FEM MODEL TO STUDY THE INFLUENCE OF TIRE PRESSURE ON AGRICULTURAL TRACTOR WHEEL DEFORMATIONS

Sorin-Stefan Biris, Nicoleta Ungureanu, Edmond Maican, Erol Murad, Valentin Vladut
University "Politehnica" of Bucharest, Romania
biris.sorinstefan@gmail.com

Abstract: It is known that proper exploitation of wheel tires of tractors is difficult and it depends on many influencing factors. Tire inflation pressure has a significant importance on their stress and strain distribution. Tire strain influences the size of the contact surface with the rolling track. Low pressure generates an exaggerated flexing of the tire carcass, increasing the rolling resistance of the wheel. Too large pressure causes the decrease of tire adhesion, irregular and faster wear, especially for the driving wheels. For various soil conditions depending on the tire pressure, different soil stress distributions can be obtained. The paper presents an analysis a model of a 65 HP tractor driving wheel tire, by means of the Finite Element Method. A model of the tire is developed, for which the parameters characterising the elastic behaviour of tire rubber were defined. The study was developed for various tire air pressures (0.5, 0.8, 1.1, 1.4, 1.7, and 2 bars). The results and conclusions obtained from the study are useful in the identification of optimal operating parameters for the tires of the driving wheels of agricultural tractors, and this FEM model can be adapted and used for other tractors and agricultural machinery.

Keywords: tractor, tire pressure, stress, strain, finite element method.

Introduction

Tires provide the following functions for a land vehicle: attenuate the shocks caused by uneven rolling tracks, ensure proper adhesion to the rolling track, and ensure safety and resistance to high-speed movement, take the loads distributed on wheels, contribute to passengers or operators comfort. The complex geometry and the multitude of factors influencing the mechanical behaviour make the modelling of stresses and strains distribution in the tires of agricultural land vehicles difficult. The interaction between the tire and rolling track is a very complex research topic and has been considered a critical problem in the design of agricultural vehicles.

Tire inflation pressure is particularly important for the shape of the contact surface between the tire and soil, and thus on the soil stress distribution (Fig. 1). For various soil conditions (soil type, moisture, etc.), depending on tire pressure, different distributions of soil stresses can be obtained.

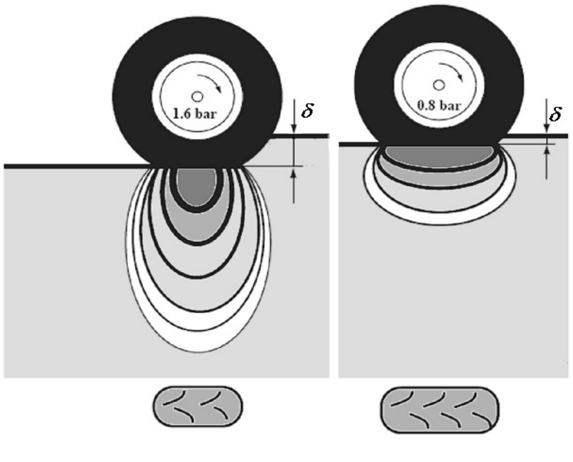


Fig. 1. **Influence of tire air pressure on the shape of the contact surface and on soil stress distribution**

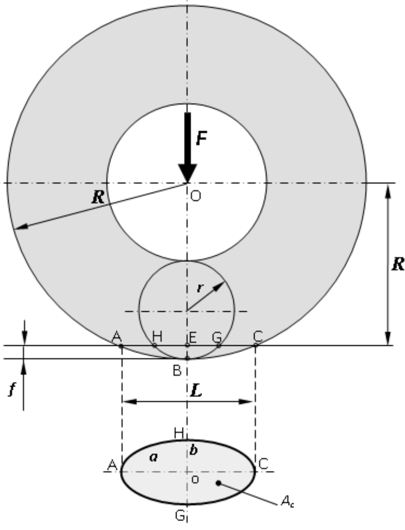


Fig. 2. **Tire deformation under the action of an external load**

Due to the wide diversity of shapes, sizes, material characteristics and operating conditions, lately more studies and researches regarding mathematical modelling and the analysis of stress and strain distribution in the tires of land vehicles have appeared. This is necessary in order to adopt a rapid and inexpensive procedure, capable to evaluate tire behaviour in different situations. With the great development of computers and numerical computation programs, a natural opportunity arose to use these tools to simulate tire mechanical behaviour of land vehicles using the Finite Element Method.

The primary difficulty is to model accurately the nonlinear mechanical behaviour of the tires material (rubber reinforced with textile or metal).

Under the action of an external load (weight per wheel), a tire deforms as shown in Figure 2. According to Hedekel's equation, tire deformation is given by the following relationship:

$$f = \frac{F}{2 \cdot \pi \cdot p_i \cdot \sqrt{R \cdot r}} \text{ (mm)}, \tag{1}$$

where F – vertical load acting on the wheel, N;
p_i – air pressure inside the tire, MPa;
R – free radius of the wheel, mm;
r – radius of the tire running path in cross section, mm.

The static tire radius is given by:

$$R_s = R - f \text{ (mm)}, \tag{2}$$

and the length of the contact chord is:

$$L = 2 \cdot \sqrt{R^2 - R_s^2} \text{ (mm)}. \tag{3}$$

Materials and methods

The analysis was developed for the tire of the rear wheel of the 65 HP Romanian tractors U-650, the main characteristics of which are given in Table 1. The analyzed tire is symbolised as 14-38 R35.

Table 1

Main characteristics of U-650 tractor

Tractor	Soil interaction part	Gauge, mm	Weight (total / per axle), kg		Contact patch width, mm
U-650 (65 HP)	Front tire	1600	3380	1170	180
	Rear tire			2210	367

The tire is made of rubber, which is generally considered to be a non-linear, incompressible or nearly incompressible, hyper-elastic material, which often experiences very large deformations upon loading [6]. The element selected for analysing the rubber material was HYPER185, used in conjunction with the two-term Mooney-Rivlin material model [6]. ANSYS v12.1 program was used for the analysis of 3D model, respectively Quick Field Students v5.6 was used to analyze the plane model of the tire section in the "plane strain" mode.

Figure 3 illustrates 3D physical model for the rear tire of the 65 HP tractors, developed by means of Solid Works program, which takes into consideration all the details on tire sizes.

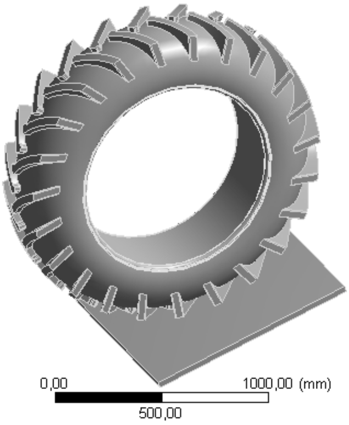


Fig. 3. **Physical tire model**

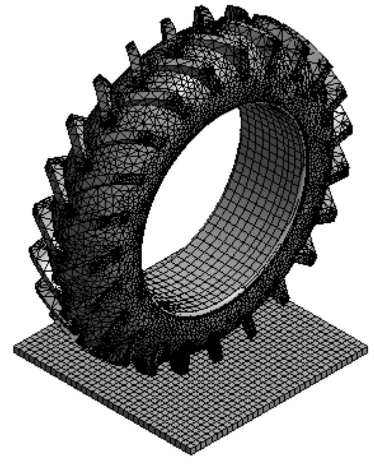


Fig. 4. **Meshed tire 3D model**

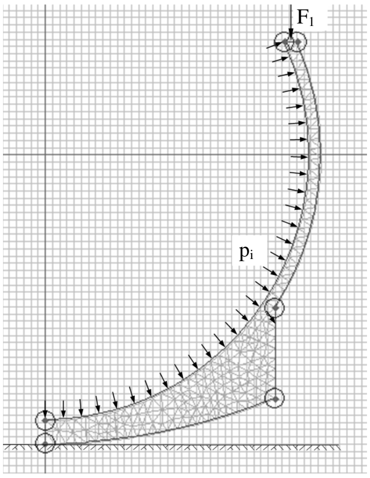
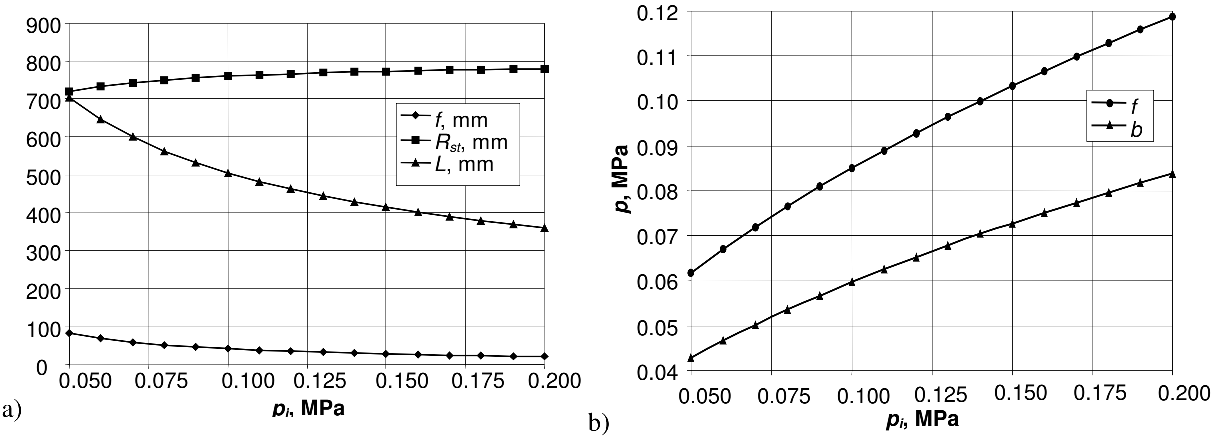


Fig. 5. **Meshed tire 2D model**

This geometrical model was imported in ANSYS v12.1, thus obtaining the meshed model of FEM analysis (Fig. 4), consisting in three dimensional finite elements for both tire and rim, as well as for the rigid surface of the rolling track. In the contact area finer and more precisely meshing was developed, using a higher number of finite elements having smaller sizes. For easier analysis also a plane, symmetric model of the tire in the frontal plane was developed, using Quick Field Students v5.6 program (Fig. 5), for which the tire air pressure and the load on the wheel were taken into account.

Results and discussion

Figure 6 (a) shows the influence of the tire pressure on the dimensional characteristics of the wheel (Figure 2), respectively the tire deformation (Eq. 1), static radius *Rs* (Eq. 2) and the length of contact chord *L* (Eq. 3), for the rear wheel. The tire air pressure influences the tire pressure applied on the soil. That dependency is shown in Figure 6 (b), for both the front (f) and the rear wheel (b) of U-650 tractor.



a) b)

Fig. 6. **Influence of tire pressure on the dimensional characteristics of the wheels (a), and on the contact pressure (b)**

Figure 7 presents the modelling results of tire air pressure on how the tire deforms. Figure 8 shows the distribution of equivalent stresses by the Von Mises criterion in the tire, in the contact area with the rolling track. Also the tire outline after the strain is traced, due to the application of the external load.

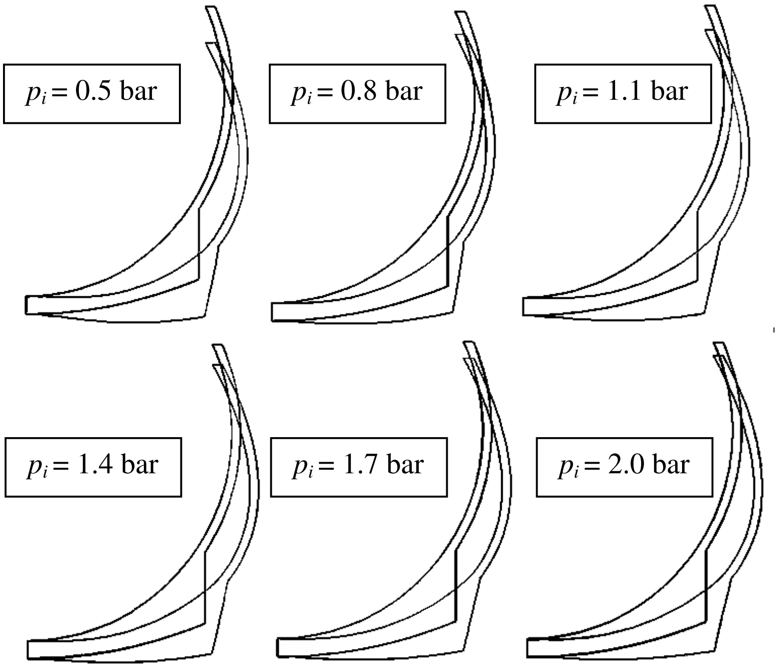


Fig. 7. **Influence of tire pressure on tire deformation**

It can be noticed that the highest values of equivalent stresses are found in the joint area of the lug with the tire carcass. Figure 9 shows the distribution of total displacement in the tire for the same section. The highest displacements arise in the mean area of the tire carcass. Figure 10 shows the graphical variation of equivalent stresses on the outline and Figure 11 shows the graphical variation of total displacements on the outline of the analyzed axis-symmetric model.

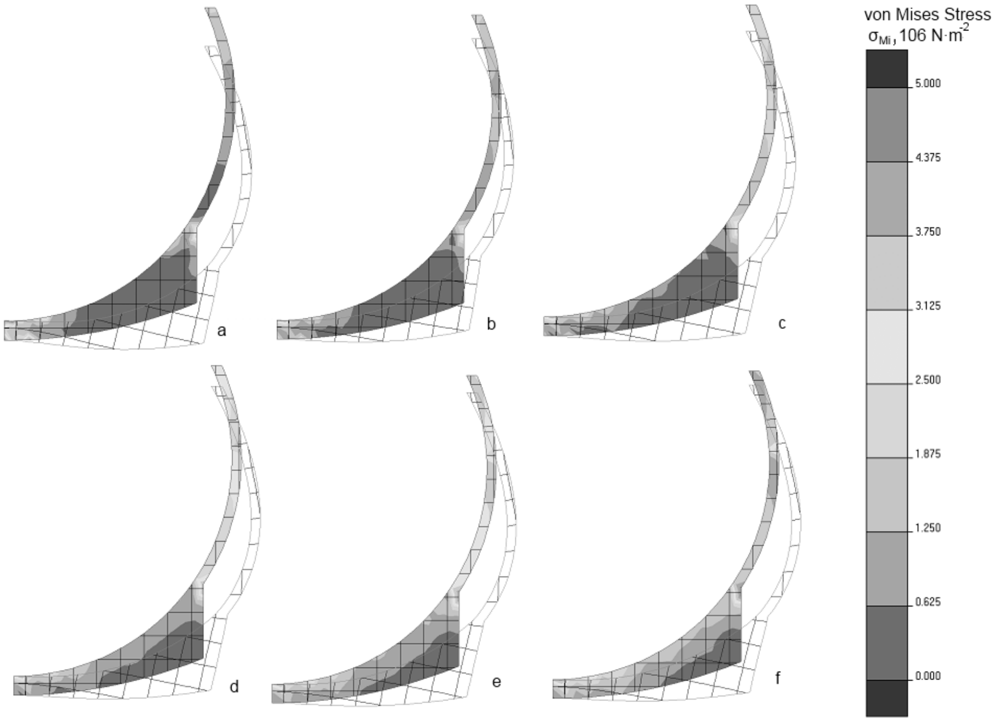


Fig. 8. **Distribution of equivalent stresses in the tire in the contact area with the rolling track:**
a – p_i = 0.5 bar; b – p_i = 0.8 bar; c – p_i = 1.1 bar; d – p_i = 1.4 bar; e – p_i = 1.7 bar; f – p_i = 2.0 bar

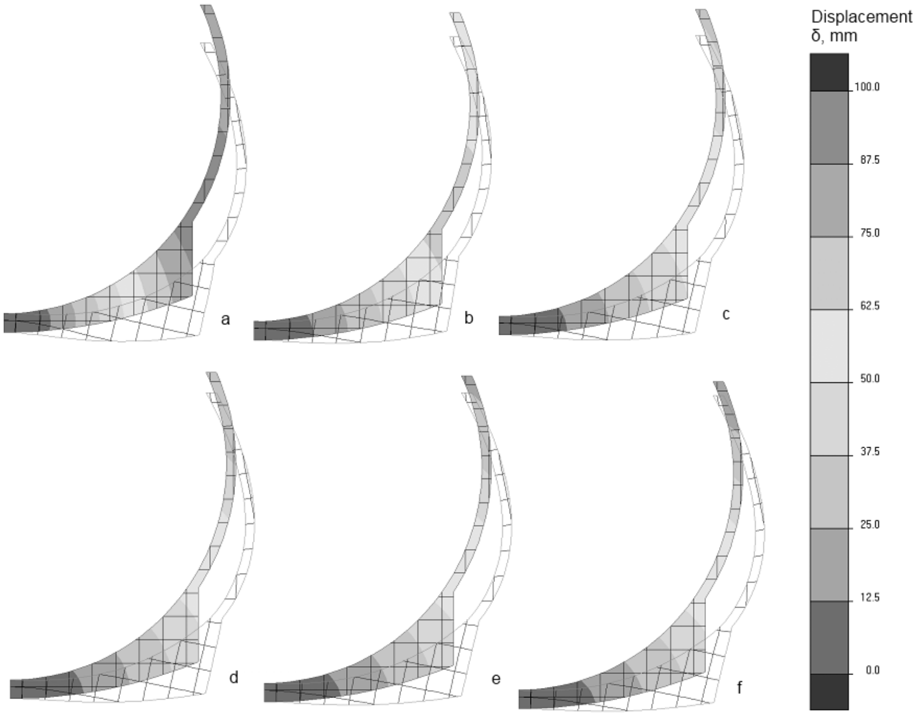


Fig. 9. **Distribution of total displacements in the tire in the contact area with the rolling track:**
a – p_i = 0.5 bar; b – p_i = 0.8 bar; c – p_i = 1.1 bar; d – p_i = 1.4 bar; e – p_i = 1.7 bar; f – p_i = 2.0 bar

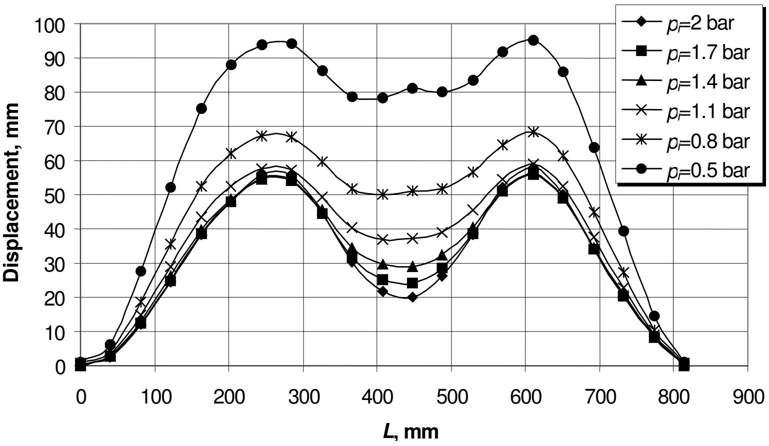


Fig. 10. **Graphical variation of equivalent stresses**

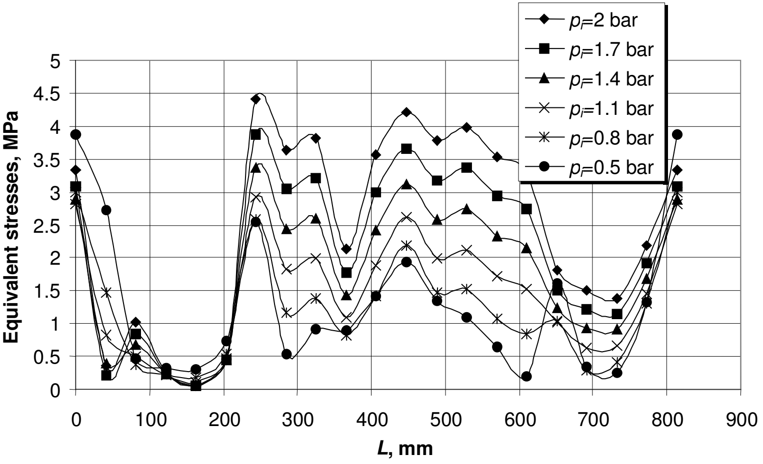


Fig. 11. **Total displacements for the analyzed plane outline, for various values of tire air pressure**

Conclusions

1. The Finite Element Method is the most advanced mathematical tool used for the complex study of the interaction between the rolling bodies of land vehicles and the rolling track.

2. The highest difficulty for this study was encountered in the modelling of nonlinear hyper-elastic behaviour of the tire material – rubber, which included the cord angles in each layer, respectively the analysis of stress and strain distribution.

3. The tire air pressure has an important influence on the equivalent stress distribution in soil. Soil stresses increase at higher tire pressure.

4. The present study allows the highlight of some areas of the analyzed tire in which stresses are higher, as well as the fact that the mean area of the tire carcass is subjected to the highest strains. This also leads to the highest danger of tire wear during depressurisation. This led to the conclusion that the thickness of the carcass walls should be increased.

Acknowledgement

This work was supported by POSDRU based on POSDRU/89/1.5/S/62557 financing program.

References

1. Burke A., Olatunbosun O.A., New techniques in tyre modal analysis using MSC/NASTRAN. Int. J. Vehicle Design. Vol. 18(2), 1997, pp. 203-212.
2. Duni E., Monfrino G., Saponaro R., Caudano M., Urbinati F., Numerical simulation of full vehicle dynamic behaviour based on the interaction between ABAQUS/Standard and explicit codes. ABAQUS User's Conference, 2003, pp. 1-19.

3. Gill W.R., Vandenberg G.E., Soil Dynamics in Tillage and Traction. U.S.A. Department of Agriculture, Handbook 316, USA, Washington D.C., 1968.
4. Kading K., Multibody Dynamic Simulation of Off-Road Vehicles for Load prediction, Stability, Safety, and Performance. ASABE Meeting Presentation. Paper Number: 061181, Portland, Oregon, 9-12 July, 2006, pp. 1-10.
5. Mohseninmanesh A., Ward S.M., Gilchrist M.D., Stress analysis of a multi-laminated tractor tyre using non-linear 3D finite element analysis. Material and Design. 30 (2009), Elsevier, 2008, pp. 1124-1132.
6. Mohseninmanesh A., Ward S.M., Tractor tyre-road and tyre-soil interactions model using ANSYS. Biosystems Engineering Research Review. Univ. College Dublin, 2007, pp. 33-137.
7. Wertz K., Grisso R., Von Bargen K., A Survey of Ag Tractor Ballasting and Tire Configurations – Part II. Applied Engineering in Agriculture. Vol. 6(5), 1990, pp. 542-547.
8. Xia K., Finite element modelling of tire/terrain interaction: Application to predicting soil compaction and tire mobility. Journal of Terramechanics, 2010, pp. 1-11.
9. Zoz F., The Cause of Powerhop. ASABE Meeting Presentation. Paper Number: 071110, Minneapolis, Minnesota, 17-20 June, 2007, pp. 1-17.