NAUKI INŻYNIERSKIE I TECHNOLOGIE ENGINEERING SCIENCES AND TECHNOLOGIES
2(33) • 2019

ISSN 2080-5985
e-ISSN 2449-9773

Piotr Gorzelańczyk
Stanislaw Staszic University of Applied Sciences in Pila
e-mail: piotr.gorzelanczyk@puss.pila.pl
ORCID: 0000-0001-9662-400X

Łukasz Rochowiak
Stanislaw Staszic University of Applied Sciences in Pila
e-mail: lukaszrochowiak1989@gmail.com
ORCID: 0000-0002-0122-831X

ASSESSMENT OF THE TECHNICAL CONDITION OF TYRES USED IN AGRICULTURAL AND FORESTRY MACHINERY

OCENA STANU TECHNICZNEGO OGUMIENIA WYKORZYSTYWANEGO W MASZYNACH ROLNICZYCH I LEŚNYCH

DOI: 10.15611/nit.2019.2.04
JEL Classification: R41

Abstract: The article addresses the issues related to the testing of properties and assessment of the impact of factors forcing the replacement of tires in agricultural and forestry machines. This is a significant problem regarding the conditions of operation and use of agricultural and forestry machinery, which affects the withdrawal of tires from further use. The first part of the article presents the characteristics of tires for agricultural and forestry machines, presenting their structure, advantages and disadvantages, and the most common damage. In the second and at the same time the main part of the article, the tires of agricultural and forestry machines were examined, and the results and analysis of the conducted measurement tests were presented. The work ends with conclusions that appeared during the tests and proposed solutions for users of the tested tires.

Keywords: technical condition, tires, agricultural machinery, forestry machinery.

Streszczenie: Artykuł obejmuje zagadnienia dotyczące badań właściwości i oceny wpływu czynników wymuszających wymianę ogumienia maszyn rolniczych i leśnych. Jest to istotny problem dotyczący warunków eksploatowania i użytkowania maszyn rolniczych i leśnych, który ma wpływ na wycofanie ogumienia z dalszej eksploatacji. Zaprezentowano charakterystykę ogumienia maszyn rolniczych i leśnych, przedstawiając ich budowę, zalety i wady oraz najczęściej występujące uszkodzenia. Zbadano również ogumienie maszyn rolniczych i leśnych, przedstawiono wyniki oraz analizę wykonanych badań pomiarowych. Artykuł kończą wnioski, które nasunęły się podczas wykonywania badań, oraz propozycje rozwiązań dla użytkowników badanych opon.

Słowa kluczowe: stan techniczny, ogumienie, maszyny rolnicze, maszyny leśne.

1. Tires for agricultural and forestry machinery

Agricultural and forestry machinery is usually fitted with pneumatic tires. Originally, the pneumatic tire was a flexible tube filled with compressed air made by Thomson, consisted of a ring made of rubber fabric and an outer jacket made of leather (Guzik and Suchecki, 1991). Initially, the market showed no demand for this type of invention, and only 50 years it was used by the Michelin brothers in the wheels of the car. The real revolution came in 1839, when C. Goodyear developed the vulcanization process. From then on, tires made entirely of rubber were used. In 1845, R. W. Thomson patented the inflated tires instead of using solid rubber tires. Initially, this did not find interest and he had to wait until 1888 until J. Dunlop produced the first pneumatic tire. After initial difficulties, progress in the field of tires began to accelerate. At the end of the 19th century, the Michelin brothers introduced the first convertible tire model. The construction they used allowed them to be replaced in less than 15 minutes. In 1889, J. F. Palmer introduced cord to the tire structure, while in 1907 the Hometron Tire and Rubber Co. applied the world's first tread. Many years later the tire structure was fully shaped and from then on it was only being modernized. In 1928, the first Polish tire factory "Stomil" opened in Poznań (Andrzejewski, 2010; Guzik and Suchecki, 1991).

Table 1. Comparison of diagonal and radial tires × – defect √ – advantage

Tire type / Criterion name	Diagonal tire	Radial tire
Rolling resistance	×	√
High speeds	×	√
Fuel consumption	×	√
Driving comfort	×	√
Tire stiffness	√	×
Traction conditions	×	√
Driving precision	×	√
Maintainability	√	×
Self-cleaning	√	×
Moment of inertia of the tire	√	×
Resistance to mechanical damage	√	×
Suppression of inequalities	√	×
Tread strength	×	√
Wall strength	√	×
Heat resistance	×	√
Durability	×	√
Aquaplaning	×	√
Bearing capacity	×	√
Wet grip	×	√
The need for metal-rubber sleeves in suspension	√	×

Source: (Warecki, n.d.).

Pneumatic tires (Figure 1) come in two variants: diagonal and radial, and their comparison is presented in Table 1. Pneumatic tires are used where there is no risk of damage to the tire structure, or it is minimal.

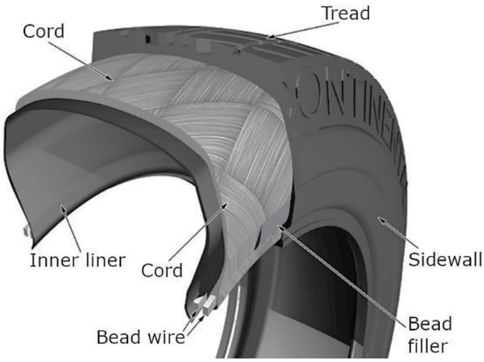

Fig. 1. Construction of the diagonal tire

Source: (Warecki, n.d.).

A diagonal tire is made with several layers of cord arranged alternately in two directions at an angle different than 90º. With this design, higher stiffness is obtained than in radial tires. The diagonal construction has advantages and disadvantages. The advantages are (Andrzejewski, 2010):

- ensuring better driving comfort,
- greater resistance to mechanical damage.

The disadvantages are (Andrzejewski, 2010):

- greater angular deformations, greater lateral drift angles, which makes driving less precise,
- greater rolling deformation, which results in higher fuel consumption.

The tire shown in the above figure consists of the following components (*Tire defects…*, n.d.; *Tire markings…*, n.d.):

- The tread is designed to create adequate adhesion of the tire to the road surface, while ensuring a sufficiently low level of abrasion. It is usually made of a mixture of different rubbers, depending on the purpose of the tire. This also affects the shape of the tread.
- The warp is the basic load-bearing element. It consists of several layers of cord fabric, arranged at different angles depending on the type and design of the tire. To increase the cohesion of individual layers and reduce internal friction, a rubber layer is used between them. Steel, polyamide, polyester, viscose and fiberglass are used for the cord.
- The sides of the tire provide adequate tire flexibility, both when driving on uneven roads and when cornering. The rubber in this zone must protect the lateral structure from damage and must also be resistant to fatigue by dynamic loads.
- The cap is a layer of rubber inside the tire that acts as a seal and covers the inner surface of the tire. In tubular tires it provides protection against wear of the tube against the warp fibers, while in tubeless tires it ensures tightness.

- The wire is a weave of steel wires giving the foot stiffness in the circumferential direction, and such a design ensures correct positioning of the foot on the wheel disc.

Another type of these tires is the radial tire (Figure 2). It was created by a radial arrangement of the warp cord, which increases the flexibility of its side. By using several layers of strapping one obtains a stiffened tire face. This design solution increases the contact area between the tire and the road. Compared to the diagonal tire, there are smaller angular deformations, lower rolling resistance and lower resistance to mechanical damage (Jaworski, 1987; *Tire markings*…, n.d.).

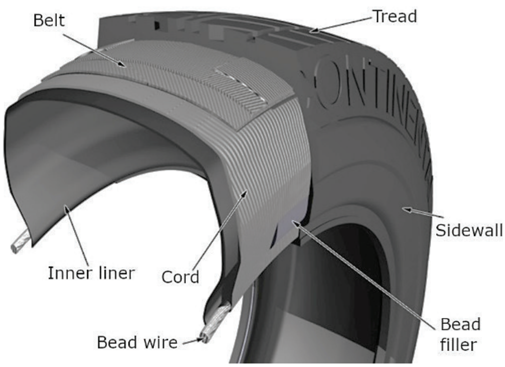

Fig. 2. Construction of the radial tire

Source: (*Tire markings*…, n.d.)

A number of components of both types of tires were described earlier, therefore only significant, different components of the radial tire are listed below (Jaworski, 1987; *Tire markings*…, n.d.):

- The tire shoulder is made of a rubber compound with good heat transfer properties, which translates into discharging it into the atmosphere. The shoulder is involved in the transfer of grip forces when driving on snowy dirt roads.
- The belt is used to stiffen the face of the tire, thus resulting in better adhesion of the tire to the road surface. In the radial tire one can distinguish external and internal strapping. External strapping is created by using two layers of polyamide cord, while internal strapping is created by using two layers of steel cord. All cord fibers are arranged in relation to each other at an angle of 70º to 85º, thus obtaining two adjacent layers of cord at intersecting angles, which ensures high rigidity of the tire face.
- The carcass is the basic load-bearing element of the tire. In its construction it connects all tire zones, i.e. the tread face, tire shoulder, tire sidewall, rim and bead. The carcass design transfers the drive torque and braking torque as well as the remaining forces loading the tire. They may come from the loading load or even from uneven ground on which the vehicle is moving. In radial tires the matrix material depends on its subsequent use, therefore textile fibres are used in passenger cars, while steel fibers are used in trucks.

- The chafer performs the function of stiffening the tire foot. It is made of a layer of steel cord covered with rubber; it is only available in radial tires.

Tires used in agricultural and forestry machinery are designed for different types of terrain and different conditions, in which they have to function. The advantages of these tires include:

- long service life,
- precise driving despite the various types of ground and its condition,
- maintaining the set direction,
- track stability,
- transfer of static and dynamic loads during field work,
- short braking distance,
- resistance to high loads, especially during acceleration,
- elimination of rolling resistance and reducing to the minimum the noise while driving,
- high absorption of road irregularities,
- good water drainage,
- ensuring user safety,
- preventing skidding and sinking into the boggy ground, which contributes to more efficient field work.

The above-mentioned features have a very large impact on driving comfort and passenger safety. They also affect tire life, fuel consumption and the economy of the entire vehicle. In order for the tires to perform their tasks properly and maintain the best technical condition for as long as possible, it is necessary to control the level of tire pressure and the degree of their wear.

The tire tread design of agricultural and forestry machine wheels (Figure 3) varies depending on the type of terrain and the operational requirements recommended by the manufacturer. There are five tread groups: R1, R1W, R2, R3, R4. The R1 design is characterized by very good self-cleaning and traction properties. It is used for field work excluding fast transport. The R1W design, on the other hand, has a tread depth increased by 20%, which has both advantages and disadvantages. The advantage is that the increased depth extends the life of the tire, while the disadvantage is that irregular tread wear occurs. The R2 type structure is characterized by twice the tread depth of the R1 type structure. It is adapted to wet, muddy terrain. This design has a 'massive' appearance due to the tread's rib angle of 45°. Tread type R3 is intended for machines in which the even distribution of pressure on the ground has a significant impact. Tread type R4 is 70% of the tread depth of R1 (*Types of agricultural tire…*, n.d.).

Damage to pneumatic tires for agricultural and forestry machinery is divided into factory and operational ones. Factory damage may arise as a result of a badly performed tire production process. The causes of factory damage are most often the wrong proportion of the mixture used, the use of cheap or old production materials, the final inspection incorrectly carried out, and thus the release of a product with

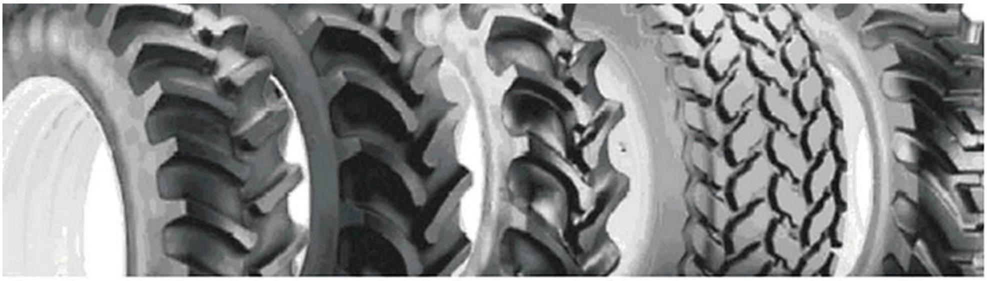

Fig. 3. Types of tires for agricultural and forestry machines

Source: (*Types of agricultural tire*…, n.d.).

a defect on the market, aside from contaminations during the production process, and the construction defects. Operational damage occurs during the use of tires, most often caused by: poor technical condition of the vehicle (any slack in the steering and suspension of the vehicle, the occurrence of leaks of operating fluids), driving style (violent collision with heavy loads on curbs and objects with sharp edges), inappropriate tire pressure, improper tire selection, incorrect tire mounting, foreign bodies, tire imbalance. The operational damage of tires according to the place of occurrence is divided into external, internal, frontal, side and shoulder (*Tire defects*…, n.d.). The problem of using means of transport related to their safety was discussed in (Gorzelańczyk, 2012, 2016a, 2016b, 2017; Gorzelańczyk and Kaczmarek, 2019; Gorzelańczyk and Michaś, 2019; Gorzelańczyk and Sikora, 2019; Wachowiak, Gorzelańczyk, and Kalina, 2018).

2. Tire testing

The object of the research is the radial pneumatic tires of currently operated agricultural and forestry machines in northern Wielkopolska. The surveyed sites were selected randomly, through visits to farms and companies that cut trees in the forests. The test consisted in the organoleptic checking of thirty tires and measuring the pressure of the tire level and tread depth, as well as reading the production date of the tires currently used. A universal vernier caliper was used to measure the tread depth, and a pressure gauge was used to measure the pressure level in the tires.

The following points were considered during the examination:

1. The tread depth must not be less than 1.6 mm in summer tires and 3 mm in winter tires, which is indicated by the identifier of the maximum degree of tire wear, located on the tire circumference marked with the symbol TWI (Figure 4) (6).

2. One should check for bubbles, bulges, visible cord threads, which causes damage to the cord fabric (4), and check for cracks on the sides of the tires (3).

3. One should check for deformed, broken wires in the steel cord (2), mechanical damage to the foot edging (5), and the presence of defects in the tread pattern (1).

4. One should check tire pressure. To find the tire pressure recommended by the manufacturer, look up its value in the machine's instruction manual. Temperature has a very large impact on the measurement result, so one should measure and top up the air when the tires are cool (while warming up). Tire pressure can be adjusted when the vehicle load changes. The reasons for the loss of natural pressure are damage, foreign bodies in the tires, temperature and leaking valves.

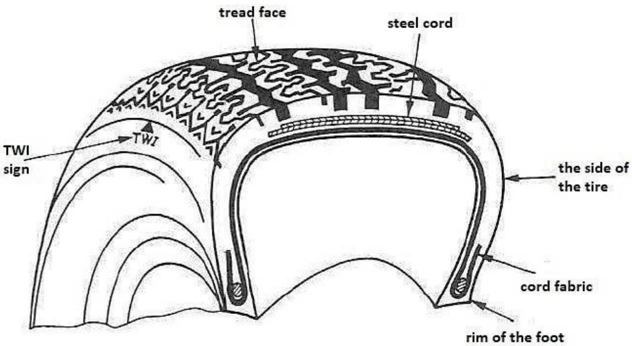

Fig. 4. Tire marking

Source: (*Uneven tire wear*, n.d.).

The tests of tread wear of tires in the currently used agricultural and forestry machines were carried out as follows:

- the tested tire surfaces were cleaned,
- the caliper has been calibrated,
- the testing instrument was applied at three points on the circumference of the tires,
- the measurement results were read from the instrument and then the average was recorded in the table.

The results of the organoleptic tests of the tires and the measurement of the tread depth as well as the reading of the production date of the thirty tires currently in use are presented in Table 2.

The results of the tests show that the tires currently in use come from the years 1999 to 2012. Most tires should be discontinued because their lifetime exceeded 10 years. The analysis of the tread depth test shows that out of the thirty tires, four are unsuitable for further use because the tread height is less than 1.6mm. Two tires had a tread depth of 1.6 mm, which is the minimum tread height allowed for road traffic of the vehicle, therefore it is recommended to replace them. Twenty-four tires can still be used because they comply with the provisions of the Traffic Code, but some of them should be replaced soon.

Table 2. Test results

Number of tire tested	Date of tire production	Tire size	Average tread depth [mm]	Organoleptic test results
1	3 week 2004	6.50-16	1.6	high one-sided wear on the shoulder of the tire
2	42 week 2008	6.50-16	1.6	high wear on the shoulders of the tire
3	14 week 2011	6.50-16	1.5	high wear in the center of the tire
4	20 week 2011	6.50-16	1.4	tread wear (longitudinal grooves)
5	44 week 2004	6.50-16	2.0	tires' wear
6	11 week 2009	6.50-16	2.1	peripheral tire damage
7	34 week 2007	6.50-16	1.8	exposed tire belt
8	23 week 2008	6.50 - 16	1.9	local tire wear
9	11 week 2010	6.50-16	1.9	damaged tread pattern in the form of grooved formations and cuts
10	34 week 2008	6.50-16	2.0	cut damage
11	25 week 2004	6.50-16	1.7	a tire burst as a result of an impact
12	50 week 2010	6.50-16	1.8	damage cut on the side of the tire
13	24 week 2012	6.50-16	2.4	side tire fracture
14	19 week 2009	6.50-16	2.4	a characteristic crack in the tire housing due to the presence of a foreign object between the twin tires
15	50 week 2000	6.50-16	2.5	tire lateral burst
16	35 week 2009	6.50-16	2.5	torn side of the tires
17	51 week 2004	6.50-16	1.4	depth damage to tires
18	23 week 2004	6.50-16	1.5	tire roughening and blackening
19	5 week 2003	6.50-16	1.8	circumferential tire damage
20	23 week 2004	6.50-16	1.7	occurrence of ageing processes in tires
21	14 week 2006	6.50-16	2.0	tire damage resulting from poor wheel alignment
22	33 week 2001	6.50-16	2.2	tire damage resulting from poor pressure in pneumatic tires
23	40 week 2003	6.50-16	1.8	damage to the tire bead
24	40 week 2003	6.50-16	1.9	damage to the tire side and rim edge
25	26 week 2003	6.50-16	2.5	damage caused by bent and protruding parts of the vehicle
26	30 week 2000	6.50-16	2.3	occurrence in tires of foreign bodies
27	13 week 1999	6.50-16	2.1	no tire damage
28	27 week 2009	6.50-16	2.3	no tire damage
29	14 week 2011	6.50-16	2.2	no tire damage
30	34 week 2007	6.50-16	2.0	no tire damage

Source: own study.

The conducted analysis (Table 2) shows that employees who use the agricultural and forestry machinery do not check the technical condition of the tires used, which is important for the proper functioning of the vehicles. This should be verified during the technical examination. However, agricultural treads are subject to technical tests, while forestry machines that do not use public roads do not have to be subjected to them. For this reason, appropriate legal regulations should be introduced urgently.

The next step involved testing the pressure in the pneumatic tires of selected agricultural and forestry machinery using a manometer. The test results are presented in Table 3.

Table 3. Pressure test results

Ordinal number	Name of the tested object	The wheel being tested	Pressure in the tire [kG/cm^2]	Pressure recommended by the manufacturer [kG/cm^2]	Results
1	URSUS C-330	rear left wheel	1.3	1.2	too high
		rear right wheel	1.1	1.2	too low
		front left wheel	0.85	1.8	too low
		right front wheel	0.95	1.8	too low
2	URSUS C-330	rear left wheel	1.2	1.2	good
		rear right wheel	1.2	1.2	good
		front left wheel	1.8	1.8	good
		right front wheel	1.8	1.8	good
3	URSUS C-360	rear left wheel	1.3	1.4-1.6	too low
		rear right wheel	1.2	1.4-1.6	too low
		front left wheel	1.85	1.8-2.0	good
		right front wheel	1.95	1.8-2.0	good
4	URSUS C-360	rear left wheel	1.5	1.4-1.6	good
		rear right wheel	1.5	1.4-1.6	good
		front left wheel	1.9	1.8-2.0	good
		right front wheel	1.8	1.8-2.0	good
5	Trailer with IMPLEMENT 10.0 / 75-15.3 tires	rear left wheel	1.9	1.8-2.2	good
		rear right wheel	1.9	1.8-2.2	good
		front left wheel	1.8	1.8-2.2	good
		right front wheel	1.8	1.8-2.2	good
6	Trailer with 6.50 - 16 tires	rear left wheel	2	1.8-2.0	good
		rear right wheel	2	1.8-2.0	good
		front left wheel	2	1.8-2.0	good
		right front wheel	2.1	1.8-2.0	too high

Source: own study.

The measurements carried out on the URSUS C-330 tractor show that the pressure of the rear wheels of the first vehicle does not fall within the range recommended by the manufacturer. Such neglect can lead to uneven tread wear, and thus reduce tire life. The other vehicle has the correct tire pressure as recommended by the manufacturer.

As a result of the tests carried out on the URSUS C-360 tractor, it follows that the tires of the first vehicle have too low pressure in the rear wheels, while the front wheels have the appropriate pressure in accordance with the manufacturer's recommendations. The pneumatic tire pressure of the second vehicle is within the range recommended by the manufacturer.

The tests carried out on the trailers indicate that the tire pressure in each trailer is within the range recommended by the manufacturer.

On the other hand, inadequate tire pressure of the vehicles causes uneven wear of the tire tread, poor driving and damage to the suspension of the means of transport. This condition can also lead to the loss of stability.

3. Conclusion

The article assessed the technical condition of selected agricultural and forestry machines currently used in northern Wielkopolska. On this basis, the following conclusions can be drawn:

1. The analysis of design solutions for agricultural and forestry machinery tires shows that currently tires with different internal construction and with different types of tread pattern are used. Pneumatic tire manufacturers use a number of markings to identify the tires and match them to each type of agricultural and forestry machine as intended.

2. The analysis of tire damage of agricultural and forestry machinery shows the following damage to tires: increased wear of the middle and side of the tire tread face, occurrence of ageing processes of tires, cracking of the tire surface, bulging, cutting or perforation of tires. The damage results, among others, from: driving with improper tire pressure, moving agricultural and forestry machinery on different types of ground, lack of wheel balance, prolonged heat exposure to tires, and hitting sharp objects.

3. The analysis of the results of measuring the tread depth of the tires shows that for a rough assessment of the tread depth, TWI indicators were used, while for the accurate assessment of the tread depth of the tire, various measuring instruments such as depth gauge and vernier caliper, universal or digital.

4. The conducted tests show that the technical condition of tires of some currently used agricultural and forestry machines is incorrect.

5. The condition of agricultural and forestry machinery tires has a significant impact on safety, therefore their condition should be monitored more often and the agricultural or forestry machinery manufacturer's recommendations should be adhered to. In addition, most of the tested tires should be replaced in the near future.

6. Moreover, in the examined tires, sensors should be introduced informing the user about the wear status of the tire, operating in a similar way as the TPMS tire pressure monitoring system. Subsequently, the authors plan to implement such solutions in practice.

7. In addition, drivers should be alerted to check the technical condition of tires, organoleptically check them for any external damage, and if the wear of the tire is approaching the limit, it should be replaced.

8. Inadequate tire pressure of the vehicle causes uneven wear of the tire tread, poor driving and damage to the suspension of the vehicle. This condition can also lead to the loss of its stability.

References

Andrzejewski, R . (2010). *Dynamics of the pneumatic road wheel*. Warsaw: Scientific and Technical Publishing House.

Gorzelańczyk, P. (2016a). Condition of paint coatings of vehicles operated in various climate zones. *Buses. Technology, Exploitation, Transport Systems*, (6), 871-875.

Gorzelańczyk, P. (2016b). Traffic noise emission testing in the city of Pila. *Buses. Technology, Exploitation, Transport Systems*, (6), 876-880.

Gorzelańczyk, P. (2017). Tire wear characteristics for public transport buses in the city of Pila. *Buses. Technology, Exploitation, Transport Systems*, (12).

Gorzelańczyk, P., and Michaś, D. (2019). Impact of eco-driving on the operation of vehicles. *Buses. Technology, Exploitation, Transport Systems*, (1).

Gorzelańczyk, P., and Kaczmarek, L. (2019). Impact of modern information systems on the operation of passenger vehicles. *Buses. Technology, Exploitation, Transport Systems*, (1).

Gorzelańczyk, P., and Sikora K. (2019). Technical and operational examination and analysis of mechanical and electric parking brakes. *Buses. Technology, Exploitation, Transport Systems*, (1).

Gorzelańczyk, P. (2012). Expert systems in the diagnostics of means of transport. *Logistics*, (3).

Guzik, H., and Suchecki, B . (1991). *Tires*. Communication and Communication Publisher.

Jaworski, J. (1987). *Tires for motor vehicles*. Warsaw: Communication and Communication Publisher.

Tire defects – operational damage. Retrieved August 20, 2018 from http://www.opony.com.pl/artykul/usterki-opon-uszkodzenie-eksploatacyjne/?id=957

Tire markings: How to read the markings on the tires, what are the indexes, how to recognize the size of the tire – all about tire symbols. Retrieved August 20, 2018 from https://www.se.pl/auto/porady/oznaczenia-opon-jak-czytac-oznaczenia-na-oponach-jakie-sa-indeksy-predkosci-jak-rozpoznac-rozmiar-op-aa-eVca-XZxQ-jgoE.html

Types of agricultural tire treads. Retrieved August 20, 2018 from http://www.hurtopony.pl/artykul/rodzaje-bieznikow-opon-rolniczych.html

Uneven tire wear. Retrieved August 20, 2018 from http://moto-technik.blogspot.com/2011/08/nierownomierne-zuzycie-opon.html

Wachowiak, P., Gorzelanczyk. P, and Kalina, T. (2018). Analysis of the effectiveness of shock absorbers in light of applicable legal regulations in Poland and Slovakia. *Buses. Technology, Exploitation, Transport Systems*, (6).

Warecki, R. (n.d.). *Radial and diagonal tires – how do they differ?* Retrieved August 20, 2018 from https://autokult.pl/13268,opony-radialne-i-diagonalne-czym-sie-roznia-opony