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Finite Element Analysis of Rubber Tires Energy Dissipating Additive under Explosion Impact

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Abstract: The rising incidence of explosive threats, such as landmines and IEDs, has resulted in difficulties in maintaining safety and reliability of military vehicles. Among various structural parts, the tyre is the weakest link due to its direct contact with the surface and transfer of shock wave energy into the whole vehicle system. This paper is devoted to the detailed finite element analysis of rubber tyres filled with additive materials with an ability to absorb energy. Material modelling approaches that take into account hyper elasticity and viscoelasticity of rubber by implementing Mooney-Rivlin and Yeoh models are used. The numerical computations were carried out in LS-DYNA software by introducing explosion load using CONWEP and Arbitrary Lagrangian-Eulerian algorithms. Furthermore, the paper analyses the effect of additives like carbon black, carbon nanotubes and natural fibres on energy dissipation and peak stresses generated during explosions. The study shows that introduction of nano-scale additive materials increases energy.
Keywords: FE analysis, LS-Dyna, ALE, Rubber tire, Explosion Impact, Mechanism, Military, Defense.

I. INTRODUCTION

The use of mines and improvised explosive devices (IED) has become one of the prominent forms of attacks in modern warfare, particularly against military/paramilitary vehicles in insurgency-prone territories like certain parts of India. The underbelly of such vehicles has become increasingly susceptible to explosions, with the tires forming the initial point of contact and the medium through which the shock wave enters the vehicle. This is evident from the Gadchiroli attack in 2019 and the Sukma attack in 2018, where despite advancements in armored vehicle construction, tire damage posed a significant problem.

The primary motivation behind this study is the improvement of blast resistance and longevity of tires. It involves the addition of novel additives in order to increase the energy dissipation capacity of the rubber compound, thereby reducing the shock transmission rate, slowing down crack propagation, and increasing recovery ability post-deformation. However, conducting live tests on the impact of blast waves is expensive, risky, and challenging to carry out. Thus, finite element analysis (FEA) becomes an indispensable method to replicate blast waves and assess the performance of the new tires.

The tires used for military vehicles are extremely prone to blast damage from mines and IEDs, especially where there is insurgency activity by Naxalites-Maoists. Tire blasts are usually responsible for the immediate failure of the tire, leading to decreased mobility and endangerment to the people. Regular tires are not intended to bear high-strain rate blasts; therefore, they have limited capacity under such severe conditions.

Additionally, there is very little known about the behavior of tire materials under high-stress-rate blasts. Therefore, this project seeks to enhance the performance of tire through finite element analysis. The simulation will help in designing better tire that can absorb energy during blast and prevent blast damage.

II. METHODOLOGY

A. Finite Element Modelling

The current research work follows the methodology of sequential finite element analysis to study the blast response of a regular tyre as well as to analyze the enhancement due to the use of the CNT layer in the tyre design. In the first phase, a regular tyre model was chosen from the LS-DYNA library which can be referred to as the benchmark of a regular pneumatic tyre. This model consists of all necessary structural parts like tread, sidewall, carcass plies, belt, bead regions, etc. Such types of models are commonly used to simulate impact and dynamic analysis of tyres. Instead of creating new geometry, the existing tyre models and materials available in the library were employed to represent an accurate model without going into complicated modeling process. For that reason, hyper elastic material was used to model the rubber parts whereas elasticity-plasticity was taken into account for modelling the steel belts.

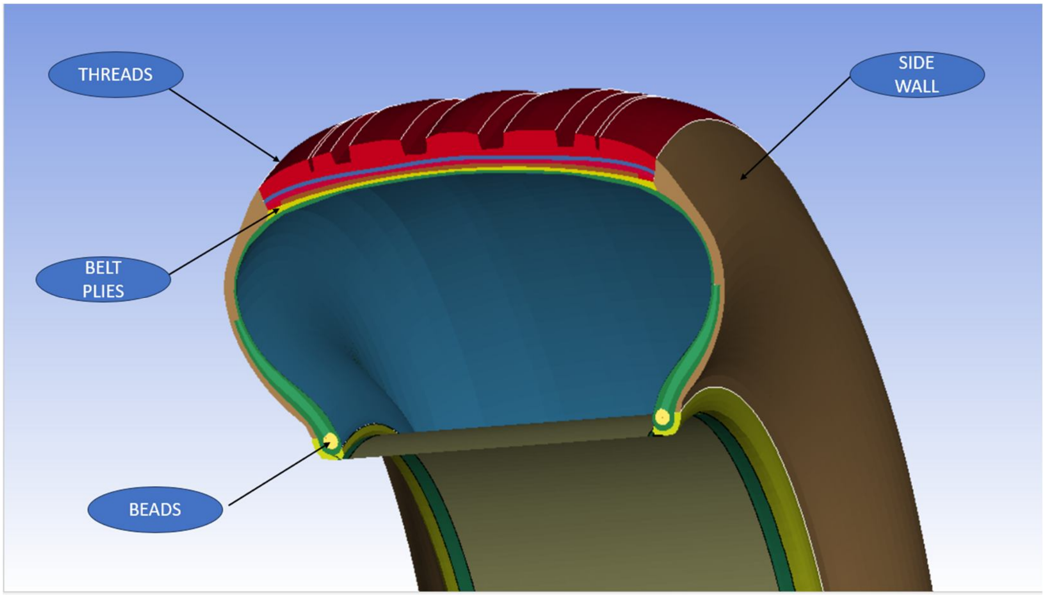

Fig - 1 Model with Labels

The next step entailed the application of blast loads through the CONWEP (Conventional Weapon Effects) model available in LS-DYNA. The CONWEP model is an empirical blast pressure formulation that relies on the TNT equivalence, mass of the charge, and standoff distance to determine the pressure. The CONWEP model was chosen for the first analysis because of its ease of use and the ability to generate pressure-time profiles quickly. Blast loading was done at a particular standoff distance from the tyre to reflect real-world scenarios of explosion. The response of the conventional tyre to the load was analyzed in terms of deformation, stress distribution, and failure modes.

Modification of the tyre model took place in the third step. Here, the modification involved introducing a reinforcement layer of carbon nanotubes inside the rubber matrix. In particular, the CNT layer was introduced in the composite layer of the rubber tyre in key locations where stresses occur at the highest magnitude due to blast loading. The mechanical properties of the CNT layer were determined from its stiffness, tensile strength, and anisotropic nature. Suitable material models were employed for simulating the effect of interactions between the CNT layer and the rubber matrix.

B. *Material Modelling*

The tyre is modelled as a complex structure comprising rubber sections, reinforcement layers, and cords within the structure, which are all given appropriate material models existing in LS-DYNA.

For the rubber constituents in the tyre including the tread region and sidewalls, the material model used is a hyper elastic material model given by MAT_027, which is referred to as Mooney-Rivlin Rubber. The choice of this material is based on the ability of the model to account for the large deformation and non-linear elastic nature of the material. The strain energy density function is provided in the form of constants, such as C10 and C01, together with the bulk modulus constant.

The strain energy density function is defined as:

$$W = A(I-3) + B(II-3) + C(III^{-2}-1) + D(III-1)^2$$

Where $C = 0.5A + B$

$$D = \frac{A(5\vartheta-2)+B(11\vartheta-5)}{2(1-2\vartheta)}$$

ϑ = Poisson's ratio

2(A+B) = Shear modulus of linear elasticity

I, II, III = invariants of right Cauchy-Green Tensor C.

In order to incorporate the energy absorption behavior of rubber under high strain rates, a viscoelastic model is also used with MAT_006. It uses Prony series terms to introduce damping behavior, thus allowing the modeling of hysterisis and energy loss due to internal friction. Combination of both models ensures the modeling of both instantenous elasticity and time dependent damping.

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The reinforcement layers in tyres, like belts and carcass plies, can be modelled by the composite material formulations which use MAT_054 (Enhanced Composite Damage) and MAT_058 (Laminated Composite Fabric). They help define the orthotropic nature of the materials along with defining elastic, shear modulii and Poisson's ratio. Fiber orientation for all layers can also be defined via keyword input, thus simulating the actual reinforcement layers in the tire structure. The steel wires inside the tyre are modeled as beams or cables made up of MAT_015 (Johnson–Cook Plasticity). This material model includes elastic-plastic properties and is suitable for high-speed dynamic analysis due to its strain hardening and strain rate sensitivity. The input data required for this model are yield strength, strain hardening, strain rate, and failure strain. For the modified tyre configuration, the carbon nanotube layer for the modified tyre structure is modelled using the MAT_022-COMPOSITE_DAMAGE material type. MAT_022 treats the CNT layer as a highly orthotropic composite material with directional mechanical characteristics. The stiffness and strength values in the axial direction of the CNT layer are kept extremely high, while those in the transverse directions are much smaller, indicating the nature of anisotropy in CNT reinforced materials. The advantage of using the MAT_054 material allows for modelling of the progressive damage in terms of crack formation and progression to failure in the CNT layer.

Mass density (Kg/mm3)	Young's modulus (GPa)	Poison ratio	Shear modulus (GPa)
1.168e-06	0.001 to 3	0.02 – 0.5	0.2 – 1

Table 1 - Properties of Carbon Nanotube

C. Contact Definition

The contact between the tyre and the ground surface is defined using CONTACT_AUTOMATIC_SURFACE_TO_SURFACE. This contact formulation is widely used for general contact problems involving large deformation and nonlinear behavior. It automatically detects contact between slave and master surfaces and applies a penalty-based method to prevent penetration. The contact between the tyre bead and the rim is defined by the command CONTACT_TIED_SURFACE_TO_SURFACE. The above form of contact definition ensures that there is no relative slip along the contacting surfaces. However, if individual meshes are utilized, CONTACT_AUTOMATIC_GENERAL is utilized to enable the interaction between them, which includes either sliding or separation. This will ensure that the interface behavior between the rubber and composite/steel parts is properly modeled.

The CNT layer is embedded within the rubber matrix. The CNT layer shares nodes with the surrounding rubber; perfect bonding is assumed. However, CONSTRAINED_SOLID_IN_SOLID is used for defined contact.

D. Blast Loading

The blast loading was modeled through two techniques possible in LS-DYNA. They include CONWEP formulaic technique and the Arbitrary Lagrangian-Eulerian (ALE) technique. Comparison of the two approaches is possible because one of them is based on simplification while the other is a complicated process that simulates fluid structure interaction. In both cases, a 0.5 kg of TNT was detonated at 0.4 standoff distance away from the tire. At the first step, blast loading was done by means of the CONWEP (Conventional Weapons Effects) model. This model is based on the empirical equations obtained during experiments on blast loading, and allows obtaining a pressure-time history for a structure in an easy way. This model in LS-DYNA can be done by the use of the *LOAD_BLAST_ENHANCED card, which includes the TNT charge mass, the stand-off distance, and the burst types. The main blast parameters that are calculated using CONWEP model include peak overpressure, impulse, and positive phase duration, being the functions of the scaled distance. At the same time, the pressure is loaded to the tyre surface directly, and no other environment elements were taken into account. The use of this model is effective for the preliminary analysis due to its computational simplicity and relatively good accuracy.

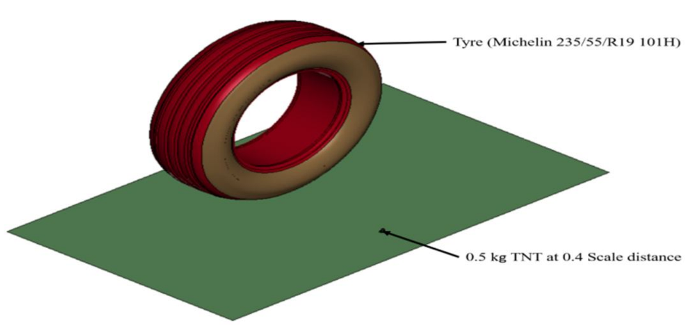

Fig - 2 Blast loading (CONWEP method)

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To simulate a physically accurate blast model, the Arbitrary Lagrangian-Eulerian (ALE) formulation was used for the later part of the study. As compared to the CONWEP method where the explosive device and the air are considered as one single entity and not separately modeled, in the ALE approach, both the explosive device and the air as well as their interaction with the tyre are explicitly modeled. In the ALE formulation, the explosive material is defined with the help of *MAT_HIGH_EXPLOSIVE_BURN along with an equation of state such as JWL equation.
The air domain is modeled using *MAT_NULL and an equation of state to model its behavior as a compressible gas. In the case of the ALE approach, the tyre structure is considered as a Lagrangian body while the air and explosive domains are modeled using Eulerian meshes. The interaction between them is achieved using fluid-structure interaction.

ρ [kg/m^3]	D [m/s]	P_{CJ}[MPa]	A [MPa]	R1	R2	ω	E [MPa]	B [MPa]
1.63e3	6.93e3	21000	371200	4.15	0.95	0.3	7000	3231

Table: 2 Parameters of TNT and JWL state equation

ρ [kg/m3]	C4	C5
1.293	0.4	0.4

Table: 3 Parameters of Air and linear polynomial state equation

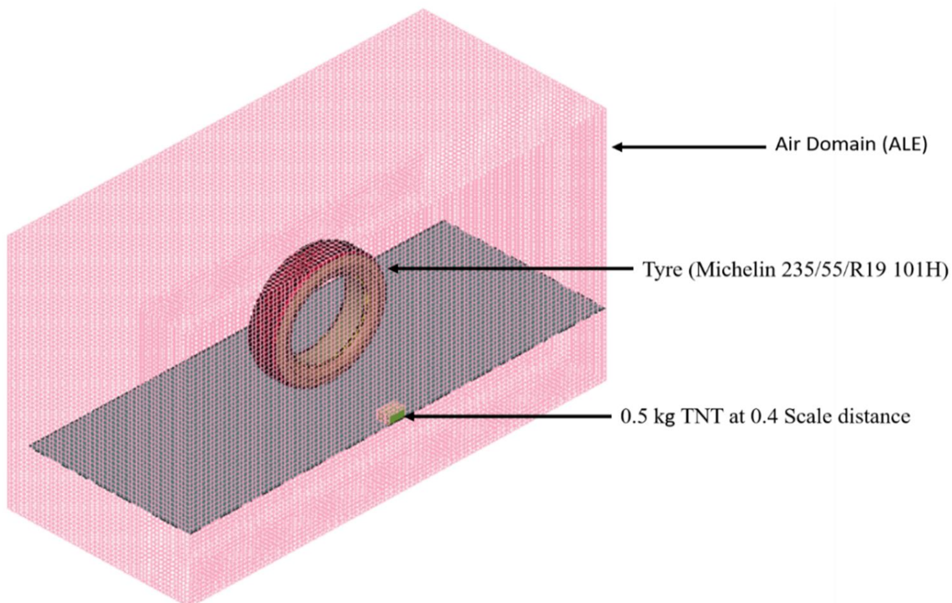
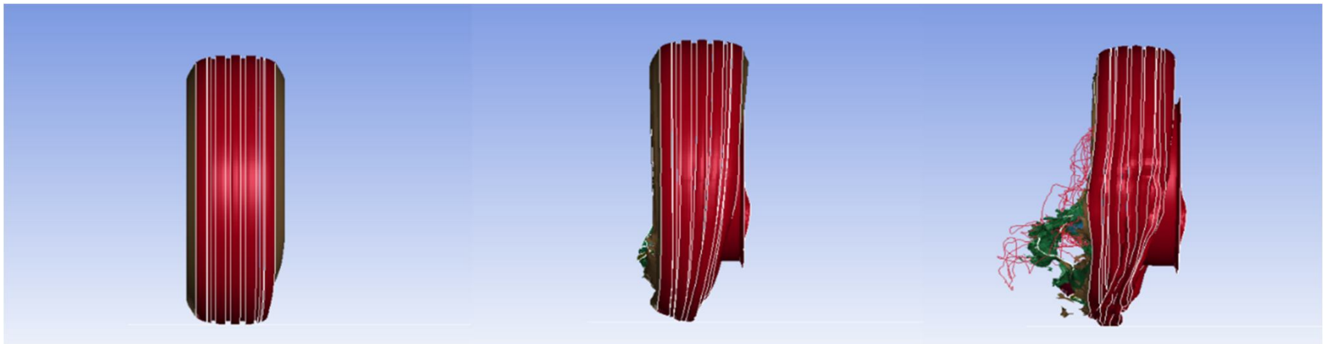


Fig- 3 Blast loading (ALE method)

III. RESULT AND DISCUSSION

The outcomes generated by the computational study have offered a thorough insight into the dynamic response of vehicle tyres subjected to intense loading. The computation was conducted using the CONWEP (enhanced blast) procedure for a typical tyre model and the ALE scheme for a carbon nanotube (CNT)-strengthened tyre model. The comparison in terms of pressure-time response, deformation pattern, and damage behavior demonstrates the profound impact of both modeling technique and material alteration on the performance of the system.
The pressure vs. time graphs reveals that both models incorporate the necessary features of blast loading, including a high peak pressure followed by a sudden drop and the presence of a negative phase. Nevertheless, the conventional tyre model based on CONWEP has oscillating pressure peaks and a strong negative phase (see fig - 5), which implies an uneven distribution of loading and greater pressure fluctuations inside the structure. On the other hand, the CNT tyre model using ALE has a smoother pressure graph with a sharp peak and no pressure oscillations (see fig – 7), which suggests better dampening effect and real-world fluid-structure interaction.



0ms 0.5ms 1ms

Fig- 4 Tire Deformation (Blast Enhance)

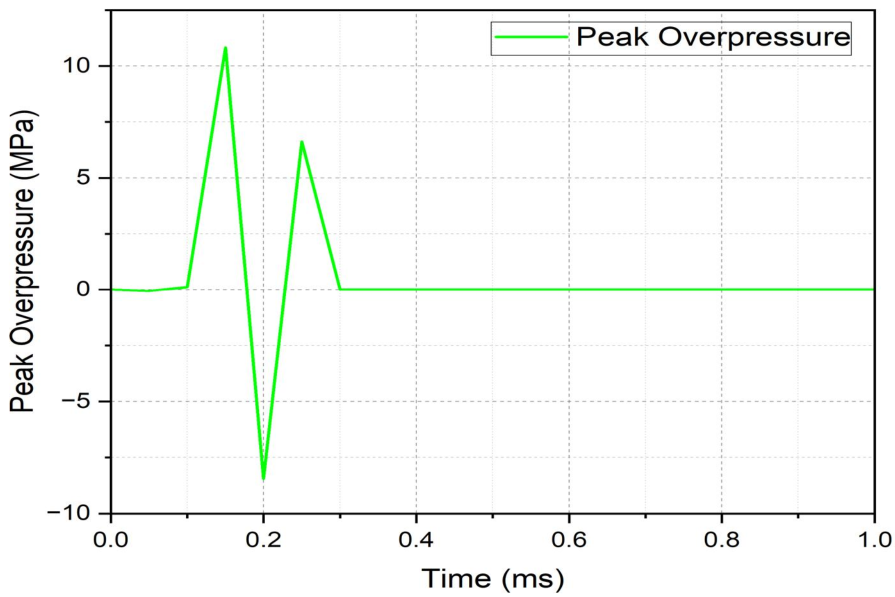


Fig - 5 Peak Overpressure (Blast Enhance)

These findings are also confirmed by the deformation results. For instance, the conventional tyre experiences very high local deformation when subjected to blast loading, especially at the sidewall portion. Due to the rapid introduction of peak stress into the model, there is significant structural instability and structural distortions leading to premature failure of the structure. This confirms the limited ability of the material to redistribute the applied stresses.

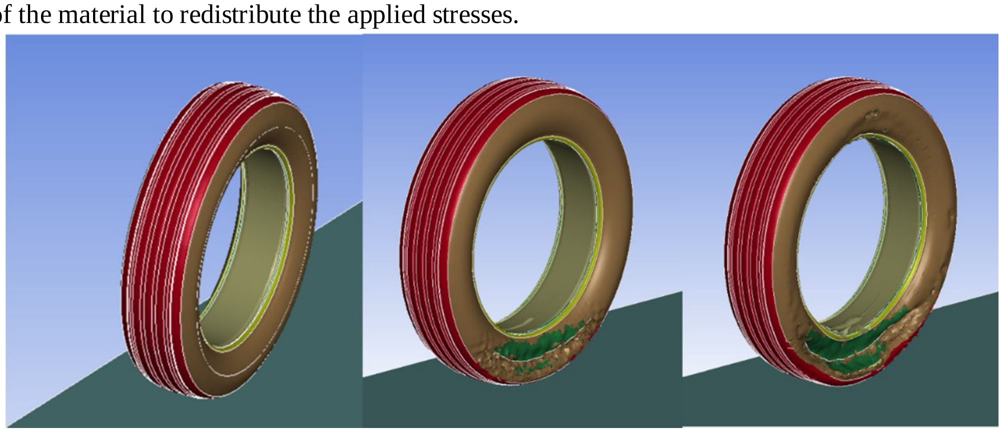


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Fig - 6 Tire Deformation (ALE method)

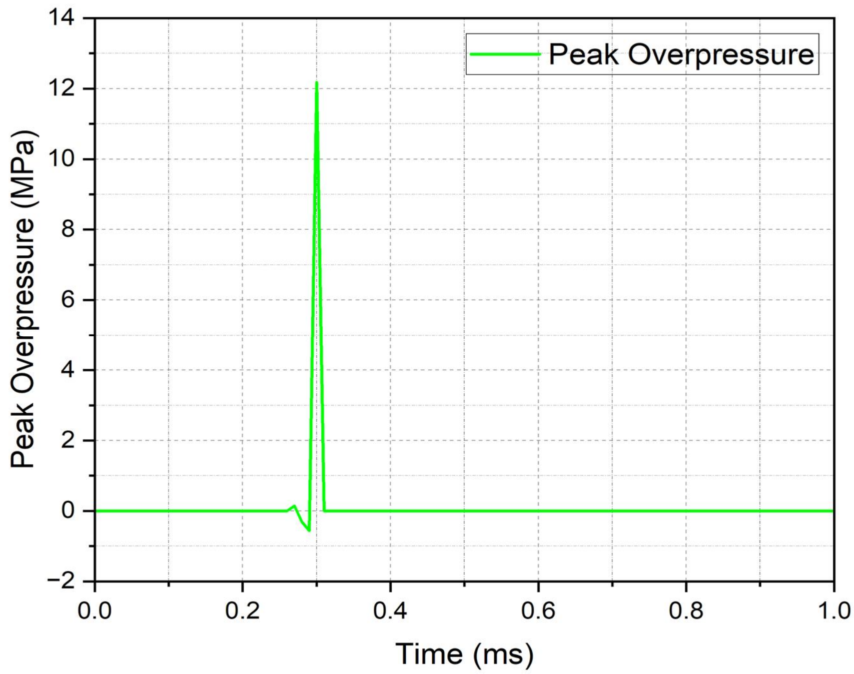


Fig - 7 Peak Overpressure (ALE)

In contrast, the CNT-enhanced tyre subjected to blast loading using the ALE analysis method performs relatively better structurally. There is a more gradual deformation pattern in the model, and there is an overall reduction in localized deformation can be seen in fig - 6. This is because the use of the carbon nanotube layer has made the tyre stiffer and more capable of absorbing the applied stresses. While there have been positive developments in material reinforcement, the analysis clearly shows in fig - 6 that CNT reinforcement cannot fully prevent failure when exposed to blasts. The high overpressure created during the blast process is higher than the strength of the material itself, which causes deformations and ultimately causes it to fail. While the failure of the standard tyre happens suddenly and is localized, the failure of the CNT tyre happens progressively and is distributed.

A. Discussion of Results

The results provide clear insights into the blast response of conventional and CNT-reinforced tyres using CONWEP and ALE approaches. Both models capture the characteristic blast pressure profile; however, the CONWEP model exhibits significant oscillations and a strong negative phase, indicating uneven load distribution. In contrast, the ALE-based CNT tyre shows a smoother pressure response with reduced oscillations, reflecting improved fluid–structure interaction and damping behavior. Deformation analysis further reveals severe localized damage in the conventional tyre, particularly at the sidewall, leading to early failure. The CNT-reinforced tyre demonstrates more gradual and distributed deformation due to enhanced stiffness and energy absorption. Despite these improvements, complete resistance to blast loading is not achieved, as the high overpressure exceeds material limits. Overall, CNT reinforcement and ALE modeling significantly improve performance, but further advancements are required for effective blast-resistant tyre design.

IV. CONCLUSION

The current research employs numerical analysis for examining the effect of blast load on the behavior of tyres using LS-DYNA with CONWEP and ALE formulations for a TNT charge weighing 0.5 kg and placed at 0.35 m standoff distance. The response of the pressure-time history indicates a typical trend in relation to the blast load; however, the CONWEP formulation leads to localized loading with maximum deformation whereas the ALE formulation considers the fluid-structure interaction by distributing the pressure effect. The conventional tyre fails due to extreme localized deformation caused by high strain rate. On the other hand, the CNT-based tyre provides an improved result through the reduction of the deformation and stress concentration, resulting in delayed failure because of energy dissipation. It must be noted that complete blast resistance is not possible since the stress values exceed those of the material's strength properties.

REFERENCES

[1] Paweł Baranowski, Jerzy Małachowski, Łukasz Mazurkiewicz. (2020) Local blast wave interaction with tire structure. Publishing Services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd (http://creativecommons.org/licenses/by-nc-nd/4.0/)

[2] Giovanna A. Nasellia, Gianni Polentesb, Emanuela E. Cepolinaa, Matteo Zoppia. Procedia Engineering 64 (2013). A Simple Procedure for Designing Blast Resistant Wheel. 2013. Published by Elsevier Ltd. www.keaipublishing.com/en/journals/defence-technology

[3] Sung-Jun Park, In-Gul Kim b, Jae-Sang Park (2025) Damage assessment and fragility curve development for vehicle tires using shock tube experiments. Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. https://doi.org/10.1016/j.dt.2025.06.021

[4] J D Reida a, D A Boesch b & R W Bielenberg (2014) Detailed tire modeling for crash applications. International Journal of Crashworthiness http://www.tandfonline.com/loi/tcrs20

[5] Pawel Baranowski, Jerzy Malachowski, Jacek Janiszewski, Jerry Wekezer (2016) Detailed tyre FE modelling with multistage validation for dynamic analysis. http://dx.doi.org/10.1016/j.matdes.2016.02.029 0264-1275/© 2016 Elsevier Ltd. All rights reserved.

[6] Wei Wang, Shan Yan and Shugao Zhao (2013). Experimental verification and finite element modeling of radial truck tire under static loading. sagepub.co.uk/journalsPermissions.nav DOI:10.1177/0731684412474998 jrp.sagepub.com

[7] R.R.V. Neves, G.B. Micheli, M. Alves (2010) An experimental and numerical investigation on tyre impact doi:10.1016/j.ijimpeng. 2009.10.001 2009 Elsevier Ltd.

[8] Mohseni manesh S.M. Ward, M.D. Gilchrist (2009) Stress analysis of a multi-laminated tractor tyre using non-linear 3D finite element analysis 2008 Elsevier Ltd. All rights reserved. doi:10.1016/j.matdes.2008.06.040.

[9] Ashraf F. Hefny , Hani O. Eid, Fikri M. Abu-Zidan, (2008) Severe tyre blast injuries during servicing Elsevier Ltd. All rights reserved. doi:10.1016/j.injury. 2008.08.042

[10] Patrick F. Acosta (2011) Overview of ufc 3-340-02, structures to resist the effects of accidental explosions. Structures Congress 2011 © ASCE 2011

[11] P. Helnwein, C.H. Liu, G. Meschke and H.A. (1993) Mang A new 3-D finite element model for cord-reinforced rubber composites Application to analysis of automobile tires @ 1993 - Elsevier Science Publishers B.V. All right reserved.

[12] Yangziyi Jia, Xiangdong Lia, Lanwei Zhoua, Xingfeng Liub (2023) Experimental and numerical study on ballistic impact response of vehicle tires. Latin American Journal of Solids and Structures, 2023 Corresponding author https://doi.org/10.1590/1679-78257764

[13] Paul A. Du Bois, A simplified approach to the simulation of rubber-like materials under dynamic loading. 4th European LS-dyna user conference.

[14] P.A. Du Boisa, S. Kolling, M. Koestersc, T. Frankb (2006) Material behavior of polymers under impact loading.International Journal of Impact Engineering 2005 Elsevier Ltd. All rights reserved. doi:10.1016/j.ijimpeng.2005.02.007

[15] Mingyao Xu, Tianfeng Du, Jinwei Shi, Chen Huang, Chen Xu and Zhuoqun Wei (2025) Modeling and finite-element performance analysis of selenol-functionalized carbon nanotube/natural rubber composites for aircraft tire applications Appl. Sci. 2025, 15, 10053 https://doi.org/10.3390/app151810053

[16] Mahmoud T. Nawar, Ahmed S. Eisa, Mohamed T. Elshazli, Yasser E. Ibrahim 1 and Ayman El-Zohairy, Infrastructures 2024, 9, 52. https://doi.org/10.3390/infrastructures9030052 Numerical analysis of rubberized steel fiber reinforced concrete beams subjected to static and blast loadings https://www.mdpi.com/journal/infrastructures

[17] Pawel Baranowski, Jerzy Malachowski, Lukasz Mazurkiewicz (2016) Numerical and experimental testing of vehicle tyre under impulse loading conditions http://dx.doi.org/10.1016/j.ijmecsci.2015.12.028 0020-7403/& 2016 Elsevier Ltd. All rights reserved.

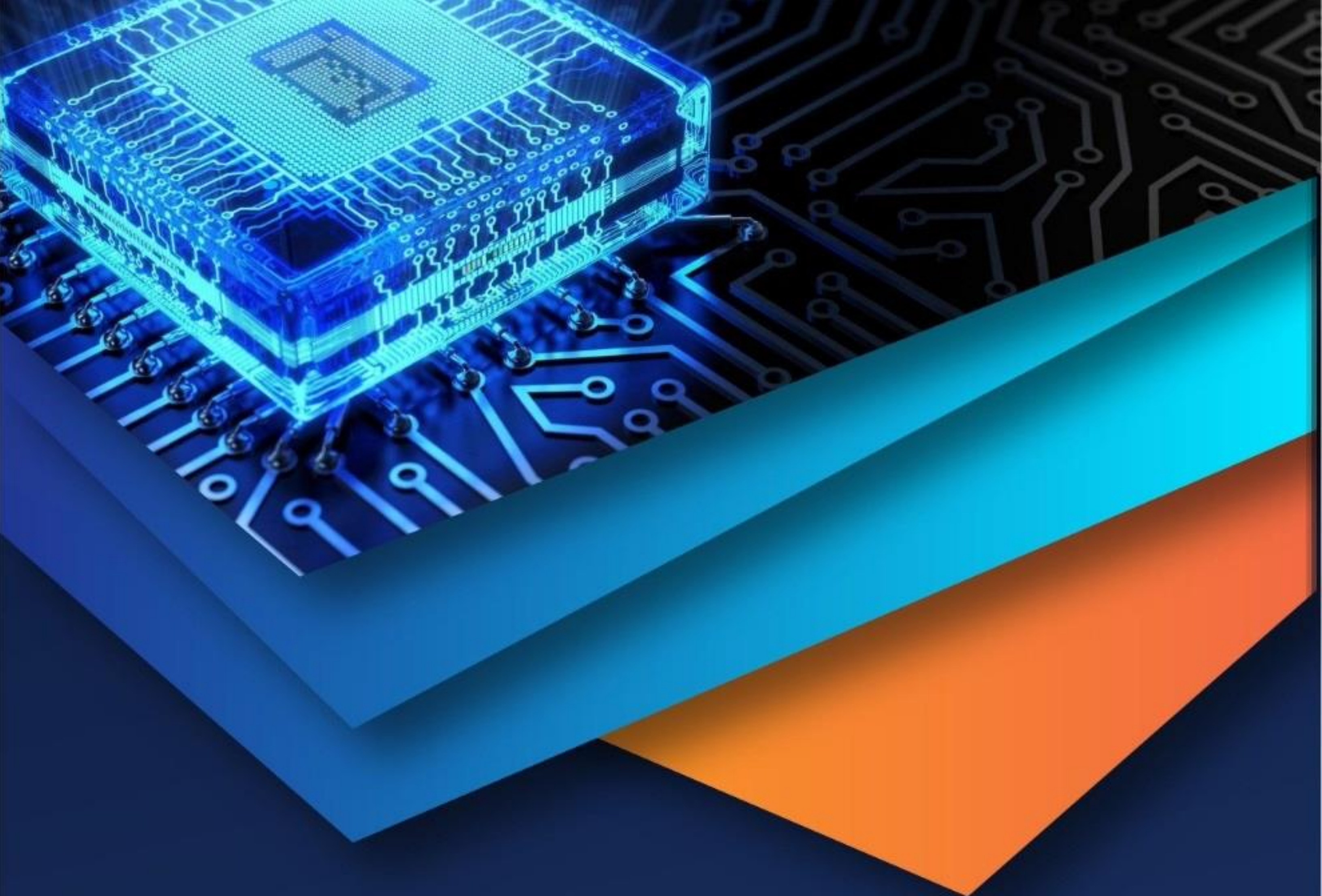
[18] J.E. Tremblay (1998) Impulse on blast deflectors from a landmine explosion Standard Form 298 (Rev. 8-98) Prescribed by ANSI Std Z39-18

[19] A Ramasamy, AM Hill, AE Hepper, AMJ Bull, JC Clasper (Blast mines: physics, injury mechanisms and vehicle protection JR Army Med Corps 155(4): 258-264

[20] A.Shakenov, A.Sładkowski, I.Stolpovskikh, (2022) Haul road condition impact on tire life of mining dump truck https://doi.org/10.33271/nvngu/2022-6/025 ISSN 2071-2227, E-ISSN 2223-2362

[21] Grzegorz MOTRYCZ, Piotr STRYJEK, Jerzy EJSMONT Heryk KAŁWA (2013) Tire performance after explosive decompression. Journal of science of the military academy of land forces Military Institute of Armored and Automotive Technology Sulejówek, Poland

[22] Yu-lei Zhang, Yan Liu, Pu Song, Hao-zhe Liang, Di Yang, Lu Han, Hai-yan Jiang, Kai Zhong (2025) Experimental study on the TNT equivalence for blast parameters in a confined space. https://doi.org/10.1016/j.dt.2025.01.011 Publishing services by Elsevier B.V. on behalf of KeAi Communications Co. Ltd. (http://creativecommons.org/licenses/by-nc-nd/4.0/).



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