

Review of Rubber Tyers Under Explosion Impact.

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Abstract - The growing risk associated with blast damage in military and mine-protected vehicles calls for innovations in rubber materials that can absorb more energy and withstand harsher conditions. Traditional rubber materials, which may possess good elastic properties, have relatively poor blast resistance at very high strain rates. This paper reviews some of the recent advances in composite rubber material, particularly those based on carbon black, nanocomposites, and natural fiber-reinforced rubbers, with an emphasis on their high-strain-rate behavior. Experimental investigations along with numerical simulations based on hyperelastic/viscoelastic models, namely Mooney-Rivlin and Yeoh models, are reviewed. The significance of the filler properties, interfacial bonding strength, and hybrid reinforcement in optimizing stress transmission and energy dissipation is highlighted. Moreover, the use of LS-DYNA as a tool for analyzing the blast-tire interaction is briefly discussed. Some of the potential deformation modes, failure criteria, and design parameters are identified. Finally, research challenges and directions are proposed for future studies.

Key Words: Rubber Tyers, Explosion Impact, Defense, Military

1. INTRODUCTION

Explosive loads caused by landmines and IEDs are among the most serious threats to both military and mine-resistant vehicles, especially regarding the stability of their tires. Although improvements have been made in the construction of armored vehicles, tires represent one of the weakest points because of their exposure to blast loads and ground shock. Rubber is not designed to withstand high-strain rates and extremely dynamic loads, thus causing its quick damage. In recent years, attempts have been made to improve the properties of rubbers with various reinforcement materials including carbon black, nanofillers, and natural fibers. This paper is going to analyze the latest developments in the sphere of creation of blast-resistant materials and their simulation models using finite element analysis.

2. LITERATURE REVIEW

The primary objective of this is impact of blast loads on the tires of vehicles in terms of the survivability of such equipment with the help of finite element analysis. In this respect, one may note that the major goal of this work is connected with increasing the survivability of military vehicle tires from the impact of blast loads. As the result, some improvements of the studied elements are proposed in order to make the tire more resistant against such an impact, since this would ensure an

increased survivability of the entire vehicle when affected by any explosives. The analysis included constructing the numerical model of the studied element, taking into account its composite nature and construction consisting of rubber and steel cord materials. The impact of blast loads on tire performance has been experimentally verified in this work, applying the LS-Dyna package. Moreover, various localized blast impact cases have been analyzed. In particular, the genetic algorithm was used in order to analyze several different constructions of tires. It has been concluded that cord angle is critical to reducing the damages.[1]

The methodology presented here represents an effective finite element technique in designing blast-resistant wheels, which was already proven in previous investigations on the LOcOSTRA (L wheel). Such an approach consists in explicit dynamics analysis under Johnson-Cook material behavior and failure properties of ASTM A283 steel as well as TNT explosive (Jones-Wilkins-Lee formulation). Air was neglected in order to save computation efforts, since the explosion distance in question is relatively small in comparison to the wheel's size. In case of numerical analysis carried out in respect of the L wheel, results were found quite adequate to reality. By applying the presented methodology to a new wheel T, the authors succeeded in optimally reducing the tread thickness from 20 mm to 10 mm, when it may endure 240 g TNT with 50 mm distance and at the same time allow acceptable plastic strains. Further reduction in thicknesses to 5 mm leads to catastrophic damage. There exists a hyperbola describing relation between thickness and average plastic strain in question. As concerns the internal rubber tire, it can be strengthened by means of adding glass fibers (~100 μ m) in order to absorb energy.[2]

The primary aim here is to design wheels capable of withstanding blast loads while retaining their mechanical integrity, especially for vehicles working under risky environments such as mines. Firstly, the complexity involved in dealing with blast loads, including the nonlinearity associated with material behavior, high strain rate, and high temperatures, among others, is discussed. Since there is a lack of adequate guidance regarding designing blast resistant mechanical parts, especially wheels, in this paper, the researchers suggest using simulation analysis to minimize dependence on costly and time-consuming experimental testing methods. The modeling is done based on an existing design known as the L-wheel design. The design includes a steel outer shell along with a solid rubber inner wheel; in this way, the steel reflects a fraction of the blast energy, while the other part is absorbed by the rubber wheel. Experiments carried out with the existing wheel are used to validate the FEA model. The validated model has been used in proposing a better wheel design referred to as T-wheel. Explicit dynamics FEA simulations will be conducted using relevant materials such as

Johnson-Cook material model for steel and JWL equation of state for TNT explosives.[3]

This article outlines a comprehensive finite element tire model used in crashworthiness analysis using LS-DYNA software. This model features the tread, which is modeled using solid elements; the sidewalls are modeled using shells; and the bead, belt, and body ply components are modeled using beams. The force versus displacement behavior of this model was verified using laboratory compression tests on tires, where good correlation was achieved. Important aspects of modeling include accurate beam orientation, appropriate airbag volume modeling for proper tire pressure, and the relative damping concept to reduce vibrations. [4]

An FE model of a truck tyre is discussed in this paper, which was tested under quasi-static and dynamic loading conditions, including radial deformation test, drop/bounce test, and blast test. The complicated structure of a truck tyre, involving steel cords, was modeled accurately based on CT scanning and reverse engineering. Material properties were defined based on the Simplified Rubber Model (SRM), where stress-strain curves were generated based on the results of quasi-static and SHPB tests. It was found that there was excellent correlation between numerical predictions and test results in terms of deformation and failure modes.[5]

The paper presents a nonlinear finite element analysis of the radial truck tire (12R22.5) by utilizing the software package ABAQUS, where the real tread design, rebar (reinforcement belt) structure, and contact interaction of tire-rim and tire-ground contacts are considered. For the hyperelastic behavior of the rubber, the Yeoh hyperelastic constitutive model is calibrated from uniaxial and biaxial testing results. Simulating the vertical static loading case gives the predicted load-deflection curve, contact area shape, and contact pressure distribution, where good correlation is found when compared with the experimental data obtained using the pressure sensing pad technique. The contact friction coefficient of 0.2 of the tire with the ground gives the best agreement with the experimentally observed contact pressures. It is found that belts 2 and 3 have the largest loads.[6]

This research is focused on studying the behavior of automotive tires under impact conditions through both experimental and numerical analysis conducted on the drop mass test rig with a circular indenter. Impact velocity, force, and indentation for different values of air pressure and impact energy are measured using laser velocimeter and high-speed video camera. A numerical model based on the finite element method in software ABAQUS/Explicit with consideration of rubber-like and orthotropic properties (steel, nylon, and polyester) was proposed, which had good agreement with the experiment data except for the peak load up to 38%, attributed to rim interaction and assumed rate insensitive materials.[7]

A nonlinear 3D FE (Finite Element) model of a multilayered tyre of 16.9R38 (tractor tyre) was developed in ANSYS software, considering solid46 element type for cord-reinforced layers and hyper185 element type for hyperelastic rubber Mooney-Rivlin formulation. Material parameters and angles of cords such as (+/-22° for belt and 90° for carcass) were derived based on the experimental investigation. Contact analysis between the tyre and the road surface was performed based on loads between 15 to 25 kN and pressure ranging from 100 to

250 kPa. Results indicate that over-inflation leads to increase in contact pressure towards the tyre centre, while under-inflation moves the pressure towards edges. Interface pressure per unit of inflation pressure ratio is found in the range of 0.21 to 2.5. Prediction of contact lengths are validated experimentally within $\pm 4\%$ error limit.[8]

This paper reviews the severe injury due to tyre explosion incidents that occur during servicing, targeting mostly young men who deal with large truck and bus tyres. Explosions usually happen during inflation and cause energy equal to that of a grenade. Injuries caused by pressure wave (primary), projectiles travelling at high speed (secondary), and acceleration-deceleration injury (tertiary) can all result from this kind of accident. Head and facial injuries account for 48% of victims, while upper limb injuries affect 20% of people. Polytrauma is recorded in 25%. Death rate reaches 19%, mostly due to head injuries.[9]

Structures for Resisting the Effects of Accidental Explosions" is a revision of the historical tri service manual TM 5 1300 (1990), containing necessary changes to include mandatory requirements for the blast design of DoD explosives safety applications. Changes in this manual primarily relate to the reinforcement of concrete, which include the updating of Dynamic Increase Factors for concrete and steel, recommendations on how to calculate concrete spalling and breaching, and requirements for single-leg stirrups (A, B, C) depending on scaled distance and support rotation. The manual highlights specific methods of blast analysis and design. Future editions will be devoted to gas pressure calculations, design of masonry and structural steel, retrofits of existing structures, and joint use with explosives safety and anti-terrorism groups.[10]

The paper suggests a novel finite element model of cord-reinforced rubber composite structures, where the idea of "rebar layer" is implemented with the reinforcement cords represented as separate overlay elements over the rubber elements without any additional degrees of freedom. In the paper, rubber elements utilize incompressible Mooney material model with Lagrange multiplier formulation, while cords employ a compressible Neo-Hookean material formulation modified to reflect the uniaxial nature of cords and their micro-buckling behavior. Material averaging errors are avoided by this technique, which allows each constituent of the composite structure to be modeled independently. An application example of the proposed modeling technique in automobile tire modeling reveals that the predicted results are in good correlation with experiments.[11]

This study investigates the impact of blast loading on a military tire (Michelin 315/70 R22.5) through an integrated experimental-numerical approach. The FE analysis of LS-Dyna is based on a detailed finite element model that employs the Simplified Rubber Material Model, where the stress strain relationship is based on quasistatic and SHPB testing data. For steel cords, the truss element is utilized in the present study with coupling of rubber bricks through penalty-based algorithm for eliminating node matching problem. Two different blasts (i.e., 0.5 kg TNT with 95 mm standoff distance from the tire and direct impact on the tread part of the tire) are analyzed by implementing MM-ALE approach.[12]

In this paper, simplified rubber material behavior is modeled by the material property model, MAT_181, in LS-DYNA,

which provides an easy-to-use substitute for rubber material simulations without any complicated material parameters. Unlike the conventional material models, which need the data from biaxial and shear tests, MAT_181 requires data from tensile and compressive uniaxial tests at different strain rates, with the assumption of incompressibility. The viscoelastic effects are replaced by rate-dependent hyperelasticity. In addition, this model gives the exact results of the uniaxial quasi-static response. This method is used to describe the material properties in LS-DYNA version 970 with no need for negative slopes on the true stress-strain diagrams. Practical suggestions include RTYPE=1, AVGOPT=1 and TENSION=0.[13]

The paper discusses polymer material models (elastomers, foams, and thermoplastics) available in LS-DYNA for crash simulation purposes. Elastomers can be modeled as nearly incompressible hyperelastic materials; the MAT_181 (Simplified Rubber) material model allows for the direct use of uniaxial stress strain curves at various strain rates, eliminating the necessity of finding the parameters through fitting. The simulations of foams can use material models such as MAT_FU_CHANG_FOAM or MAT_CRUSHABLE_FOAM, although size effects and negative volumes still exist in those models. Thermoplastics have nonlinear elastic properties, show tension-compression asymmetry, necking, and strain-rate-dependent modulus. Von Mises plasticity does not apply to thermoplastics. A Drucker Prager model can simulate the different yielding behavior under tensile and compressive loading, whereas a damage model can be used to simulate the unloading process. Examples include pedestrian head and leg impactors, wherein MAT_181 was able to correlate with experimental data for headform vinyl skins.[14]

The development of a novel rubber composite based on Se-CNTs (Selenium-functionalized carbon nanotube) resulted in an increase in the modulus, tensile strength, and better dispersion distribution. The material behavior was predicted by using a second-order polynomial hyperelastic constitutive model. The rubber composite was used in the tread of a Bridgestone 1270×455R aircraft tire, and finite element modeling in ABAQUS showed that all design criteria including dimensional stability, contact pressure, and radial stiffness (≈ 22.9 kN/mm between 1.5 and 2.0 MPa inflation) were satisfied. The results were consistent with the experimental observations.[15]

This research study examines the numerical behavior of reinforced concrete beams made from recycled crumb rubber with 5-20% fine aggregates and 1% steel fiber reinforcements. Static and blast loading analyses were performed through finite elements modeling using ABAQUS software for static loading analysis and LS-DYNA for blast loading analysis, which were compared to experimental results. It was found that the addition of up to 10% rubber improves ductility and energy dissipation, but steel fiber retains good blast loading carrying capacity. The increase in the amount of rubber leads to lower compressive strength and blast load carrying capacity; however, the presence of steel fiber helps improve it. [16]

The finite element model of the Michelin 315/70 R22.5 tyre used for this study was created through reverse engineering and CT scans to ensure that the cord configuration was properly captured. The rubber material was assumed to follow a strain-rate dependent Simplified Rubber Material (Ogden), whereas

the steel cords were idealized as truss elements connected to the rubber by means of the penalty method. Two blasts were simulated for the 315/70 R22.5 tyre; one for the case when the blast occurred at 95 mm from the tread surface (inflated tyre) and another when the bomb detonated on the tread surface (deflated). The numerical results obtained using LS-DYNA with the MM ALE formulation agreed well with experimental results regarding tread damages and pressures. The reflected pressure was found to be 3–4 times the incident pressure, while the deflated tyre failed earlier and had a significantly larger hole compared to the inflated one.[17]

The objective of this technical memorandum is to give algebraic expressions to calculate the total impulse exerted on blast deflectors (horizontal, inclined or vertical) due to an explosion of a buried mine using an empirical formula of vertical specific impulse of pancake type buried charges. Algebraic approximations have been used to convert the empirical equation to an exponential equation that allows analytical integration as well as easy computation using spreadsheet software. Expressions to find total impulse exerted on blast deflectors oriented at any desired angle have been obtained using the concept of normal impulse to vertical impulse ratio with $\cos 2\theta$ terms. Solutions have been obtained using error functions and Gauss Legendre quadrature technique to integrate over the area of the deflector surface.[18]

The paper examines the correlation between the state of haul roads and the lifespan of off-the-road tires (OTR) of mining dump trucks in terms of digital monitoring applied at Bogatyr Komir coal mine in Kazakhstan. In fact, the share of natural rubber in OTR may be from 10% to 15%, while tire deterioration leads to deforestation and extra expenses. The data was obtained by means of Racelogic V box Micro, which allows measuring speed, slopes, temperature, and pressure to determine the TKPH (ton kilometers per hour) index. Specifically, it has been established that slopes of over 8% lower the lifespan of tires for up to 36%, while high summer temperature (over 38 °C) leads to heat peeling.[19]

The results of the experiment on explosive decompression of the tires of an armored personnel carrier have shown that the absence of inflation but undamaged tire leads to an increase in the understeer effect compared to the recommended value for pressure, while the blown tire contributes to the decrease in understeer effect and makes the vehicle susceptible to oversteer. In the case of steady-state circular motion, the occurrence of the blown tire resulted in the emergence of oscillations of the lateral tilt angle with frequency of approximately 0.9 Hz, which indicates dynamic instability. The driving force depends on the radius of the dynamic tire, the blowout results in the instantaneous change in its value.[20]

3.CONCLUSION

Based on the literature review, considerable progress has been achieved in the development of FE modeling and experimental investigation of the dynamical and blast response of tires. It has been established that hyperelastic and rate-dependent material models provide accurate prediction of the deformation and failure of tires. Reinforcement through carbon black, nanofillers, and fibers increases energy absorption and resistance to wear and tear. Despite this progress, research conducted has tended to concentrate on one aspect such as the materials used without adopting an all-rounded approach. Also,

there is a dearth of experimental data at higher strain rates and no validation procedures have been adopted yet.

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