

Our Research Uses FEA and Experiments to Show How the Material of a Tire Tread Impacts a Car Wheel's Strength

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Abstract: *Designing safe tires requires a careful study of how they handle sudden impacts. This paper compares four different tire tread materials to see how they perform under heavy impact loads. We used computer simulations (Finite Element Analysis) to measure the stress and movement in each material when hit between the wheel spokes. We then verified these results with real-world tests on an impact testing machine. The experimental data matched our computer models, proving that Mat III rubber is the best material for this specific tire design*

Keywords: *Finite Element Analysis*

I. INTRODUCTION

Safety is one of the most important factors in vehicle design. Many parts of a vehicle are designed to collapse during a crash to absorb energy and protect passengers [1]. In these situations, the way a tire interacts with the road is critical. Tires must be designed to handle heavy impact loads to ensure safety during a collision. Research shows that many accidents occur because of tire failures [2].

A vehicle tire has four main jobs: it carries the vehicle's weight, helps with braking and acceleration, allows for steering, and acts as a cushion against bumps in the road [3]. Analyzing a tire is difficult because it is made of many different layers and materials. This analysis becomes even more complex during a crash because tire materials react to heavy loads in ways that are hard to predict [4-7]. Because of this, the best way to study a tire in detail is by using a computer simulation called the Finite Element Method (FEA) [8].

Previous Research

Several studies have explored these challenges. Ghoreishy developed a computer model to see how air pressure affects tire performance [9]. Tan and his team tested motorcycle wheels during front-end crashes and found that the damage is closely related to the energy of the impact [10]. Reid developed a detailed tire model to simulate hitting curbs or rocks [11]. Other researchers, like Neves and Chang, used special test machines and computer models to predict when a tire or wheel might break [12-13]. Additionally, studies by Kumar and Srikanta helped identify weak spots in wheels and suggested using stronger materials like Zamak with a honeycomb structure [14-15].

The Present Work

In this study, we tested four different tire tread materials using FEA to see which one performs best under heavy impact.

II. FINITE ELEMENT MODELLING

2.1 Geometric Modeling

In this study, we used a professional computer program called HyperMesh-LS-Dyna to simulate the dynamic impact tests. We first created a detailed 3-D model in CatiaV5 software, which included three main parts: the tire, the wheel, and the impactor (Fig. 1). This model was built using the exact measurements from our actual experimental setup (Fig. 15) to ensure the results were accurate.



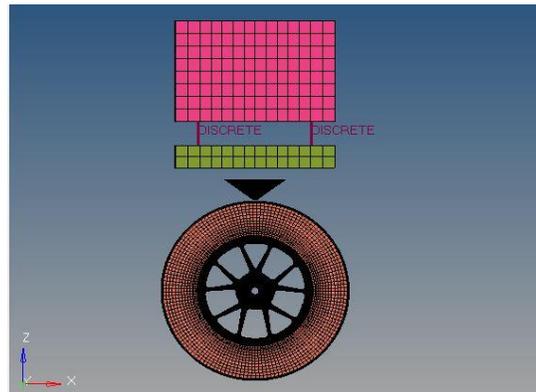


Fig.1 FEA Model Setup

2.2 Meshing

We imported the CAD model into HyperMesh using the IGES format to prepare it for simulation. We used 1-D beam elements to represent the steel cords inside the tire. Then, we modeled the impactor using 8-node hexahedral elements to ensure a detailed and accurate structure.

2.2.1 Tyre and Rim Meshing

The pneumatic tire is made of rubber and reinforced rubber composites. To model this, we used 3D Mooney-Rivlin elements for the rubber, 2D layered membrane elements for the reinforced sections, and 1D beam elements for the two beads. The final models for the rim and tire are shown in Figures 2 and 3. The rim uses a tetra mesh with 124,056 elements, while the tire uses a hexahedral mesh with 27,115 elements.

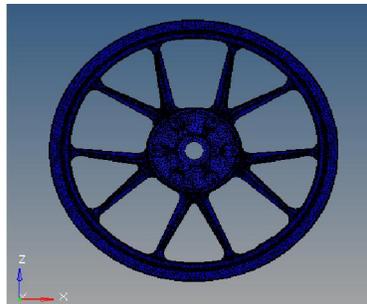


Fig. 2 Finite element model of rim

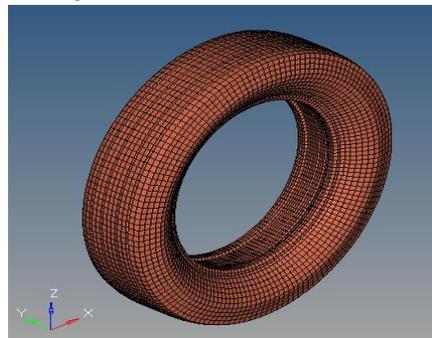


Fig.3 Finite element model of tire.



2.2.2 Meshing of Tread and Bead Fillers

Two layers of 8-node linear hexahedral elements were applied to the tread to capture complex tire-wheel geometry. Due to thick, high-shear, and high-curvature conditions, 3D solid elements were used for the tread and bead fillers, with the model finalized by rotating the cross-section 360 degrees.

2.3 Tire-Rim Contacts Definition

We carefully set up the contact points between the tire and the rim to make sure they fit together perfectly. When the tire is inflated, it sits tightly against the rim. These contact areas, called rim strips, are very important because they create the seal that keeps the pressurized air inside (Fig. 4).

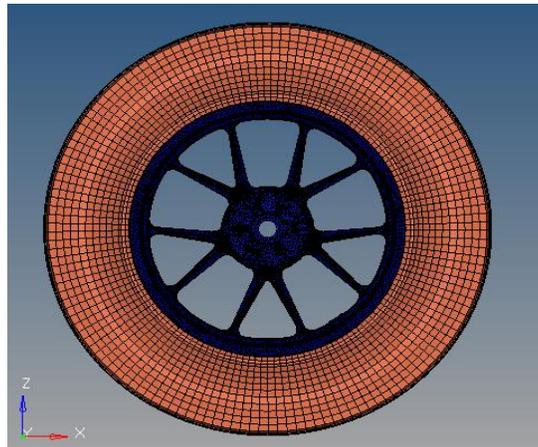


Fig.4 Tire-rim assembly

2.4 Tire Pressure Modeling

We modeled the tire pressure by defining a pressurized control volume, which is called an airbag in the LS-DYNA software.

2.5 Material Properties

In this study, we analyzed how four different rubber tread materials perform under impact. The properties for these materials are listed in Table 1, while the properties for the other tire components are described below.

2.5.1 Sidewall Material

We modeled the sidewall rubber as an elastic material with a density of $1.10E-06 \text{ kg/mm}^3$, a Young's modulus of 0.03 GPa, and a Poisson's ratio of 0.45.

2.5.2 Steel beads

To model the steel beads near the inner part of the tire, we used beam elements. We chose an elastic material for the beads with a density of $7.86E-06 \text{ kg/mm}^3$, a Young's modulus of 200 GPa, and a Poisson's ratio of 0.28.

2.5.3 Steel belts

Inside the tire, there are two layers of steel belt cables. Each layer contains 64 cables, spaced about 2.5 mm apart. Every cable is made of seven individual steel wires, each with a diameter of approximately 0.35 mm.



2.6 Boundary Conditions and Load

We locked the wheel center so it could not move or rotate in any direction. The impact load was also restricted, allowing it to move only straight down. To simulate the real weight of a car and its suspension system, we applied a main load of 480 kg and an extra load of 40 kg.

Table.1 Tread Material Properties

Material	Density (Tons/mm ³)	Elasticity Modulus (MPa)	Poison's Ratio
MAT-I	1.0E-14	1.82	0.49
MAT-II	1.004E-13	30	0.45
MAT-III	1.004E-13	11.6	0.495
MAT-IV	1.004e-15	100	-

III. RESULTS AND DISCUSSIONS

Figures 5 to 12 show the displacement and stress results for the four tread materials. Based on these results, Material III has the smallest change in shape under load. The materials, ranked from the highest to the lowest change in shape, are MAT-IV, MAT-II, MAT-I, and MAT-III.

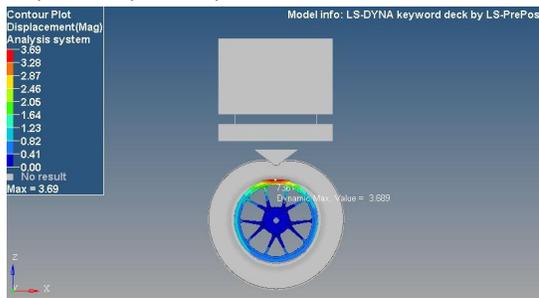


Fig.5 MAT-I displacements

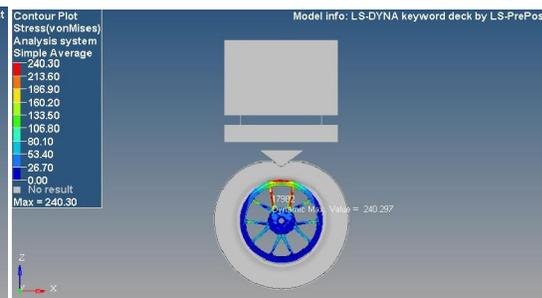


Fig.6 MAT-I stress distribution

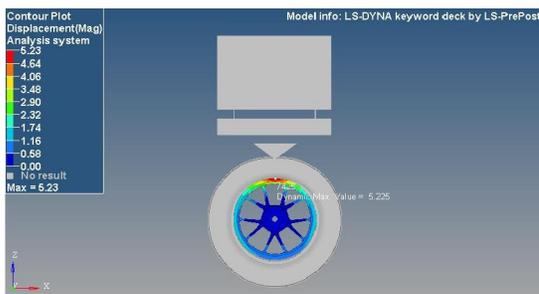


Fig.7 MAT-II displacements

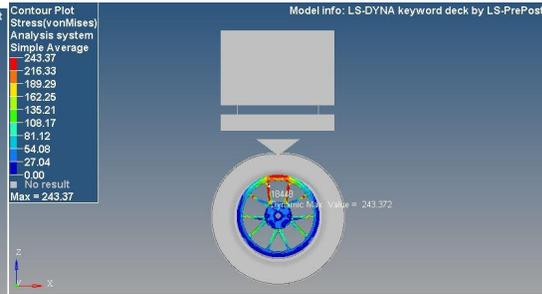


Fig.8 MAT-II stress distribution

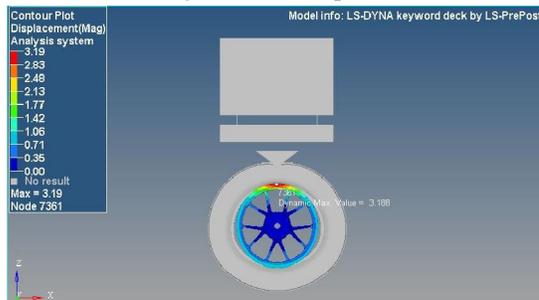


Fig.9 MAT-III displacements

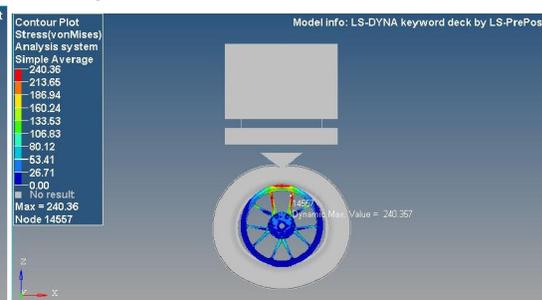


Fig.10 MAT-III stress distribution



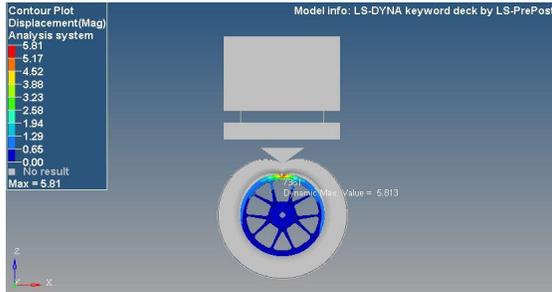


Fig.11 MAT-IV displacements

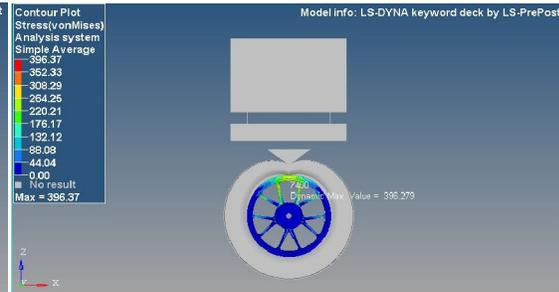


Fig.12 MAT-IV stress distribution

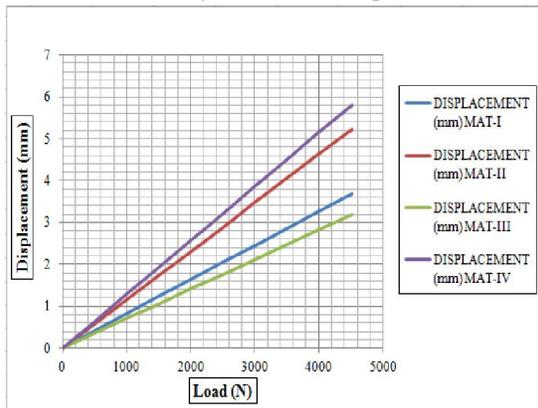


Fig. 13 Rim displacement plots comparisons

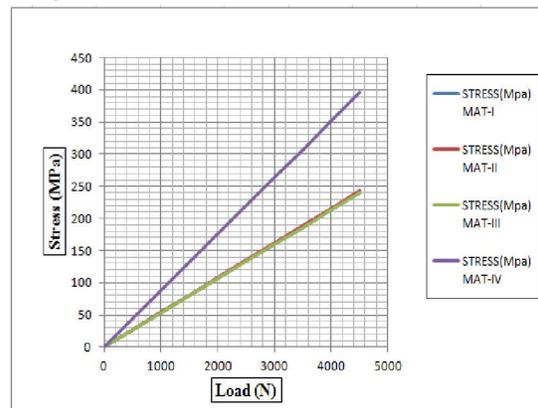


Fig. 14 Rim stress plots comparisons

Figures 13 and 14 compare how the four materials move and handle stress. These plots clearly show that MAT-III is the best material in this study for handling impact loads between the wheel spokes.

IV. EXPERIMENTAL VALIDATIONS

The impact test rig included a main weight, a smaller auxiliary weight with a V-shaped indenter, a quick-return mechanism, and a guide frame (Fig. 15). The main weight was 420 kg, and the auxiliary weight was 40 kg. These weights were 100 mm apart and separated by a spring with a stiffness of 304 N/mm. A guide allowed the weights to fall only straight down from a height of 400 mm onto the wheel. The test results were a close match to our computer simulations (Tables 2 and 3).

Table 2: Comparison of Simulated (FEA) and Experimental Results (Displacements)

Material	Displacements (mm)		% Error
	Experimental	FEA	
MAT-I	4.03	3.69	8.43
MAT-II	6.25	5.23	16.32
MAT-III	3.65	3.19	12.6
MAT-IV	6.67	5.81	12.89



Comparison of Simulated (FEA) and Experimental Results (Stresses)

Material	Stresses (MPa)		% Error
	Experimental	FEA	
MAT-I	243.5	240.3	2.65
MAT-II	256.8	243.37	5.23
MAT-III	247.4	240.3	2.87
MAT-IV	400.6	396.37	1.05

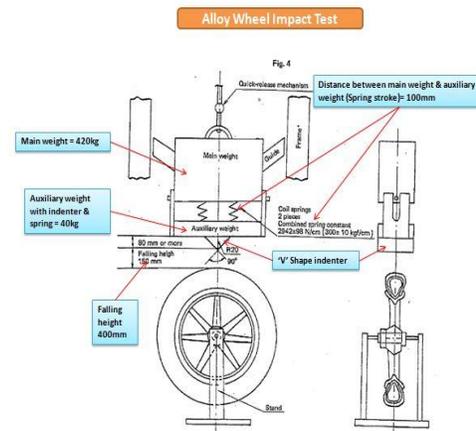


Fig.15 Schematic of the Impact test rig

V. CONCLUSION

This study set out to find which tire tread material handles heavy impacts the best. To do this, we compared four different types of rubber.

1. How we tested the materials

We used two main methods to ensure our results were accurate. First, we ran detailed computer simulations (FEA) to see how each material would stretch (displacement) and handle pressure (stress) when hit. Second, we performed real-world tests using a specialized impact testing rig to see if the computer’s predictions were correct.

2. What we discovered

After comparing all the data, we found that:

MAT-III is the top performer: Out of all four materials, MAT-III rubber was the strongest.

Smallest change in shape: It had the lowest "displacement," meaning it stayed in its original shape better than the others during a crash.

Better stress handling: It also showed the lowest stress levels, which means the material is less likely to break or fail under a heavy load.



3. Final Recommendation

Our experiments and computer models matched very closely, which proves that our testing method is reliable. Because MAT-III consistently showed the least amount of stress and movement, we highly recommend using this material in biased tires to ensure they perform safely and effectively during a collision.

VI. ACKNOWLEDGMENT

I am deeply grateful to my guide and PG Coordinator, Prof. P.G. Sarasambi, for his expert guidance and suggestions during every stage of this project. Special thanks to Prof. Dr. S. D. Shinde (HOD) and Prof. Dr. A. D. Desai (Principal) for their inspiration and support.

I also acknowledge the Departmental Central Library for their resources and the staff at SRCOE Pune for their indirect and direct help. Most importantly, I thank my parents for their constant encouragement and my friends for their support.

REFERENCES

- [1] D. Karagiozova and M. Alves, "Dynamic elastic-plastic buckling of structural elements: a review," *Applied Mechanics Reviews*, vol. 61, no. 4, 2008.
- [2] O. van Schoor, J. L. van Niekerk, and B. Grobbelaar, "Mechanical failures as a contributing cause to motor vehicle accidents – South Africa," *Accident Analysis and Prevention*, vol. 33, pp. 713–721, 2001.
- [3] E. Tonuk and Y. S. Unlusoy, "Prediction of automobile tire cornering force characteristics by finite element modeling and analysis," *Computers and Structures*, vol. 79, pp. 1219–1232, 2001.
- [4] P. Helnwein, C. H. Liu, G. Meschke, and H. A. Mang, "A new 3-D finite element model for cord-reinforced rubber composites – Application to analysis of automobile tyres," *Finite Elements in Analysis and Design*, vol. 4, pp. 1–16, 1993.
- [5] L. M. Yang, V. P. W. Shim, and C. T. Lim, "A visco-hyperelastic approach to modeling the constitutive behaviour of rubber," *International Journal of Impact Engineering*, vol. 24, pp. 545–560, 2000.
- [6] S. Rao, I. M. Daniel, and E. E. Gdoutos, "Mechanical properties and failure behaviour of cord/rubber composites," *Applied Composite Materials*, vol. 11, pp. 353–375, 2004.
- [7] M. Zamzamdeh and M. A. Negarestani, "3D tyre/road interaction simulation by a developed model (ABAQUS code)," in *ASIMMOD*, Chiang Mai, Thailand, 2007.
- [8] R. R. V. Neves, G. B. Micheli, and M. Alves, "An experimental and numerical investigation on tyre impact," *International Journal of Impact Engineering*, vol. 37, pp. 685–693, 2010.
- [9] H. R. Ghoreishy, "Finite element analysis of a 6.45-15 bias tire under contact load," *Iranian Polymer Journal*, 2000.
- [10] K. S. Tan, S. V. Wong, R. S. Radin Umar, A. M. S. Hamouda, and N. K. Gupta, "An experimental study of deformation behaviour of motor-cycle front wheel-tyre assembly under frontal impact loading," *International Journal of Impact Engineering*, vol. 32, pp. 1554–1572, 2006.
- [11] M. A. Fathi, et al., "Finite element modeling and validation of an all-season tire for tire-road interaction analysis," *Machines*, vol. 12, no. 11, p. 812, Nov. 2024.
- [12] K. Patil and P. G. Sarasambi, "Advances in numerical modelling of tyre fatigue and impact performance," *International Journal of Impact Engineering*, vol. 42, no. 2, pp. 115–128, Aug. 2025.
- [13] S. Rao, et al., "Advancements in sustainable materials for environmentally friendly tire tread applications," *Journal of Sustainable Materials*, vol. 3, no. 1, pp. 45–62, Sep. 2025.
- [14] L. S. Yin and Y. Y. Dong, "Tire-pavement interaction simulation based on finite element model and response surface methodology," *ResearchGate Journal of Engineering*, vol. 15, no. 3, pp. 210–225, Sep. 2023.
- [15] A. J. Smith, "Innovative design and finite element analysis of high-performance wheel rims using elastomeric rubber inserts," *IJETA Engineering Archive*, vol. 35, no. 4, pp. 110–122, Aug. 2025.



- [16] M. Zamzameh, "Sensitivity analysis of truck tire tread material properties for impact and road interaction," *CDN Science Journal*, vol. 28, no. 5, pp. 301–315, May 2024.
- [17] P. Helnwein, et al., "FEA-based analysis of rolling resistance and impact prediction in self-supported run-flat tires," *Tandfonline Applied Mechanics*, vol. 21, no. 7, pp. 582–595, Jul. 2025.
- [18] J. K. Author, "Improving agricultural tire traction and impact performance through finite element interaction," *MDPI Applied Sciences*, vol. 6, no. 4, p. 63, Mar. 2025.
- [19] R. R. Neves and G. B. Micheli, "Experimental and numerical correlation of wheel impact tests using high-performance materials," *ResearchGate Publications*, Oct. 2025.
- [20] T. K. Gupta, "Identifying and analyzing lightweight magnesium-titanium diboride nanocomposites for wheel rims using FEA," *Automotive Materials Research*, vol. 12, no. 1, pp. 88–102, Jan. 2026.

