Keywords: tire wear; experimental research; truck tire

Rosen IVANOV*, Krasimir GEORGIEV, Georgi KADIKYANOV, Gergana STANEVA
University of Ruse
8, Studentska str., 7017 Ruse, Bulgaria
**Corresponding author*. E-mail: rossen@uni-ruse.bg

AN EXPERIMENTAL RESEARCH ON THE WEAR OF TRUCK TIRE

Summary. An experimental device and methodology for tire wear investigation are presented. An indirect method for wear evaluating is used. The experimental results in cases of straight motion with and without side slip are obtained. The distribution of wearing on tread pattern wide is evaluated in different running conditions.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ ИЗНОСА ШИН ГРУЗОВОГО АВТОМОБИЛЯ

Резюме. Представлены экспериментальная установка и методика оценки износа шин. Использован косвенный метод оценки износа. Получены экспериментальные результаты при движении при наличии и отсутствии бокового увода. Сделана оценка неравномерности износа по ширине шины при разных условиях движения.

1. INTRODUCTION

There are 3 types wear of pneumatic tires: abrasive, due to the rolling and due to the tire material fatigue. The part of each type wear depends on the running conditions [1, 2, 9, 10, 12 - 14].

Irregularity of the wear in tread pattern due the fast amortization of the tire. The problems concerning decreasing of the wear irregularity are more important, because they are connected with reducing the expenses for new tires. That expenses may consist to 30% from price of all consummative (fuel, lubricants etc.), and for the all period of use they consist of approximately 70% of the price of a new vehicle [1, 6].

There are many investigations concerning tire properties and tire wear, carried out by the different authors and research groups [1…14]. A team from University of Ruse, for 20 years have worked on this problems and they have a lot of researches, including dissertations [1, 6, 8 etc.].

2. METHODOLOGY AND TEST DEVICE

The purpose of the present research is to study the normal load, the air pressure in the tyre, the side inclinations, side slip and the degree of wheel blocking on the tire wearing across the width of the protector.

The target of the investigation is a truck tire model DNEPROSHINA 11.00R20.

For the study of the tire wearing an accelerating method has been applied [1, 2, 6, 7]. It is based on a relative quantitative evaluation on the tire wearing and artificial information sources have been used – indicators such as button-head rivets. The indicators repeat the moving of the protector elements during the rolling of the wheel and are worn out proportionally to the slippage and the specific pressure in the contact, regardless of their inclination to the road surface (Fig. 1).

The choice of the indicators dimensions and their shape is based on the following requirements:

- to have information sufficiency – to lose certain weight during not a big run of the tires;
- to repeat the motion of the elementary parts of the protector, where they are fixed;
- easy fixation to the protector, as well as easy removal.

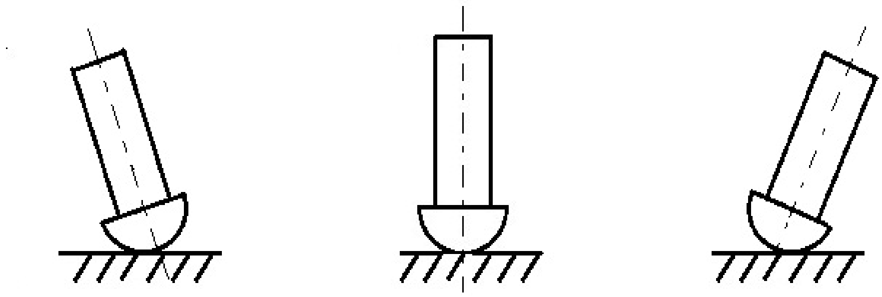
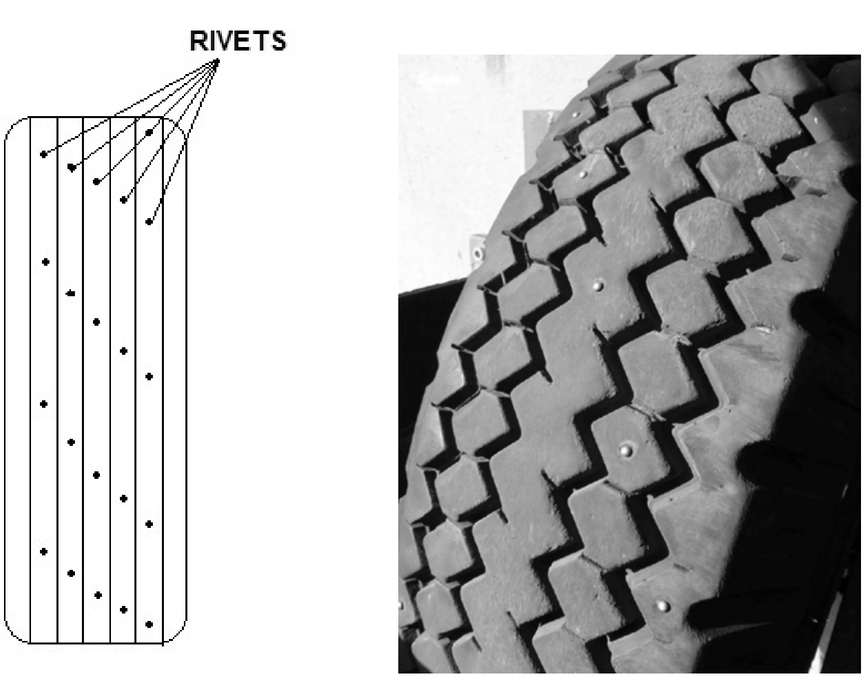


Fig. 1. Orientation of the indicators to the road surface
Рис. 1. Ориентация индикаторов по отношению к опорной поверхности



a) b)

Fig. 2. Location of the indicators across the width of the protector (a) and a part of the tire with already fixed indicators (b)
Рис. 2. Расположение индикаторов по ширине протектора (a) и часть шины с уже установленными индикаторами (b)

The indicators are fixed symmetrically along the circumference and the width of the protector (Fig. 2). To decrease the influence of the friction process upon moving in and out of the tire elements from the contact zone, the indicators are placed across the width of the protector along 5 circles (paths). The total number of the indicators placed on a tire amounts to 50. Before fixing the indicators, the pneumatic tire is cleaned and holes with a definite diameter are punched. The diameter of the holes is smaller than the diameter of the rivets. For indicators button-head 3 x 10 steel rivets have been used corresponding to the requirements.

It is well known [1, 2] that such rivets show adequate results because their contact with the road do not depend on the wheel inclination and the rivet location (Fig. 1 and 2).

Before each new series of experiments the indicators should be washed well with acetone and sorted by 10 in envelopes for each path. Each group of 10 rivets should be weighed by analytical balance model WA-33 (Fig. 3). The measurement accuracy is 0,00005 g.

Fig. 3. Analytical balance WA-33
Рис. 3. Аналитические весы WA-33

Fig. 4. Pliers for fixing the indicators (rivets) to the tire
Рис. 4. Инструмент для установки индикаторов в шине

Before each experiment, the rivets are put in the holes with the help of special pliers (Fig. 4) protecting from damage the button heads of the rivets.

After the experiment the rivets are carefully removed and are arranged at paths back in the envelopes, cleaned with acetone and weighed again. The difference in the measurements before and after the experiment defines the wearing out of the indicators which shows the influence of the different factors over the wearing of the tire.

Before starting the experiments it is necessary to obtain the relationship between the weight losses of the traveled distance in order to define the maximum distance for linear dependability between the wearing of the indicators and the passed distance [1, 2]. That operation was made at a straight motion over horizontal asphalted road in a good condition. There has been estimated a linear dependence between the wearing of the rivets and the traveled distance of up to 7 km.

The road experiments have been held in the yard of Ruse University „Angel Kanchev”. There has been chosen a straight road area with a good dry asphalted surface, without road failures, potholes, etc. In experiments there has been used a mobile device for testing of pneumatic tires (Fig. 5)

The normal loading G_k at the experiments is measured by dynamometer, taking into consideration the weight of the axis hub, the nave, the lever fork, the fork, the strain-gauge unit and the wheel rim.

The air pressure in the tire $p_в$ is measured at a lifted tire. The side inclination of the wheel α_o is set at a lifted position of the wheel with the help of fulcrum screw and the fork is inclined together with the wheel. The angle of the side slip is set at a lifted position of the wheel with the help of a screw as the fork is twisted together with the wheel in a horizontal plane.

For intensive tire wearing process there have been introduced an additional longitudinal slip between the tire and road surface by braking force is applied on the wheel. For that purpose the pneumatic brake is used in the nave of the wheel, fed by additionally assembled tank for compressed air and pressure regulator (Fig. 5).

The compressed air submission is controlled manually through a stopcock and the same pressure level is maintained by the pressure regulator. During the experiments the mobile device for testing of the pneumatic tires was trailed by a wheeled tractor.

Fig. 5. Mobile device on the experimental section
Рис. 5. Мобильная установка на испытательном участке

After the experiments with side slip visible footprints remain on the asphalt (Fig. 6).

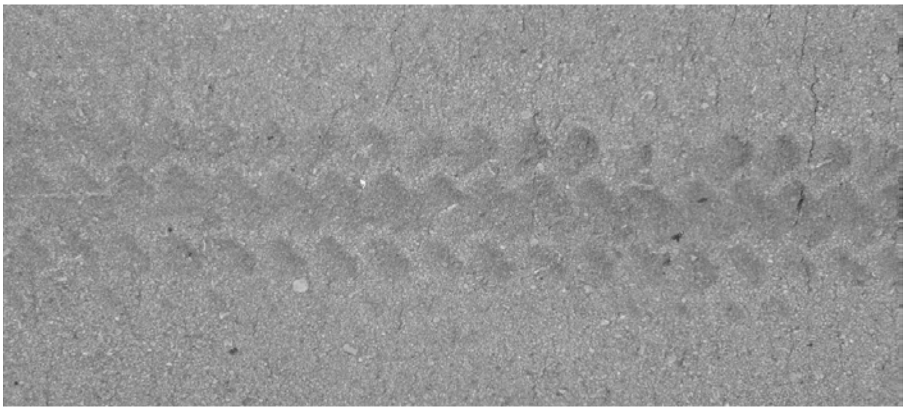


Fig. 6. A tire trace after an experiment whit an angle of side slip
Рис. 6. След на асфальте после эксперимента с боковым уводом шины

After end of each experiment, the tire is raised from the asphalt and all the indicators are removed path by path.

The difference between the two distances – at free rolling, without braking force and at rolling with braking force defines the degree of wheel blocking (longitudinal slip) for the according experiment. These measurements are to be repeated for every experiment as well as at the other pressure values in the pneumatic tire.

3. RESULTS FROM THE ROAD EXPERIMENTS

Three series of experiments have been carried out:

- motion without side slip and G_k = 12 kN, $p_в$ = 0,2; 0,4; 0,6 MPa и $\alpha_o = 0^\circ$;
- motion without side slip and G_k = 12 kN, $p_в$ = 0,2; 0,4; 0,6 MPa и $\alpha_o = 2^\circ$;
- motion with side slip $\delta = 2{,}8^\circ$, G_k =12 kN, $p_в$ = 0,2; 0,6 MPa и $\alpha_o = 0^\circ$

The results from the first series are shown at table 1 and at Fig. 7

Table 1

Results from the tire wearing by paths at $\alpha_o = 0^{\circ}$

Level of the factors	Total wearing, mg/km
$G_к$=12 *kN*, $p_в$=0,2 *MPa*, $\alpha_o = 0^{\circ}$, *blocking* 4,95 %	30,10
$G_к$=12 *kN*, $p_в$=0,4 *MPa*, $\alpha_o = 0^{\circ}$, *blocking* 3,9 %	27,90
$G_к$=12 *kN*, $p_в$=0,6 *MPa*, $\alpha_o = 0^{\circ}$, *blocking* 3,4 %	26,00

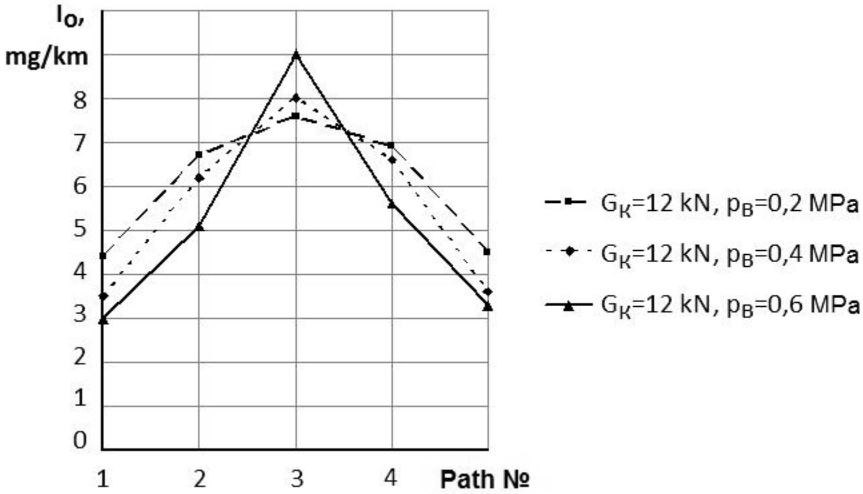


Fig. 7. Relative wear of the tire by paths at straight motion and $\alpha_o = 0^{\circ}$

Рис. 7. Специфический износ шины при прямолинейном движении и $\alpha_o = 0^{\circ}$

The results show that at the first series of experiments (table 1 and Fig. 7) the increase of the pressure leads to increase of the wearing at the middle path 3, been also the most loaded, respectively with larger normal and tangential stresses. Similar results, concerning stress distribution on road surface depending on the tire pressure, are described and discussed by De Beer [4] and Steyn [15].

At increase of the pressure from 0,2 to 0,6 Mpa, the wearing of the middle path is increased with 15,6%. The rest four paths show decrease of the wearing together with the increase of the air pressure in the tire. The wearing at path 1 decreases with 31,8% and at path 5 with 26,7%. Paths 2 and 4 show decrease of the wearing with 23,9 and 18,9% respectively. At maximum pressure of 0,6 Mpa, the wearing of the end paths is three times less than the wearing of the middle path. In case of comparison of the total wearing of the tire, the intensity of the wearing at changing of the air pressure in the tire from 0,2 to 0,6 Mpa decreases with 13,6%. It leads to a conclusion that the load G_k and the air pressure $p_в$ reflects much more the wearing of the pneumatic tire paths and less on the tire as a whole. The fast wearing of some of the paths could decrease significantly the exploitation time of the tire.

The results from the second series of experiments are shown at table 2 and Fig. 8. The degree of wheel blocking at changing the pressure in the tire is kept the same as at the first series of experiments.

This series of experiments show again that the middle path 3 is most loaded and the relative wearing decreases with 11,2% at changing of the pressure from 0,2 to 0,6 MPa. At pressure 0,4 and 0,6 MPa the wearing of the middle tire is been kept constant. The influence of the side inclination and the accuracy also show certain influence. Most significant is the difference in the intense wearing of paths 1 and 3. This is caused mainly by the side inclination which loads path 5 and frees path 1.

Table 2

Results from the wearing of the tire at paths at $\alpha_o = 2^\circ$

Levels of factors	Total wearing, mg/km
$G_к$=12 *kN*, $p_в$=0,2 *MPa*, $\alpha_o = 2^\circ$, *blocking* 4,95 %	30,90
$G_к$=12 *kN*, $p_в$=0,4 *MPa*, $\alpha_o = 2^\circ$, *blocking* 3,9 %	29,00
$G_к$=12 *kN*, $p_в$=0,6 *MPa*, $\alpha_o = 2^\circ$, *blocking* 3,4 %	25,10

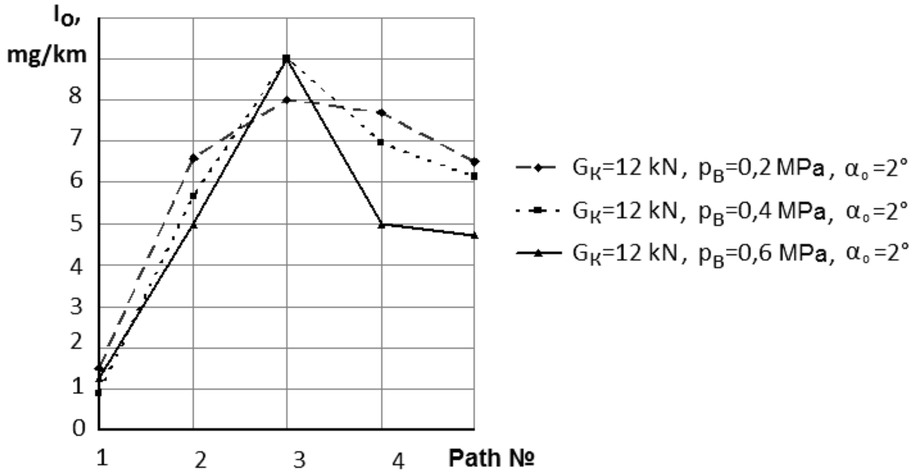


Fig. 8. Relative wearing of the tire on paths at straight motion and $\alpha_o = 2^\circ$

Рис. 8. Специфический износ шины при прямолинейном движении и $\alpha_o = 2^\circ$

The biggest difference at changing the air pressure appears at wearing of path 4 – 33% decrease of the wearing at pressure change from 0,2 to 0,6 MPa. The change at path 2 is bigger. The analyses of the data achieved and the dependence on the two series of experiments (without and with side inclination of the wheel) show the influence of the side inclination α_o of the wheel on the wearing of the tire on paths. The side inclination of the wheel does not influence significant the total wearing of the pneumatic tire.

Third series includes two experiments at pressure 0,6 *MPa* and 0,2 *MPa* at G_k = 12 *kN*, $\alpha_o = 0^\circ$. At this series there is an angle of the side slip $\delta = 2{,}8^\circ$. The degree of wheel blocking at the experiments varies at different values. The results are shown at table 3 and Fig. 9.

Third series of experiments confirm that the middle path 3 is the most loaded and the increase of the pressure increases its wearing even at side slip and certain blocking of the wheel. A comparison between the wearing of the tire by paths and as a whole shows a substantial difference in the wearing at different degrees of blocking of the wheel.

Table 3

Results from the wearing of the tire on paths at $\alpha_o = 0^\circ$ and $\delta = 2{,}8^\circ$

Levels of the factors	Total wearing, mg/km
G_k=12 *kN*, $p_в$=0,6 *MPa*, $\alpha_o = 0^\circ$, *blocking*3,4%	192,80
G_k=12 *kN*, $p_в$=0,2 *MPa*, $\alpha_o = 0^\circ$, *blocking* 20%	233,00
G_k=12 *kN*, $p_в$=0,6 *MPa*, $\alpha_o = 0^\circ$, *blocking* 41%	482,00

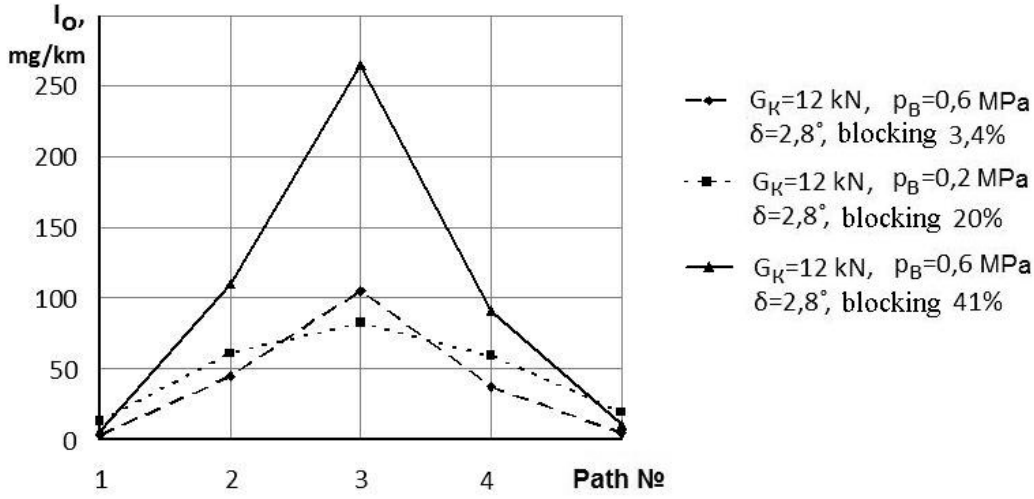


Fig. 9. Relative wearing of the tire on paths at straight motion and $\alpha_o = 0^\circ$, $\delta = 2{,}8^\circ$

Рис. 9. Специфический износ шины при прямолинейном движении и $\alpha_o = 0^\circ$, $\delta = 2{,}8^\circ$

These conditions of experiments are similar to the braking regimes at moving of the real automobile with a different braking deceleration. At blocking of 3,4% of the wheel and air pressure in the tire 0,6 MPa, the wearing at the middle path increases 11,7 times compared to the wearing at the path without wheel blocking. At blocking 41% and the same air pressure in the tire, the wearing on the middle path is approximately 30 times higher compared to the wearing without wheel blocking.

The total wearing at blocking 3,4% of the wheel and air pressure in the tire 0,6 MPa is 7,4 times higher compared to the total wearing of the tire without wheel blocking. At blocking 41% and the same air pressure in the tire, the total wearing of the tire is 18,5 times higher compared to the wearing without blocking. These results show that at stopping of the automobile with a bigger braking deceleration and non-functioning anti-blocking system, processes of intensive wearing of the pneumatic tires could reflect negative on their exploitation period.

Upon defining the accuracy of the results there should be taken into consideration the accuracy of setting of the loading, the air pressure in the tire, the side inclination, the entrainment, the road distance and the weight of the indicators.

The accuracy for defining the tire characteristics and the relative wearing is satisfactory. The maximum total mistake at the experiments is $\delta_{\sum} = 8{,}7\%$.

4. CONCLUSIONS

Based on the laboratory and road experiments of the examined tire and the analyses of the results the following conclusions could be made:

1. At the experiments without side inclination, the irregularity of the wearing across the width of the tire is increased with the pressure increasing. Due to the round profile the middle path is most intensively worn. At side inclination of the wheel = 2°, bigger irregularity of wearing across the width of the tire is reported. By that reason and considering the wearing it is better this lateral inclination of the tire to be removed.
2. For the monitored combinations of factors the relative wearing of the tested tire changes in a wide range. The optimization of the levels of these factors could lead to a significant decrease of the relative wearing. For example, at moving without side slip and at one and the same loading 12 kN, the increase of the pressure in the tires from 0,4 to 0,6 MPa leads to decrease of the relative wearing with 7,3%.
3. The used methods and experimental device workability was proven. They are appropriate for experiments concerning the tire wearing.

References

1. Георгиев, К. *Изследване износването на пневматични гуми на товарен автомобил*. Дисерттация за ОНС „доктор“. Русе. 2014. [In Bulgarian: *Investigation on the wear of a truck pneumatic tires*. PhD thesis. Ruse. University of Ruse].
2. Троицкий, В.П. и др. Ускоренный способ оценки неравномерности износа шин. *Труды МАДИ.* 1982. [In Russian: An accelerated method for evaluation tire wear irregulation. *Proceedings of MADI.* 1982].
3. Baranowski, P. & Bogusz, P. & Gotowicki, P. & Małachowski, J. Assessment of Mechanical Properties of Offroad Vehicle Tire: Coupons Testing and FE Model Development. *Acta mechanica et automatic*. 2012. Vol. 6. No. 2. P. 17-22.
4. De Beer, M. & Maina, J.W. & van Rensburg, Y. & Greben, J.M. Towards Using Tire-Road Contact Stresses in Pavement Design and Analysis. *Tire Science and Technology*. 2012. Vol. 40. No. 4. P. 246-271.
5. Guang Tong & Xiaoxiong Jin. Study on the Simulation of Radial Tire Wear Characteristics. *WSEAS TRANSACTIONS on SYSTEMS*. 2012. Vol. 11. No. 8. P. 419-429. E-ISSN: 2224-2678.
6. Ivanov, R. & Liubenov, S. Possibilities for reduction of the tires wear through the design parameters of the steering axle. *Proceedings of the Institution of Mechanical Engineers, Part D: Journal of Automobile Engineering*. 1995. Vol. 209. P. 111-115.
7. Sapragonas, J. & Dargužis, A. & Daya, E.M. & Daouadji, A. & Merzoug, B. Model of radial deformations of protector of vehicle tire. *Mechanika*. 2011. Vol. 17. No. 1. P. 21-29.
8. Ivanov, R. & Rusev, R. & Ilchev, P. A laboratory investigation of tyre sliding grip coefficient. *Transport*. 2006. Vol. 21. No 3. P. 172-181. ISSN 1648-4142.
9. Pacejka, H. *Tire and Vehicle Dynamics*. SAE. Warrendale. 2007.
10. *The Pneumatic Tire*. National Highway Traffic Safety Administration, DOT HS810561. 2006.
11. Uil, R.T. *Tyre models for steady-state vehicle handling analysis*. Master's thesis, Eindhoven University of Technology. 2007.
12. Wang, H. & Al-Qadi, I. & Stanciulescu, I. Effect of Surface Friction on Tire-PavementContact Stresses during Vehicle Maneuvering. *Journal of Engineering Mechanics.* 2013. doi:10.1061/(ASCE)EM.1943-7889.0000691.
13. *Tyre wear: Causes and Consequences*. Available at: http://www.timloto.org/download/pdf_lesbrieven/steering/chapter3tyrewear.pdf.
14. *Factors Affecting Treadwear.* Available at: http://www.goodyeartrucktires.com/pdf/resources/service-manual/Retread_S7_V.pdf.
15. *Steyn, W. & M. Haw. The effect of road surfacing condition on tyre life.* Available at: http://researchspace.csir.co.za/dspace/handle/10204/1863.

Received 23.08.2014; accepted in revised form 01.12.2015