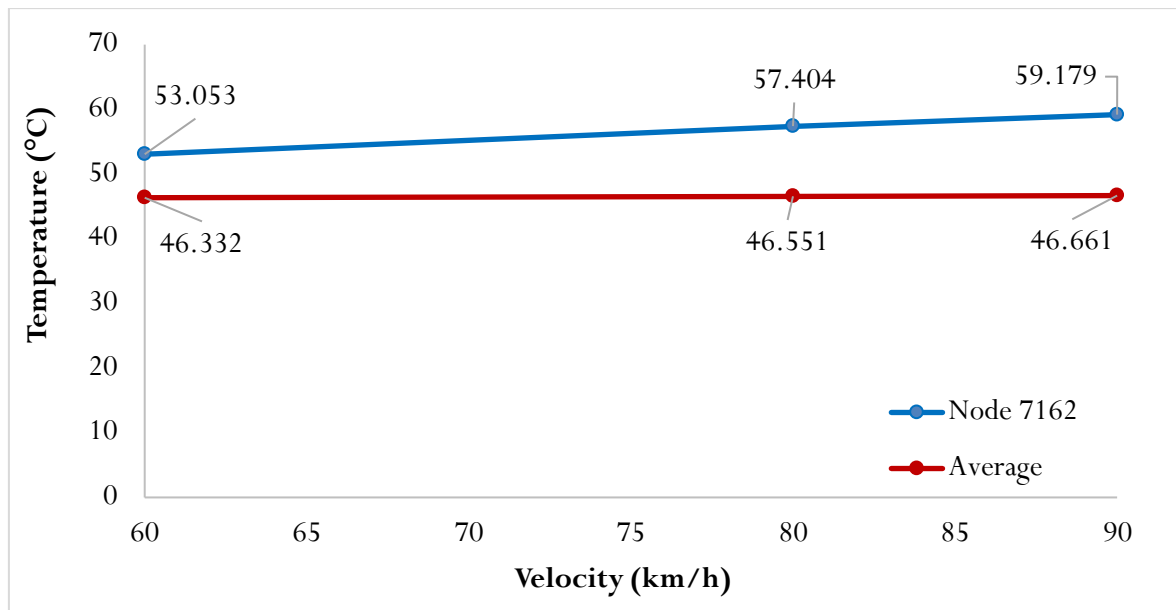


Figure 4. Tire temperature under different speed conditions

At 60 km/h, the tire experiences low thermal loading, resulting in a relatively uniform temperature distribution across the tread and limited heat concentration in the shoulder region. This behavior is reflected by a lower temperature at Node 7162 and a stable average tire temperature, indicating effective heat dissipation and favorable operating conditions. At 80 km/h, localized heating becomes more pronounced in the shoulder area, leading to a noticeable rise in temperature at Node 7162. This trend is associated with increased cyclic deformation and hysteresis losses in the rubber material. In contrast, the average tire temperature remains nearly unchanged, suggesting that the influence of speed is mainly confined to high-load and high-friction regions rather than the entire tire structure. At 90 km/h, significant heat accumulation is observed at the shoulder and edge regions, with the temperature at Node 7162 increasing markedly from 53.053°C to 59.179°C, while the average tire temperature remains within 46.3–46.7°C. This indicates that localized hotspots are strongly affected by increasing speed, whereas the tire's global thermal state remains relatively stable. Furthermore, the reduced rate of temperature increase at higher speeds in these regions reflects the material's heat-dissipation capability under elevated thermal loading.

3.2 Effect of pressure on tire temperature

Across all four scenarios examined, the vehicle speed was consistently held at 90 km/h. Figure 5 presents the temperature response at the tire shoulder under different combinations of load and inflation pressure at a constant vehicle speed. The results show that temperature variation is governed by the coupled effects of tire deformation and contact conditions, with inflation pressure acting as the primary controlling factor and load influencing its effectiveness. At 100% load, increasing the inflation pressure from 30 psi to the standard value of 34 psi results in only a minor temperature reduction, from 59.69 °C to 59.179 °C. This limited change indicates that, under high load conditions, the increased structural deformation dominates heat generation, reducing the effectiveness of pressure adjustment alone.

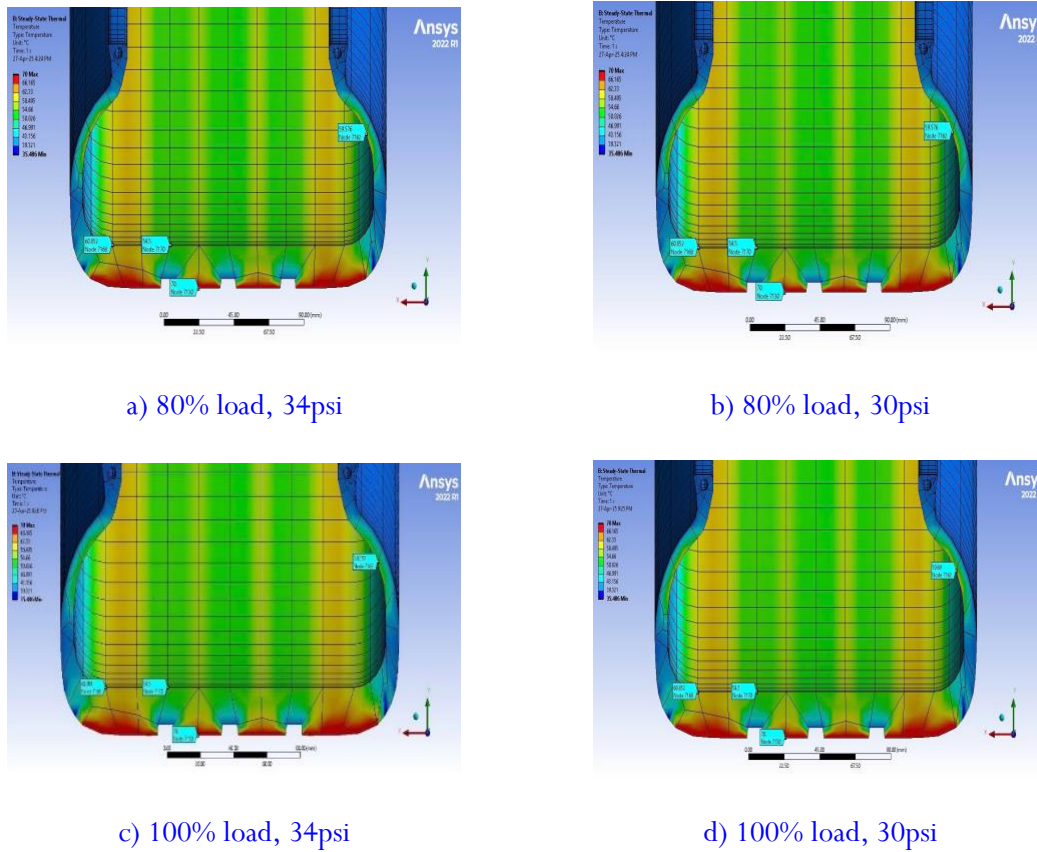


Figure 5. Temperature accumulation at node 7162

In contrast, at 80% load, raising the inflation pressure from 30 psi to 34 psi produces a substantially larger temperature decrease, from 59.576 °C to 56.166 °C. Under lower load conditions, the tire experiences reduced deformation, allowing higher inflation pressure to more effectively limit the contact area and frictional energy dissipation.

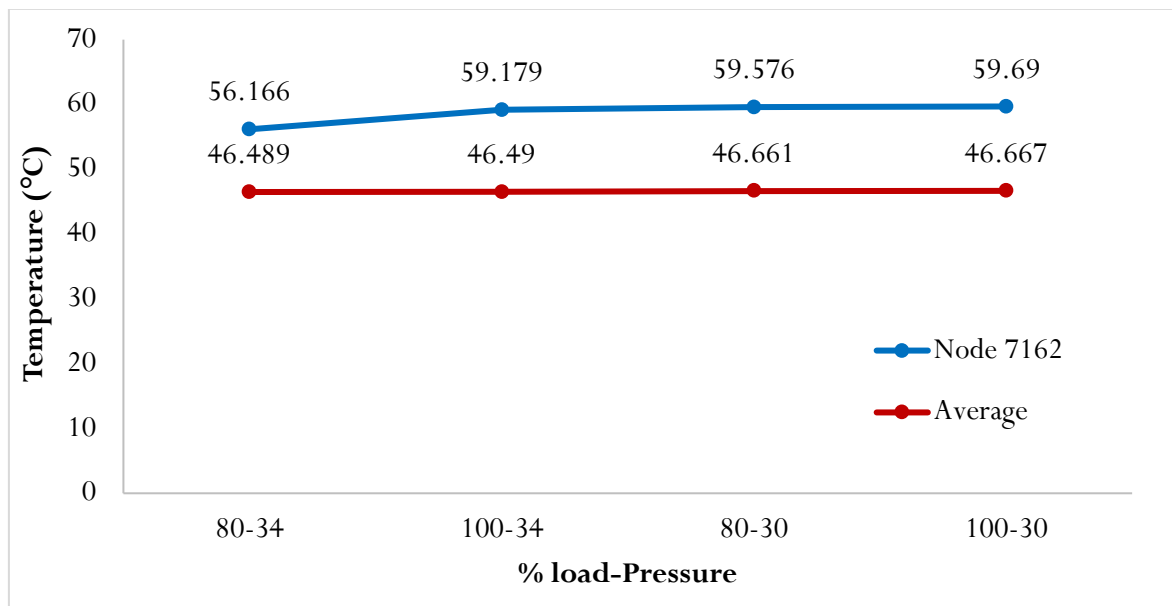


Figure 6. Temperature concentration chart at node 7162 on the tire

The influence of load is further clarified when pressure is held constant. At 30 psi, reducing the load from 100% to 80% leads to only a marginal decrease in temperature, whereas at 34 psi, the same load reduction results in a pronounced temperature drop. These observations indicate that load reduction alone has a limited thermal benefit unless accompanied by adequate inflation pressure. Overall, Figure 5 demonstrates that minimizing localized heat accumulation is most effectively achieved through the combined application of standard inflation pressure and moderate loading, underscoring the importance of their interaction in tire thermal management.

3.3 Effect of pressure and load on tire durability

Figure 7 illustrates the distribution of equivalent stress in the tire under different combinations of load and inflation pressure. The results indicate that stress levels increase with both applied load and internal pressure, reflecting the combined effect of vertical loading and structural stiffening of the tire carcass. Among these factors, inflation pressure exerts a more pronounced influence, as higher pressure increases the internal tensile stress within the rubber layers, leading to elevated stress values even at lower loads.

Despite this increasing trend, the simulated stress remains within the elastic operating range of rubber-based tire materials. As a hyperelastic material, rubber can withstand relatively high stress levels without permanent deformation or structural damage. Consequently, even at the maximum stress value of 8.6769 MPa observed in Figure 7, no critical degradation in tire strength or durability is predicted under the operating conditions investigated. These results suggest that, within the considered pressure and load ranges, stress variations are not the limiting factor for tire durability, whereas thermal effects and contact-related phenomena play a more critical role.

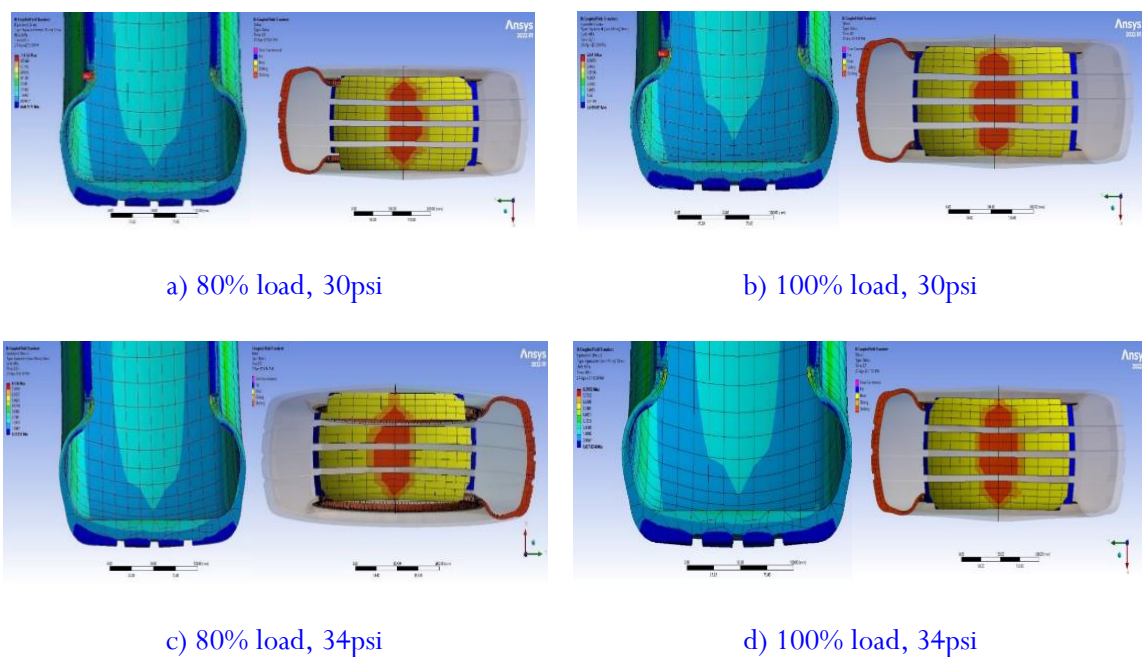


Figure 7. Effect of load and pressure on tire durability

However, a critical factor influencing tire performance during operation is the contact area between the tire and the road surface. According to Table 2, when the initial internal pressure is 30 psi and the load increases from 80% to 100%, the contact area increases from 13,539.96 mm² to 19,112 mm², an increase of 5,572.04 mm² or approximately 41.15%. At a pressure of 34 psi, increasing the load from

80% to 100% results in a contact area change from 12,754.92 mm² to 18,852.02 mm², representing an increase of 6,103.1 mm² or about 47.8% compared to the initial value.

Table 2. Stress values and contact areas in each case

Pressure (psi)	Load (N)	Contact area (mm ²)	Maximum stress (Mpa)
30	2700 (80%)	13539.96	7.661
	3375 (100%)	19112	8.17
34	2700 (80%)	12754.92	8.39
	3375 (100%)	18858.02	8.6769

4. Conclusion

Automobile tires are critical to vehicle safety and performance, as they are the only components in direct contact with the road surface. Through a coupled thermo-mechanical numerical analysis, this study shows that vehicle speed, load, and inflation pressure collectively govern localized temperature distribution and structural response. Consistent with previous research, the results confirm the importance of proper inflation pressure in limiting excessive deformation and heat generation. Beyond this, the present work demonstrates that temperature reduction is most effective when standard inflation pressure is combined with moderate loading and identifies an optimal operating condition of approximately 53 °C at 60 km/h, 80% load, and 34 psi, which supports improved durability, safety, and energy efficiency. The primary contribution of this study lies in its focus on localized thermal behavior rather than global average temperature, providing clearer insight into the interaction between operating parameters and tire thermo-mechanical response. From a practical standpoint, the findings offer guidance on tire pressure management and load control, particularly in high-temperature or tropical climates. The study is limited by its reliance on numerical simulations and simplified operating scenarios, without considering material aging, tread wear, or transient driving maneuvers. Future work should therefore incorporate experimental validation and extended modeling to better capture dynamic loading conditions and long-term tire behavior.

Author's declaration

Author contribution

Vu Hai Quan: Conceptualization, Methodology, Validation, Writing – Review & Editing. **Tran Quang Tam:** Formal analysis, Software, Investigation, Data Curation, Writing – Original Draft. **Nguyen Trong Duc:** Validation, Writing – Review & Editing. **Le Hong Quan:** Validation, Writing – Review & Editing. **Tran Phuc Hoa:** Validation, Writing – Review & Editing. **Kirill Evgenievich Karpukhin:** Validation, Writing – Review & Editing

Funding statement

This research received no external funding.

Acknowledgements

The authors would like to thank the School of Mechanical and Automotive Engineering, Hanoi University of Industry, for providing the necessary equipment and materials to conduct the experiments and complete this research.

Conflict of interest

There are no conflicts of interest in this research.

Ethical clearance

This research does not involve humans as subjects; therefore, ethical approval is not required.

AI statements

This article is the original work of the author without using AI tools for writing sentences and/or creating/editing tables and figures in this manuscript.

Publisher's and Journal's Note

Researcher and Lecturer Society as the publisher, and the Editor of Innovation in Engineering state that there is no conflict of interest towards this article publication.

References

- [1] Organisation Internationale des Constructeurs Automobiles, "Production Statistics - International Organization of Motor Vehicle Manufacturers." Accessed: Jul. 20, 2025. [Online]. Available: <https://oica.net/production-statistics/>
- [2] S. Ma, L. Wu, and W. V. Liu, "Numerical Investigation of Temperatures in Ultra-Large Off-the-Road Tires Under Operating Conditions at Mine Sites," *J. Therm. Sci. Eng. Appl.*, vol. 15, no. 2, Feb. 2023, <https://doi.org/10.1115/1.4056086>
- [3] T. Tang, D. Johnson, R. E. Smith, and S. D. Felicelli, "Numerical evaluation of the temperature field of steady-state rolling tires," *Appl. Math. Model.*, vol. 38, no. 5–6, pp. 1622–1637, Mar. 2014, <https://doi.org/10.1016/j.apm.2013.08.033>
- [4] F. Li *et al.*, "Thermo-mechanical coupling analysis of transient temperature and rolling resistance for solid rubber tire: Numerical simulation and experimental verification," *Compos. Sci. Technol.*, vol. 167, pp. 404–410, Oct. 2018, <https://doi.org/10.1016/j.compscitech.2018.08.034>
- [5] R. Behnke and M. Kaliske, "Numerical modeling of thermal aging in steady state rolling tires," *Int. J. Non. Linear. Mech.*, vol. 103, pp. 145–153, Jul. 2018, <https://doi.org/10.1016/j.ijnonlinmec.2018.01.012>
- [6] L. Teodosio *et al.*, "A numerical methodology for thermo-fluid dynamic modelling of tyre inner chamber: towards real time applications," *Meccanica*, vol. 56, no. 3, pp. 549–567, Mar. 2021, <https://doi.org/10.1007/s11012-021-01310-w>
- [7] T.-C. Nguyen, K.-D. Do Cong, and C.-T. Dinh, "Rolling Tires on the Flat Road: Thermo-Investigation with Changing Conditions through Numerical Simulation," *Applied Sciences*, vol. 13, no. 8, p. 4834, Apr. 2023, <https://doi.org/10.3390/app13084834>
- [8] Y.-J. Lin and S.-J. Hwang, "Temperature prediction of rolling tires by computer simulation," *Math. Comput. Simul.*, vol. 67, no. 3, pp. 235–249, Nov. 2004, <https://doi.org/10.1016/j.matcom.2004.07.002>
- [9] J.-W. Park and H.-Y. Jeong, "Finite Element Modeling for the Cap Ply and Rolling Resistance of Tires," *International Journal of Automotive Technology*, vol. 23, no. 5, pp. 1427–1436, Oct. 2022, <https://doi.org/10.1007/s12239-022-0125-8>
- [10] Y. Wang, Y. Wei, X. Feng, and Z. Yao, "Finite Element Analysis of the Thermal Characteristics and Parametric Study of Steady Rolling Tires," *Tire Sci. Technol.*, vol. 40, no. 3, pp. 201–218, Oct. 2012, <https://doi.org/10.2346/tire.12.400304>

- [11] X. L. Duan, S. G. Zuo, Y. Li, C. F. Jiang, and X. L. Guo, "Test and Finite Element Simulation of Steady-State Temperature Field of Rolling Tire," *Applied Mechanics and Materials*, vol. 236–237, pp. 536–542, Nov. 2012, <https://doi.org/10.4028/www.scientific.net/AMM.236-237.536>
- [12] R. Ren, X. Liang, X. Liu, wen-yong Ma, and Q. Liu, "Study on Reynolds number effect of aerodynamic characteristics of quasi-streamlined bridge section," *Engineering Mechanics*, vol. 37, no. S, pp. 139–144, 2020, <https://doi.org/https://dx.doi.org/10.6052/j.issn.1000-4750.2019.04.S023>
- [13] "Ecopia EP300." Accessed: Jul. 20, 2025. [Online]. Available: <https://www.bridgestone.com.vn/vi/tire/ecopia-ep300/205-55r16>
- [14] M. Rafei, M. H. R. Ghoreishy, and G. Naderi, "Thermo-mechanical coupled finite element simulation of tire cornering characteristics—Effect of complex material models and friction law," *Math. Comput. Simul.*, vol. 144, pp. 35–51, Feb. 2018, <https://doi.org/10.1016/j.matcom.2017.05.011>
- [15] V. H. Quan, N. A. Ngoc, N. M. Tien, N. T. Hong Hanh, H. Van Hoan, and H. T. Duong, "The Research Design Calculations and Optimization of Control Arms in Mac Pherson Suspensions in Automobile," in *2023 International Conference on Control, Robotics and Informatics (ICCR)*, IEEE, May 2023, pp. 19–23. <https://doi.org/10.1109/ICCR58865.2023.00011>
- [16] H. C. Park, S. Youn, T. S. Song, and N. Kim, "Analysis of Temperature Distribution in a Rolling Tire Due to Strain Energy Dissipation," *Tire Sci. Technol.*, vol. 25, no. 3, pp. 214–228, Jul. 1997, <https://doi.org/10.2346/1.2137541>
- [17] V. Haiquan, N. Thanh Tung, N. Anh Ngoc, and D. Ngoc Minh, "Application of Finite Elements to Analysis of Side Collision Problems of Vehicle: A Case Nissan Rogue 2020 SUV Model," *International Journal of Automotive Science and Technology*, vol. 9, no. 1, pp. 81–88, Mar. 2025, <https://doi.org/10.30939/ijastech..1581465>
- [18] H. S. Song, S. P. Jung, and T. W. Park, "Simulation of temperature rise within a rolling tire by using FE analysis," *Journal of Mechanical Science and Technology*, vol. 32, no. 7, pp. 3419–3425, Jul. 2018, <https://doi.org/10.1007/s12206-018-0645-3>
- [19] P. Cattani, L. Cattani, and A. Magrini, "Tyre–Road Heat Transfer Coefficient Equation Proposal," *Applied Sciences*, vol. 13, no. 21, p. 11996, Nov. 2023, <https://doi.org/10.3390/app132111996>
- [20] M. Zanchini, D. Longhi, S. Mantovani, F. Puglisi, and M. Giacalone, "Fatigue and failure analysis of aluminium and composite automotive wheel rims: Experimental and numerical investigation," *Eng. Fail. Anal.*, vol. 146, p. 107064, Apr. 2023, <https://doi.org/10.1016/j.engfailanal.2023.107064>
- [21] J. Hyttinen, M. Ussner, R. Österlöf, J. Jerrelind, and L. Drugge, "Estimating Tire Pressure Based on Different Tire Temperature Measurement Points," Jan. 2024. <https://doi.org/10.4271/2024-01-5002>
- [22] D. Savitski, K. Hoepping, V. Ivanov, and K. Augsburg, "Influence of the Tire Inflation Pressure Variation on Braking Efficiency and Driving Comfort of Full Electric Vehicle with Continuous Anti-Lock Braking System," *SAE International Journal of Passenger Cars - Mechanical Systems*, vol. 08, no. 2, pp. 2015-01–0643, Apr. 2015, <https://doi.org/10.4271/2015-01-0643>
- [23] J. Li, Z. P. Wang, W. X. Liu, and F. H. Zhang, "Numerical Simulation of Tire Steady-State Temperature Field Based on ANSYS Workbench," *Key Eng. Mater.*, vol. 501, pp. 382–387, Jan. 2012, <https://doi.org/10.4028/www.scientific.net/KEM.501.382>
- [24] J. Hyttinen, M. Ussner, R. Österlöf, J. Jerrelind, and L. Drugge, "Truck tyre transient rolling resistance and temperature at varying vehicle velocities - Measurements and simulations," *Polym. Test.*, vol. 122, p. 108004, May 2023, <https://doi.org/10.1016/j.polymertesting.2023.108004>