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A LITERATURE REVIEW ON TIRE COMPONENT REQUIREMENTS

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Abstract *This paper is a literature review about tire component requirements for innovation in tire construction. Herein are pointed out essential aspects expected in Tires' structures from the mechanical point of view for future development of a realistic model for advanced simulation of tires (in miscellaneous operating conditions) and innovation in tire mechanics. Being composite structures, tires are made of many elements chosen with delicacy due to their intrinsic physical properties in regards to load effects. Since tires mechanical behaviour is directly linked to the parameters of its constituents (carcass, steel cord belt, and textile cord belt, namely), it is thereof imperative to grasp some solid pieces of knowledge about. Wherefore, the current contribution explored the mechanical requirements to be taken into account in the matrix (rubber) and reinforcements (steel cords and textile cords) for determining the inputs enabling to build up an accurate and simple computer model for improving tires simulation.*

Keywords *rubber, visco-hyperelasticity, model, tire, identification, steel, thermodynamics*

1 INTRODUCTION

Nowadays where an emphasis is increasingly put on safety conditions, durability, and reliability of tires' structures on the road, many scientific works are being conducted by researchers and scientists for its improvement and innovation in the field. This objective has been hitherto a big challenge since it implies many factors not yet mastered from the mechanical aspect. Indeed, from aeronautic to road transports, tires are essential structural parts of our transportation systems (planes, vehicles, bikes, bicycles, etc.) with the specificity to withstand severe static and dynamic loads with expected moderate wear over time while ensuring an acceptable level of safety and comfort in operation. Thereby, it is worth it to pay attention to its structure and mechanical performance, both influenced by physical capabilities of its constitutive compounds which, from the macroscopic scale form a composite structure made of three major components: *elastomer* (rubber), *textile cords*, and *steel cords* as illustrated in Fig. 1(Yang et al., 2010)

In Fig. 1 below is shown a quarter cross-section of a sport tire in which one can scrutinize a particular arrangement of specially selected materials to play two main roles:

- Matrix of the composite structure: essentially rubber-like material (tread, sidewall, undertread, apex and inner-liner);
- Reinforcements: embedded in the matrix and provide the matrix with supplementary mechanical properties (rigidity) necessary to give the tire desired performances. As reinforcement inserted, one distinguishes belts, carcass, bead, cap ply and bead; made of either steel or textile.

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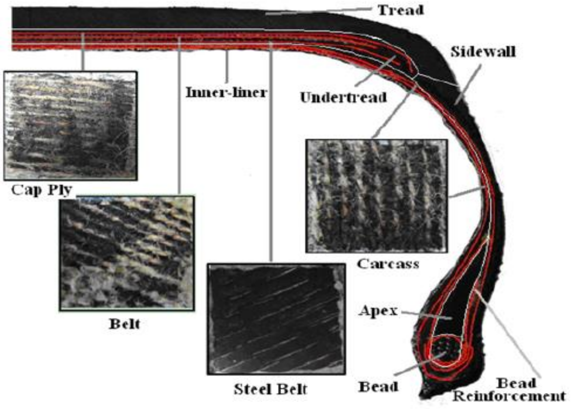

Fig. 1: Macro-mechanical structure of tires (Yang et al., 2010)

At a moderate level of solicitations and in several existing works such as those by (Koutný, 2007) and (Wei et al., 2013), tires modelling has been approached so far by assuming that each of its components remains in the purely elastic domain and the obtained results have brought some interesting pieces of information namely the deformation, footprint pressure, etc. Though this approximation is accurate at a low rate of deformation and under static load, it is rather inaccurate when it is used to treat dynamic (in cornering, rolling, etc.) and wear cases where damping properties come drastically into play (Yang, 2011), (Chae 2006). Furthermore, the association of such structurally different elements does not go without constraints since their properties play a role of choice when it comes to characterising the failure mechanism of the structure as a whole.

Therefore, the main purpose of this paper is to get important information (about mechanical contributions) from tire compounds and use them in forthcoming works to propose an improved computer-aided model for tires simulation under dynamic loads.

2 TIRE COMPOUND REQUIREMENTS:

a) Rubber compound:

Being the matrix of the composite structure, rubber is characterized by its great capacity to present very large elastic deformations under loading and to return to its original equilibrium (true in a purely elastic consideration but, in practice more complex due to dissipation) when the load is released. This particular and well-known response of elastomer materials is called hyperelasticity as investigated in (Yang et al., 2010), (Krmela et al., 2014), and (Dalrymple and Pürgstaller, 2017). For instance, in (Krmela and Krmelová, 2017), a dynamic experimental test of a normalized specimen of rubber reinforced with textile cords oriented with respective angles of 0 and 45 degrees, enabled to obtain the stress-strain response of the specimens under a series of cyclic loadings. The experiments were performed in agreement with standards and data were collected by video-extensometer and processed in the software Trapezium X. The results of the dependency of true stress against true strain are depicted in Fig. 2 (Krmela and Krmelová, 2017).

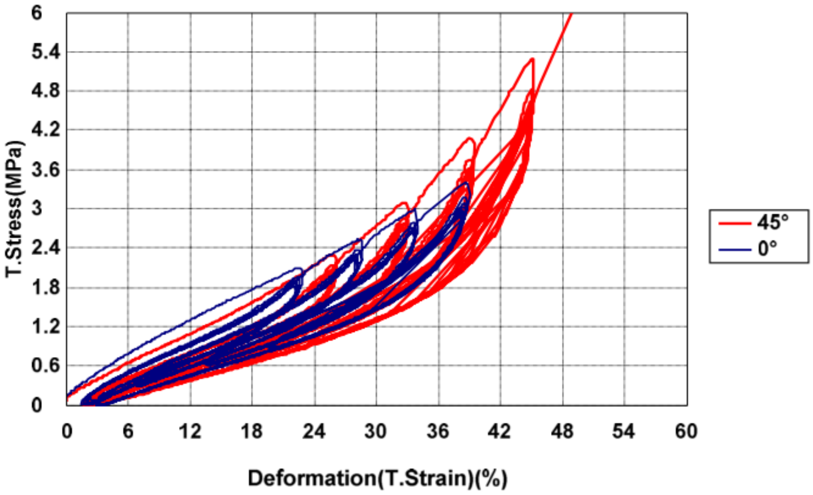

Fig. 2: dependency of the true stress against the true strain (Krmela and Krmelová, 2017).

A close observation of Fig. 2 brings up the main finding that the specimen reinforced with 45° oriented textile cords witnesses a higher response under a series of cyclic loadings. This experiment typically confirms that incorporation of reinforcements in rubber compounds leads to an increase of the structure's strength to failure. However, to date, there is no approved and efficient model capable of predicting the failure mechanism of tires accurately.

On other hand, rubber is highly temperature dependent and its elasticity is closely related to its thermodynamic state. Any time an external tension load is applied to a piece of rubber, there is an internal combination of extension/sliding of molecular chains causing an increase in temperature. This phenomenon is even significant in rolling conditions because of the contact tire-road. In existing scientific works attention has been given most often to only the conservative part (hyperelastic) of the material inner energy whereas the damping properties of tires is governed by the nonconservative term (viscosity) of the internal energy (resumed as visco-hyperelastic).

b) Textile cords:

Another component of no less importance, textile cords are exploited in the manufacturing process of tires for their elasticity, durability, and tenacity (Krmela and Krmelová, 2018). Textile cords deployed in tires structure to resist against compression/ tension in operation are of many types, some of them have a high elasticity modulus (preferred in tires’ construction however tend to be bad when it comes to withstanding fatigue(Tian et al., 2019)) whereas others rather point to a low elasticity modulus. As proved in (Tian et al., 2019), tires’ textile cords with low elasticity modulus exhibit better fatigue performance due to their higher hysteresis responses which improve their abilities in the transmission and absorption of vibrations occurring in the body of the tire when it is moving on a road with many disparities or obstacles. Even though many tire manufacturers are aware of all these points and have been giving attention to textile cords used in their products, the behaviour of rubber-textile bond in extreme vibratory conditions is not yet well mastered and therefore undocumented. Also, the hysteresis tendency of textile cords has not yet been fully included in tire models whereas the work (Tian et al., 2019) proved experimentally that textile cords exhibit such responses under a series of loadings and unloadings as depicted in Fig. 3

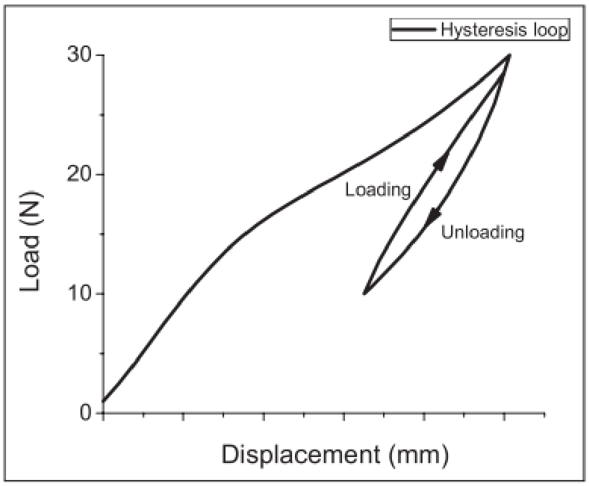

Fig. 3: Hysteresis loop observed in a synthetic tire cord under cyclic loading. (Tian et al., 2019)

c) Steel cord belts:

They are also used as tires' reinforcements and embedded at specific locations of the cross-section where it is observed a concentration of stresses in the tire body. They strengthen and stabilize treads and sidewalls to properly absorb loads effects (vehicle loads, shocks on roads with disparities such as potholes, etc.) by providing them with needed rigidity. In tire construction, manufacturers make use of several types of steel cord belts depending upon the utilization:

- Steel cord for passenger car tires;
- Steel cord for sport utility vehicles and light trucks tires;
- Steel cord for truck radial tires ;
- Steel cords for off the road tires.

From the purely mechanical aspect, steel cords selected in tire manufacturing generally exhibit a nearly linear elastic behaviour in a tensile test as observed in experiments carried out by (Koutný, 2007) and depicted in Fig. 4 hereafter.

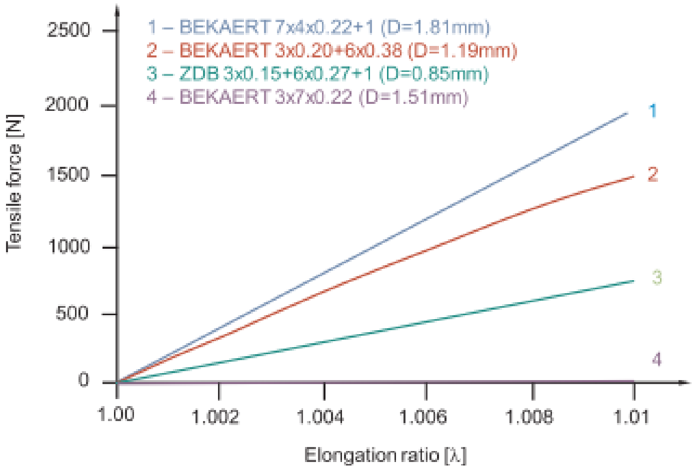

Fig. 4: Tensile test result of some selected steel cords (Koutný, 2007)

To sum up, what is hereinbefore mentioned, the following table presents the requirements expected for ensuring satisfying performances of tire components (Rodgers, 2001):

Tab. 1: Tire components and requirements

	Types	Functions	Requirements
Rubber compounds	• Vulcanized rubber; • Vulcanized rubber with carbon black; • fibre-reinforced rubber; • Natural Rubber	• Support the vehicle load; • Transmit traction and braking forces to the road surface; • change and maintain the direction of driving; • Absorb road shocks.	• Spread low contact pressures on the road; • High strength; • High bending stiffness; • High resistance to cracks initiation and growth; • High resistance to tread wear; • Resistance to chemical attacks; • High adhesion to reinforcements
Textile cords	• Rayon; • Polyester; • Nylon; • Aramid • Etc…	• Provide the tire with the axial, lateral rigidity required for acceleration, braking, and cornering. • Increase the internal transmission of efforts in the body of the tire; • Reinforce the resistance of the tire again fatigue and vibrations.	• High modulus in tension; • Good lateral flexibility; • Filament with high tensile strength; • Twisted filament to fully mobilize the properties in tension; • Twist and tire design to prevent cords from being solicited in compression; • High adhesion to rubber; • Resistance to chemical attacks.
Steel cords	• Regular cord; • Open cord; • Compact cord; • High elongation cord • Etc…	• Reduce footprint pressure; • Strengthen the tensile performance of tires; • Protect the tire from impacts due to road obstacles or disparities; • Improve tires' performances to wear.	• High strength; • High bending stiffness; • low creep and relaxation; • High modulus in compression; • High durability; • High dynamic modulus; • Low heat generation.

3 CONCLUSION

This paper aimed at investigating the state of art on the requirements of tire components from the mechanical point of view only, as an essential condition for having a broad understanding of the whole tire and its behaviour on the tarmac. Throughout this study, we have explored the structure (composite consisting of rubber and reinforcements), functions, requirements and some physical information associated with each component of tires. Most particularly, we have found that mechanical responses observed experimentally in dynamic loads were significantly influenced by a dissipative thermodynamic variable which must be included in future works for efficient dynamic modelling of tires.

With the information gained through this contribution and based on experiments, we will proceed with the determination of material parameters according to our proposed constitutive behaviour. Although from the macroscopic scale, the complexity of tires as a composite structure poses a real computational obstacle (since its standard finite element analysis implicates a very dense system of algebraic equations), recent developments of supercomputers have made it feasible together with high-performance computing technics on parallel architectures and domain decomposition methods. Our forthcoming works will exploit them to dive into the steps that will lead us to our target to propose an improved computer model for tires simulation.

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Conflicts of Interest:

The authors declare no conflict of interest.

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