

## RESEARCH ON OPERATIONAL CHARACTERISTICS OF TYRES WITH RUN FLAT INSERT

**Grzegorz Motrycz, Piotr Stryjek**

*Military Institute of Armoured and Vehicle Technology  
Department of Automotive Vehicles, Automotive Vehicle Laboratory  
Okuniewska Street 1, 05-070 Warsaw, Poland  
tel.: +48 226811046, fax: +48 226811073  
e-mail: grzegorz.motrycz@witpis.e, p.stryjek@wp.pl*

**Jerzy Jackowski, Marcin Wieczorek**

*Military Technical University  
Faculty of Mechanics, Institute of Motor Vehicles and Transport  
Gen. Sylwestra Kaliskiego Street 2, 00-908 Warsaw, Poland  
tel.: +48 22 683-92-76, fax: +48 22 683-73-70  
e-mail: jjackowski@wat.edu.pl, mwieczorek@wat.edu.pl*

**Jerzy Ejsmont, Grzegorz Ronowski, Sylwia Sobieszczyk**

*Head of the Automotive and Heavy Machinery Group at the Mechanical Faculty of the Technical  
University of Gdansk  
G. Narutowicza Street 11/12, 80-952 Gdańsk-Wrzeszcz, Poland  
tel.: +48 58 347-26-95, fax: +48 58 3472695  
e-mail: jejsmont@pg.gda.pl gronowski@pg.gda.pl, ssobiesz@pg.gda.pl*

### **Abstract**

*The paper describes results of research on heavy vehicle tyre with Run Flat VFI insert. The experiment has included the determination of heat generation, rolling resistance, and radial stiffness of two different tyre designs (textile and steel carcass). The results have been used for the purpose of evaluation of tyre operating characteristics. The study included research on non-inflated tyre properties.*

*The purpose of the paper is to determine characteristics of the tyres equipped with inserts, which are essential for driving wheeled APCs. The inserts are composed of polymer rings mounted on the rims inside the tyres. If the inflation pressure of the tyre is very low or if there is no inflation pressure at all, the ring transfers the loads imposed on the tyre to the rim. Usually in such a case, there is a contact of the ring and inner surface of the tyre tread area.*

*Laboratory facility for surveys of heavy vehicles tyres, summary characteristics of radial stiffness and hysteresis of test tyres, temperature distribution on the external surface of the test tyre, comparison of radial characteristics of the tyres tested, example of stiffness characteristics, distribution of temperature on the side of tyre during the road test and carcass damages on the flat tyre are presented in the paper.*

**Keywords:** *transport, vehicles, VFI, run flat, military, tyres, run flat insert*

### **1. Introduction**

Various failures of military hardware in combat conditions are very common. The tyres seem to range among the weakest points of ROSOMAK wheeled armoured personnel carriers (APCs) which are commonly used in Afghanistan (earlier in Iraq) as well as of MRAP and Hummer armoured cars. Consequently, ROSOMAKs are equipped with simple yet efficient systems that ensure uninterrupted driving if one or more tyres are damaged. This helps to continue the mission

and/or the evacuation of the crew from the combat zone. Run Flat insert of VFI (Variable Function Insert) type are used in all wheels of ROSOMAKs. The inserts are composed of polymer rings mounted on the rims inside the tyres (see Fig. 1). If the inflation pressure of the tyre is very low or if there is no inflation pressure at all, the ring transfers the loads imposed on the tyre to the rim. Usually in such a case, there is a contact of the ring and inner surface of the tyre tread area. To lower friction and heat generation, the tyre is filled with a small amount of a very slippery liquid. In case the tread area of the tyre is severely destroyed, the ring may substitute the tread and roll on the ground.

The purpose of this study is to determine characteristics of the tyres equipped with inserts, which are essential for driving wheeled APCs.



Fig. 1. Left - assembling diagram and Run Flat VFI 1400x20x10 G20, right - insert set mounted on the rim

## 2. Methodology of the tests

The process of wheel failure has been investigated for three cases. The first case involves tyre puncture as a result of bullet penetration, driving over a sharp object, etc. In such a case, leak of air may be usually compensated by the vehicles central tire inflation system. The wheel interfaces the ground under standard or somewhat reduced inflation pressure. Unfortunately, if the pressure is gravely reduced, prolonged driving will most probably lead to prompt spread of the failure due to heat and excessive tyre sidewalls deformations and the second case will develop. In the second case the wheel rolls without inflation pressure. In this case most of the forces imposed on the tyre are transferred by the Run Flat system insert, which contacts the inner surface of the tyre in the tread area. The tyre carcass is exposed to considerable deformations up to the point of breaking that is boosted by heat generation in deflected area. The third case is when the tyre is destroyed (by explosion or heat) to such an extent that the insert directly rolls on the ground. Having no protection, the insert will be exposed to severe abrasive wear and repeatedly lose large pieces of its structural material. Finally, the insert will be entirely destroyed (see Fig. 2).

This study includes identification of tyre performance for the first two cases described above. Unavoidable growth in tyre carcass deformations leads to production of large amounts of heat and increases tyre rolling resistance. The process has an adverse effect on tyre characteristics (increases rolling resistance and lowers traction), increases tyre temperature, degrades materials used for tyre construction and wears the tyre very fast. On top of this the tyre is not able to properly interact with the ground, especially if the surface is very uneven. To investigate this problem, measurements of rolling resistance, tyre temperature, tyre radial stiffness and hysteresis were performed at standard, low and zero inflation.

The survey of thermal condition and wheel rolling resistance has been conducted on the roadwheel facility with external drum (2050 mm diameter) covered by replica road surface. The replica imitated asphaltic concrete with chippings size up to 16 mm - see Fig. 3. The test facility

was designed and built by the Automotive Division at the Technical University of Gdansk. Rolling resistance has been measured by means of the “torque method” which is based on the difference between the driving torque applied to the drum shaft in order to make it rotate at a constant speed with fully loaded test wheel, and the torque necessary to rotate the drum at the “idle” conditions (so called “skim”). The load on the test tyre is obtained by means of gravitation, i.e. by putting weights on the arm, which presses the wheel to the drum.



*Fig. 2. Run Flat insert - wear and tear [photo: archives]*



*Fig. 3. Roadwheel facility for determination of tyre rolling resistance*

Radial stiffness has been determined using the laboratory facility for surveys of heavy vehicles tyres (see Fig. 4) at the Military Technical University. The tests are based on simultaneous measurements of the load and tyre deflection.

Road surveys using the test track at the Military Institute for Armour and Vehicle Technology have been scheduled to include the thermal condition and forecasted mileage of a punctured tyre until the development of the first visible damages to the carcass or tread (the damages being connected with the driving on a flat tyre).

In the project, two 14.00R20 tyres (see Fig. 5) have been tested:

- Tyre 1: with textile carcass and a distinctive tyre tread pattern with trapezoidal tread blocks placed in the central part of the tyre tread,
- Tyre 2: with steel cord carcass and tread pattern with massive hexagonal blocks.



Fig. 4. Laboratory facility for surveys of heavy vehicles tyres



Fig. 5. Test tyres: a) Tyre 1, b) Tyre 2

### 3. Test Conditions and Results

Initially, rolling resistance survey has been planned for wheels under normal (vertical) load  $Z_K$  of: 27.5 kN; 13.7 kN, and 6.8 kN, at speed of 50 km/h. Unfortunately, for flat tyres the rolling resistance has proved to be so high that the power unit of the facility has not been able to overcome the rolling resistance for normal loads higher than 12.6 kN. During the experiment, rolling resistance coefficients were evaluated for inflation pressures  $p_K = 500; 250, \text{ and } 0 \text{ kPa}$  (only within a limited range of loads in the case of an uninflated tyre). Fig. 6 shows the average results of measurements. The impact of inflation pressure and tyre design is clearly visible. Tyre 2 with a single-layer steel carcass presents a considerably smaller rolling resistance. This was proved also by the survey of temperature distribution under reduced tyre pressure. In the case of Tyre 2, more favourable distribution of heat is noticeable. Steel cord carcass means that the heat generated by the deflection process is evenly distributed in the carcass. Due to this, the maximum temperature in the tread area is by about  $27^\circ\text{C}$  lower than in the case of Tyre 1. In the sidewalls, this difference is equal to  $5\text{-}10^\circ\text{C}$  in favour of Tyre 2. This means that Tyre 2 will ensure better driving abilities in case of loss of the inflation pressure.

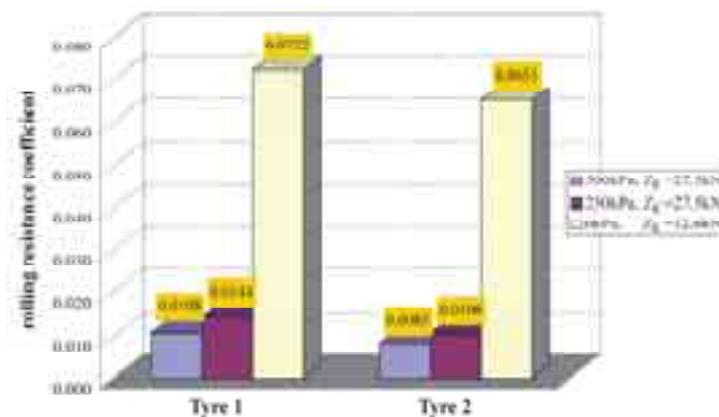


Fig. 6. Test tyres: average values of rolling resistance coefficients ( $v = 50 \text{ km/h}$ )

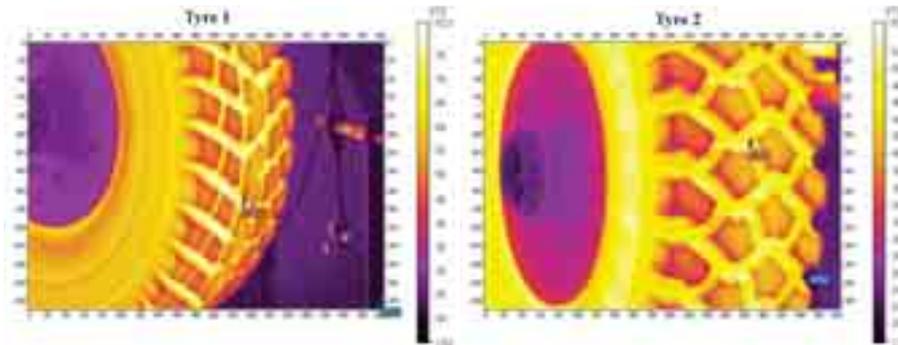


Fig. 7. Temperature distribution on the external surface of the test tyre ( $v = 50$  km/h;  $p_K = 250$  kPa;  $Z_K = 27.5$  kN)

Selection of the values of inflation pressure adopted for the purpose of survey of changes in radial stiffness was based on the recommendations for driving on various types of the ground, according to the vehicle's technical manual. Taking into account the recommended limit values, the following inflation pressure values have been adopted in the study to measure the stiffness characteristics:  $p_K = 530; 450; 380; 270; 180$ , and  $0$  kPa. Broad selection of the inflation pressures was made to cover all possible situations where vehicles central tyre inflation system is not able to fully compensate for air leaks. The value of  $0$  kPa (uninflated tyre) takes into account the driving with flat tyre resting on the insert. Summary of measurements results (see Fig. 8) shows that the two test tyres feature similar radial stiffness. Pressure drop inside the tyre will produce a decrease in radial stiffness and an increase of hysteresis that is a measure of energy losses. Pressure drop from  $530$  kPa down to  $180$  kPa goes along with the increase in the hysteresis by about  $20\ldots 30\%$  and is comparable with the increase of the rolling resistance coefficient (see Fig. 6). Tyre 1 (with textile carcass) shows bigger changes than Tyre 2 (with steel carcass). At zero tyre pressure the  $\Delta E/E$  factor shows an essential growth and achieves the level of  $30\text{-}35\%$ , Tyre 2, however, will achieve again smaller values.

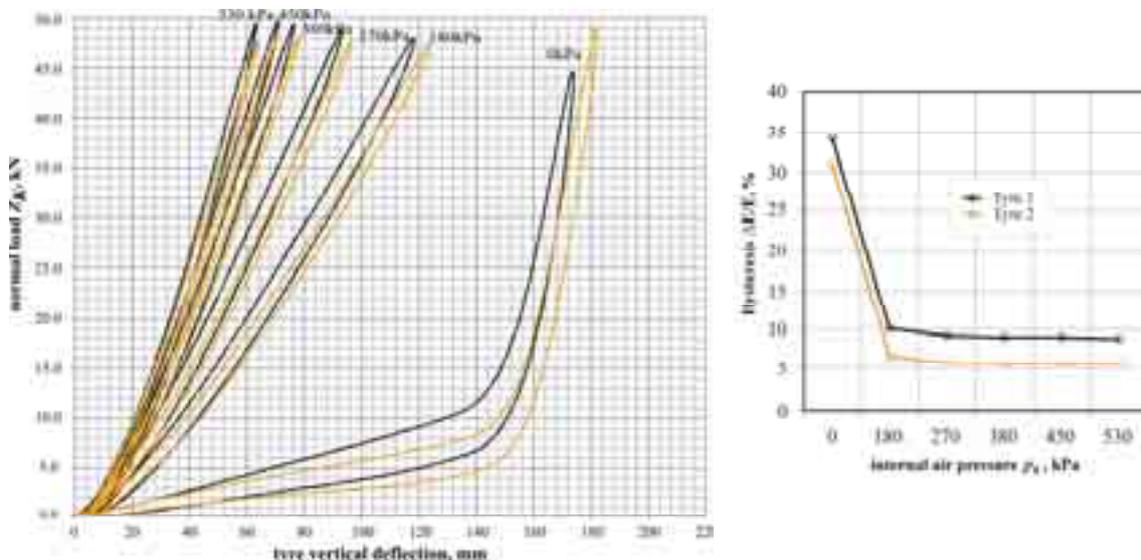


Fig. 8. Summary characteristics of radial stiffness and hysteresis of test tyres

Survey of tyre radial stiffness was conducted also on uneven road surface as the tyre radial stiffness decreases on short irregularities (the wavelength smaller than the length of the tyre footprint). The VFI insert reduces the space available for tyre carcass deformations and it may contact the carcass at low inflation pressure. The survey has used triangle “bumps” (height:  $52$  mm; base width: double height value). Surveys conducted under the inflation pressure  $p_K$  of  $270$  kPa and  $180$  kPa (see Fig. 9) have revealed that during the drive, the insert may possibly contact the tyre structure (at a deflection of about  $0.14$  m).

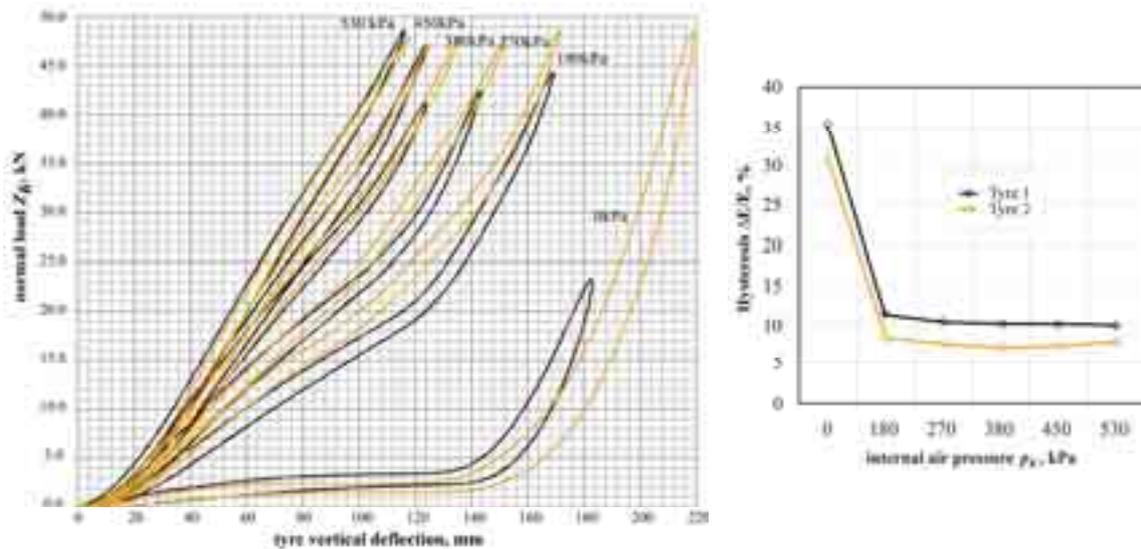


Fig. 9. Comparison of radial characteristics of the tyres tested on "bumps"

Shown in Fig. 10 is the progress in tyre stiffness changes as a function of actual normal load. In the case of Tyre 1, the characteristics are almost linear to the deflection of 0.10-0.11m (depending on the tyre air pressure). Later on, the stiffness increases until the insert rests against the tyre inner structure at a deflection of about 0.145 m. Interestingly, further changes in stiffness are similar to the changes determined in the case of a loaded wheel on an even surface at proper tyre inflation pressure. If the load of 37.5 kN at the inflation pressure of 180 kPa is exceeded, the stiffness increases due to the influence of the insert. In the case of Tyre 2, the nature of changes under small loads seems similar. Afterwards, however, there is an area of almost constant and considerably lower stiffness comparing to the stiffness on a flat surface. Still later on, there is an increment in the stiffness, which, similarly as in the previous case, depends on the insert stiffness. Furthermore, interesting differences can be noticed when flat tyres are loaded. In spite of the fact that the test tyres were equipped with the same inserts, the changes in stiffness due to the load are different. This may result from the differences in the construction of the carcasses and tread area located under the insert.

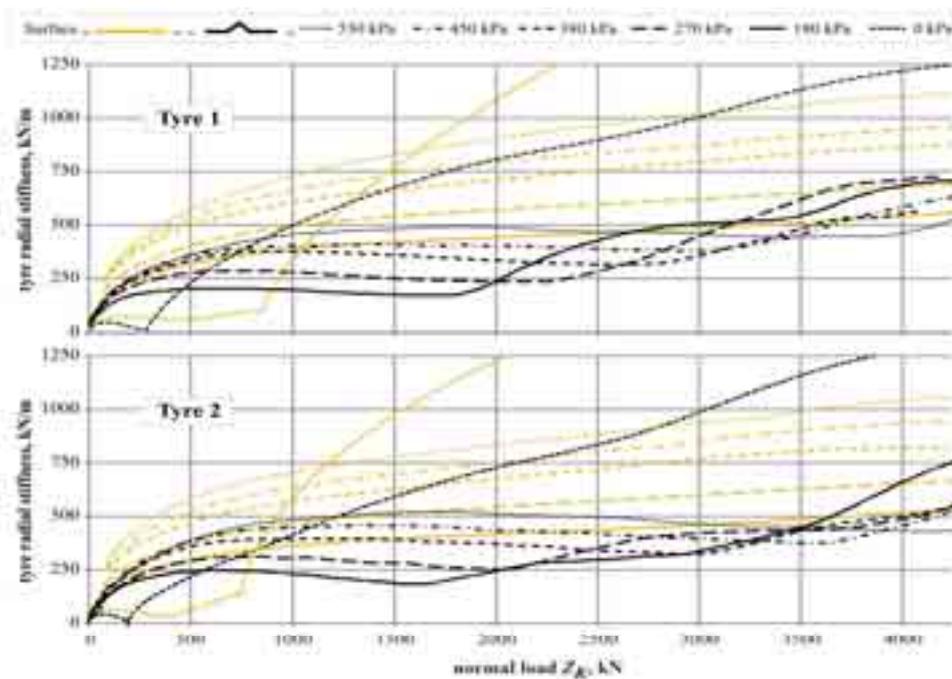


Fig. 10. Example of stiffness characteristics

The results of laboratory testing were validated by means of the road test described below. The vehicle was equipped with test tyres and was driven at a speed of 40 km/h. Tyre heat generation and tyre temperature were monitored for two conditions: tyre inflated to 530 kPa, and entirely flat tyre (see Fig. 11). Irrespective of the tyre inflation, the tyre sidewalls have been found to be the zone of the strongest heat generation (highest temperature). The areas of increased temperature are also visible at sidewalls where in the shoulder region transverse tread grooves terminate (temperature at about 80 °C in spite of the fact that the tests were conducted in winter at the ambient temperature close to -15 °C). After driving on a flat tyre the distance of almost 22 km the first rubber damages appeared at these places. They were followed by carcass cracks due to weakened structure thereof as a result of rubber degradation at the sidewalls of the tyre.



Fig. 11. Distribution of temperature on the side of Tyre 2 during the road test and carcass damages on the flat tyre

#### 4. Summary

The study has revealed the impact of the tyre construction (steel versus textile) on its properties during the operations under reduced inflation pressure or with flat tyre of the wheel equipped with the Run Flat insert. The results indicate that Tyre 2 is the one featuring better properties. Smaller hysteresis means less heat generation at the carcass and probably longer driving distance at given speed of the vehicle with flat tyre. On the other hand, the use of this tyre seems to have a negative

impact on dynamical interactions between the road and the vehicle bodywork. In this case, however, changes in the vehicle suspension rigidity should be included, since the suspension can compensate the increase of tyre stiffness by expansion of the gas strut.

Furthermore, the obtained results show the necessity for more research on the matter, especially on distribution of contact pressure between tyres and road surface when tyres use inserts.

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