OPERATIONAL TESTS OF THE TECHNICAL CONDITION OF TRUCK TIRES

Piotr Cieślak, Daniel Pieniak, Leszek Gil, Artur Dmowski, Andrzej Niewczas

Abstract

Tire wear and damage tests have been carried out on a sample of 45 trucks in Warsaw. The aim of the research was to assess the damageability and to determine the qualitative characteristics of typical operational damage to the truck tires. A linear measurement of the tread height and organoleptic assessment of the form of damage were used. Three groups of vehicles were analysed: trucks with an integrated body, used in severe conditions on short routes – category I; tractor-semi-trailer combinations, used in conditions of heavy loads on intercity routes – category II; truck-trailer combinations, used with moderate load on intercity routes, long – category III. It has been shown that the most common types of damage are: excessive tread wear, mechanical cut of the tread and uneven tread wear (35%, 30%, 24% of all tested tires, respectively). It was shown that tires in vehicles of categories I and II are distinguished by high damageability (30.5% and 28.6%, respectively), with tread cut damage prevailing in the first group, and excessive tread wear in the second group. The damageability of vehicles in the third group was more than two times lower.

Keywords:

trucks, tires, wear, operational damage

Citation:

Cieślak P., Pieniak D., Gil L., Dmowski A., Niewczas A., Operational tests of the technical condition of truck tires. Motor Transport 66 (2), 17-34

DOI: 10.5604/01.3001.0016.2052

1. Introduction

One of the most important factors affecting road safety is the technical condition of vehicle tyres. At the same time, it is known that tires are subject to intensive wear and their service life is several times shorter than that of entire vehicles. Guided by these premises, the authors of this paper conducted a study of wear and operational damage to the tires in trucks in Warsaw. The aim of the work was to assess the damageability and to determine the descriptive characteristics of typical operational damage to the truck tires. From the view point of road safety, the most important component of a tire is the tread. The tread is responsible for absorbing vibrations and wheel grip the in contact with the road surface. The design of the tread and the rubber compounds used determine many very important performance characteristics of the tire [1,10]. When undertaking the research, the following theses were adopted based on the literature: the tread wears out during use due to friction in the contact zone with the road surface and internal friction in the tire material. Tread wear should be uniform over the entire surface of contact with the road and be clearly dependent on the intensity of use and the number of kilometres driven. However, practice shows that the tread can also wear unevenly, as well as be subject to local damage (cracks, detachment of entire tire fragments). This often constitutes a direct threat to traffic safety [12].

The construction of modern car tires is a complex structure because it combines many engineering elements, including steel, rubber and textile elements. Each of the listed construction materials has different properties that give the tire its characteristic features, e.g. colour, flexibility, stiffness, strength, vibration damping, heat dissipation [5]. The selection of materials and the technology of the production process have a significant impact on the performance characteristics of the tyre. Tires are subject to a number of specialist qualification tests and control tests. A particularly important element of the tire is the tread. The material from which the tire tread is made should be resistant to abrasion and dynamic loads. In addition, the stability and strength of the material at both low and high temperatures are important [10].

According to the applicable law, the minimum tread height is regulated by the Ordinance of the Minister of Infrastructure, Journal of Laws of February 26, 2003 on the technical conditions of vehicles and the scope of their necessary equipment. The minimum tread height is determined by the Tire Wear Index (TWI). The minimum height should be at least 1.6 mm (excluding buses, which must be at least 3 mm high) [10]. Tire manufacturers place markings on the sidewall of the tire specifying the detailed characteristics of the tire's operating parameters in the form of pictograms [12].

The main material used in the production of tires is rubber. A characteristic process of rubber operational wear and tear is the aging process. This process involves chemical changes in the structure that increase the hardness and brittleness of the material. The aging process occurs much faster if the rubber is exposed to high temperature, e.g. as a result of the impact generated by the braking system of vehicles or heat generated by the engine [7]. Important elements are also textile and steel cords forming the structural framework of the tire [10]. The tire carcass determines its shape and stiffness, which translates into proper driving performance. At the production stage, it is covered with a layer of brass or bronze to ensure a good connection between the cord and rubber during further vulcanization operations.

Car tires are used in different climatic zones. Tires used in hot zones are exposed to increased impact of high temperatures, dry air and solar radiation. A tire exposed to constant sunlight undergoes accelerated aging processes, which leads to a decrease in its resistance to deformation and cracking [13]. The cause of overheating of the tire may be the incorrect selection of the load index for the vehicle load. Tires are the most important components of motor vehicles, which become a concern due to their contact with the ground which is for the vehicle only contact with it. The stability and safety of the vehicle may be significantly deteriorated as a result of a sudden failure or bursting of the vehicle's tires [6]. The type of surface on which the vehicle is moving also has an impact on the formation of tire damage. Tires used on dirt and stony roads are exposed to cuts, cracks or detachment of part of the tread block. These damages occur as a result of contact of a loaded tire with sharp edges of stones (Figure 7) or other hard elements on the road surface. Vehicles travelling mainly on roads with bituminous, concrete or cobblestone surfaces are characterized by a lower risk of impact damage to tires, while they are exposed to more intense abrasion (tribological) wear of the tread. Tire damage can cause corrosion of the steel wires in the tire skin, which can even lead to the separation of small pieces from the tire profile of the car [3].

Friction is the main cause of tire tread wear. The contact surface of the tire with the road in trucks is quite large, and causes significant rolling resistance [13] and damage to the road surface caused by cooperation with new generation tires with a wide base is greater [4]. The air pressure in the tire also has a large impact on the degree of tire wear and its durability. Too low pressure can cause deformation of the tire, increased wear of the side bands of the tread pattern, cracks in the sidewall of the tire. Too much pressure also has a negative effect on tire life. In particular, it can cause increased wear of the middle bands of the tread pattern with a simultaneous decrease in the loss of side bands [5]. Common phenomena accompanying excessive tire pressure are cracking of the tread groove pattern, cracks in the sidewall and delamination of the tread from the tire carcass. By maintaining adequate tire pressure, the risk of aquaplaning is reduced.

Another factor indirectly influencing tire wear is the geometry of the suspension system in the vehicle. The suspension system determines the setting of the wheels relative to the road surface and ensures proper contact of the tire face with the road surface. Camber causes increased tire deformation and rolling resistance. The consequences of poor suspension geometry may be one-sided, uneven or scaly wear of the tread pattern along the entire circumference of the tire [13].

Tire tread wear also has a significant impact on cooperation with the road. The contact area between an unworn tire with a deep tread and a road surface with increased susceptibility (e.g. an unpaved road on a construction site or an access road to the load recipient's premises) will be larger, and the meshing effect between the cooperating surfaces of the tire and the road will be stronger. Thus, a tire that is not excessively worn, with deep tread grooves preserved, absorbs more driving force [14]. This state of affairs has a positive effect on the traction properties of the vehicle on roads with increased surface susceptibility.

In the light of the above considerations, the aim of the work was to assess the damageability and to determine the descriptive characteristics of typical operational damage to truck tires.

2. Own research

2.1. Research objects

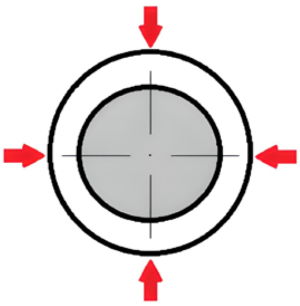
The subject of the tests were tires used in three groups of vehicles:
- Truck with integrated body – category I,
- A set consisting of a tractor unit and a semi-trailer – category II,
- A combination consisting of a truck and a trailer – category III.

The test was conducted on a sample of fifteen vehicles from each of the three test sample categories. The division into groups of vehicles was in accordance with the classification defined by the Act – „ Road Traffic Law" Art. 2 [12]. In the group of category I vehicles, 112 tires (15 vehicles) were tested. In the group of category II vehicles, 150 tires were tested (15 sets of tractor unit and semi-trailer). In the group of category III vehicles, 120 tires (15 sets of car and trailer) were tested.

2.2. Research method

The basic research methods were the organoleptic evaluation of tires and the measurement of tread wear. Observations included the sidewall, shoulder and front of the tire tread (Figure 1). Visible operational damage was described in the test report and photographed. Particular attention was paid to large damage, which could result in the disqualification of further use of the tyre. Tread wear was measured in places shown schematically in Figure 1. The accuracy of the measurement was 0.01 mm.

Fig. 1. Location of tire tread height measurements



Source: Own study

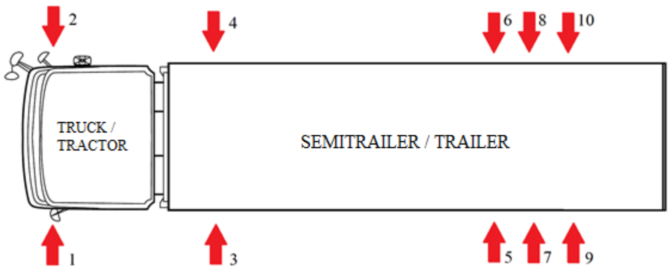
The measurement method is shown in Figure 2.

Fig. 2. Example of tire tread height measurements

Source: Own study

Measurements were taken, in sequence, from left to right on the front axle. Then, the measurements were made according to the axle number. The measurement sequence system is shown in the diagram – Figure 3.

Fig. 3. Sequence of measurements



Source: Own study

The results of tread height measurements were each time supplemented with the technical and record data of the tested vehicle and a description of the form of tire damage in the test report. The model of the test report is given in Appendix 1. The vehicle make, mileage, year of manufacture and number of axles were recorded. The measurement results were arranged according to the adopted test method (vehicle category, axle number), and then the average value of the tread height was calculated.

2.2.1. Test conditions

The research was carried out in the area of Warsaw's public road network. Observations and measurements were carried out at different times of the day in different weather conditions with variable lighting. The vehicles under observation were randomly selected from among road users. Thanks to cooperation with the Warsaw Municipal Roads Authority, measurements were carried out at the weighing stations adapted to control the technical condition of trucks.

2.2.2. Measuring instruments

The REDATS digital tread depth gauge was used to measure tire wear (Figure 4). This device allows to quickly measure the geometric parameters of the tread pattern.

Fig. 4. REDATS digital tread depth gauge

Source: Own study

Before each measurement, an initial calibration of the gauge was carried out. Below are its basic technical and operational parameters:

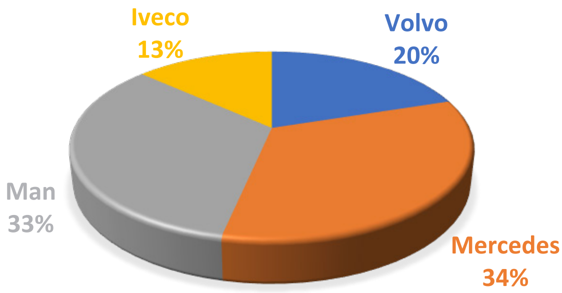
- measuring range 0.00 mm–25.4 mm;
- measurement accuracy 0.01 mm;
- dimensions 60 mm x 113.5 mm x 13 mm;
- weight 90 g;
- operating temperature range: 0°C–40°C.

3. Research results

3.1. Tread wear

As part of the conducted tests of category I vehicles, fifteen randomly selected trucks of various makes with an integrated body and an individual number of axles in the vehicle were subjected to observations (Figure 5). It is worth noting that in cars with 4 axles, the two front axles were steering axles.

Fig. 5. Percentage share of individual makes of vehicles in the tested sample of category I



Source: Own study

The main type of body in the tested category I sample was a tipper used to transport loose materials (12 vehicles). Two vehicles had a universal body, and one vehicle had a hook body for transporting skips. The technical and operational indicators of the tested category I vehicles are given in Table 1. The following were distinguished: vehicle make, year of production, mileage, number of axles and type of bodywork. The average mileage of category I vehicles was 405,000 kilometres and the average age was 9 years.

Tab. 1. List of tested category I vehicles (trucks with integrated bodywork)

No.	Vehicle make	Production year	Vehicle's mileage [km]	Number of axles	Number of steering axles	Type of bodywork
1.	VOLVO	2011	255 551	4	2	Tipper
2.	MERCEDES	2007	452 088	4	2	Tipper
3.	MAN	2006	282 742	4	2	Tipper
4.	MERCEDES	2007	341 928	4	2	Tipper
5.	MAN	2004	743 821	3	1	Universal
6.	VOLVO	2006	698 273	4	2	Tipper
7.	VOLVO	2008	593 428	4	2	Tipper
8.	MAN	2013	274 693	2	1	Hook
9.	MERCEDES	2011	329 483	4	2	Tipper
10.	MERCEDES	2013	417 284	4	2	Tipper
11.	IVECO	2011	372 232	4	2	Tipper
12.	MERCEDES	2011	409 277	4	2	Tipper
13.	MAN	2018	164 485	4	2	Tipper
14.	MAN	2015	343 284	4	2	Tipper
15.	IVECO	2017	297 421	3	1	Universal
Average	-	2010	405 066	-	-	-

Source: Own study

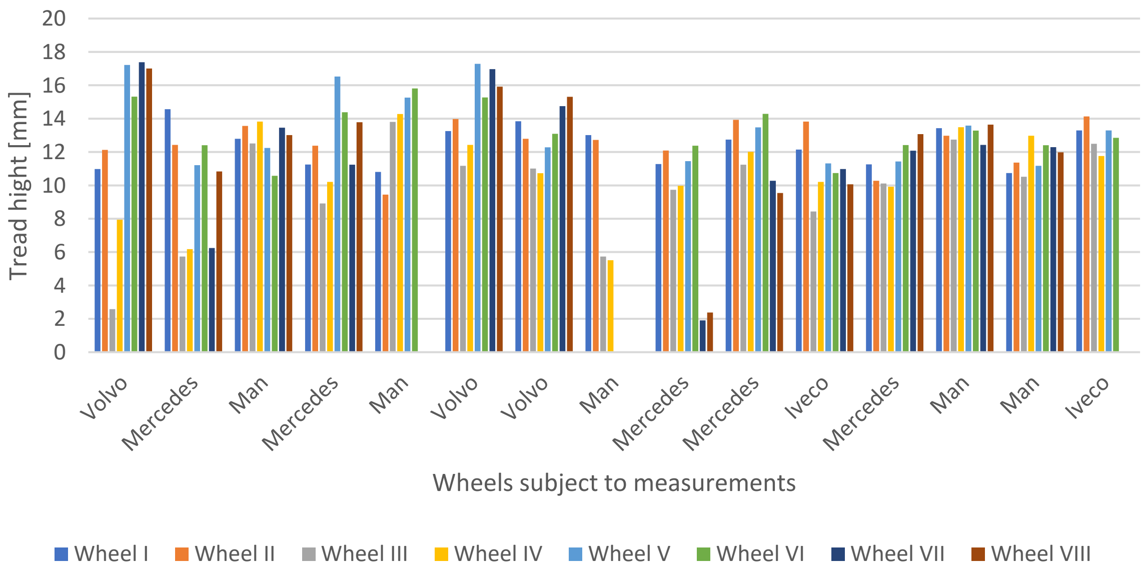
Table 2 and Figure 7 show the results of tread height measurements divided into vehicle axles. It should be added here that the minimum permissible tread height is 1.6 mm. The table shows that the largest tread depth of 17.38 mm was on the left wheel on the fourth axle of vehicle No. 1. The lowest tread height was on vehicle No. 9 on the fourth axle of the left wheel, 1.91 mm.

Tab. 2. Measurement results of the category I vehicles' tread height

No.	Vehicle make	Type of bodywork	Average tyre tread height [mm]							
			Axle I		Axle II		Axle III		Axle IV	
			Wheel I	Wheel II	Wheel III	Wheel IV	Wheel V	Wheel VI	Wheel VII	Wheel VIII
1.	VOLVO	Tipper	10,98	12,13	2,58	7,94	17,22	15,32	17,38	17,01
2.	MERCEDES	Tipper	14,57	12,43	5,73	6,18	11,21	12,41	6,25	10,84
3.	MAN	Tipper	12,79	13,56	12,51	13,82	12,24	10,58	13,46	13,01
4.	MERCEDES	Tipper	11,25	12,38	8,92	10,21	16,52	14,38	11,24	13,79
5.	MAN	Universal	10,81	9,45	13,81	14,28	15,26	15,81	-	-
6.	VOLVO	Tipper	13,26	13,98	11,17	12,43	17,29	15,27	16,97	15,92
7.	VOLVO	Tipper	13,84	12,79	11,01	10,73	12,28	13,09	14,75	15,31
8.	MAN	Hook	13,01	12,73	5,73	5,51	-	-	-	-
9.	MERCEDES	Tipper	11,28	12,09	9,74	9,98	11,45	12,38	1,91	2,38
10.	MERCEDES	Tipper	12,74	13,93	11,24	12,01	13,48	14,29	10,28	9,54
11.	IVECO	Tipper	12,15	13,82	8,43	10,21	11,32	10,74	10,98	10,06
12.	MERCEDES	Tipper	11,26	10,28	10,11	9,92	11,43	12,42	12,08	13,07
13.	MAN	Tipper	13,43	12,98	12,74	13,49	13,58	13,28	12,43	13,64
14.	MAN	Tipper	10,74	11,37	10,52	12,98	11,17	12,41	12,29	11,98
15.	IVECO	Universal	13,29	14,13	12,49	11,76	13,29	12,85	-	-
Average			**12,36**	**12,53**	**9,78**	**10,08**	**13,41**	**13,24**	**11,66**	**12,21**

Source: Own study

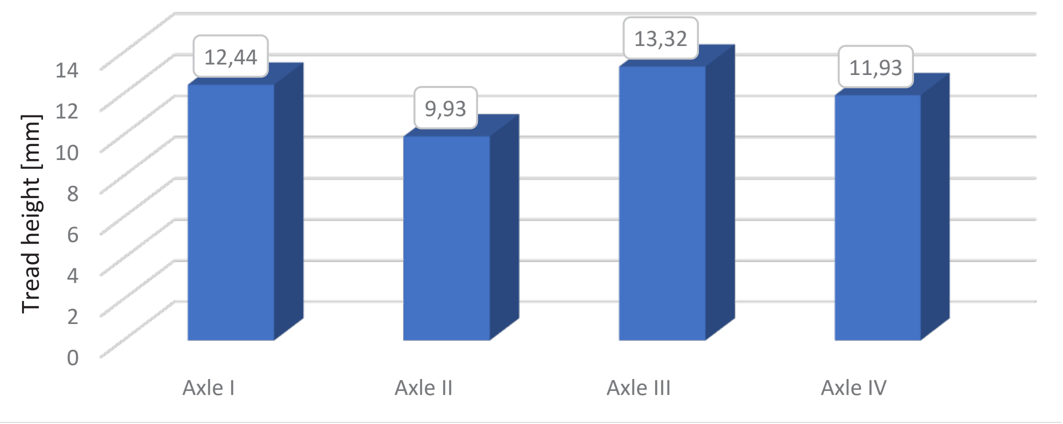
Fig. 6. Comparison of the tread height in the sample of category I vehicles, broken down into axles: axle I – wheels I and II, axle II – wheels III and IV, axle III – wheels V and VI, axle IV – wheels V and VI



Source: Own study

A summary of the average values of the tread height in the groups arranged according to the axle numbers of the vehicles in test I is shown in Figure 7. The results of the calculations show that in the sample of category I vehicles, the highest tread wear was found on the second steering axle. The average tire tread height was 9.93mm. Significant tread wear was also found on the fourth axle, where the tread height was 11.93mm.

Fig. 7. Average tread height of individual axles of a given group of vehicles



Source: Own study

The second examined category consisted of fifteen vehicle combinations consisting of truck tractors and semi-trailers. The group of tractors included six different makes of vehicles with the percentage share shown in Figure 8 and four makes of semi-trailers shown in Figure 9.

Fig. 8. Percentage share of (individual) makes of tractors in the category II sample

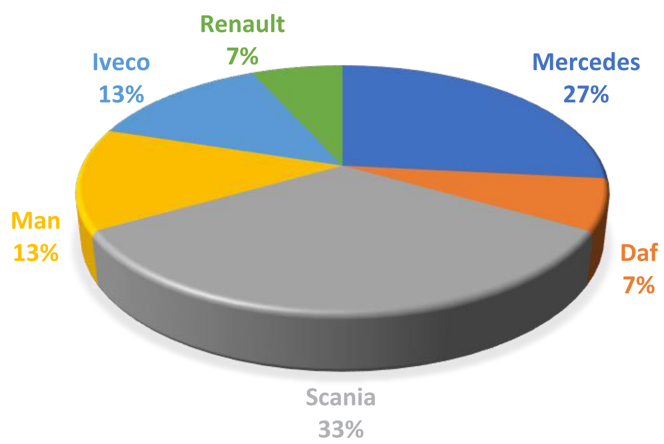
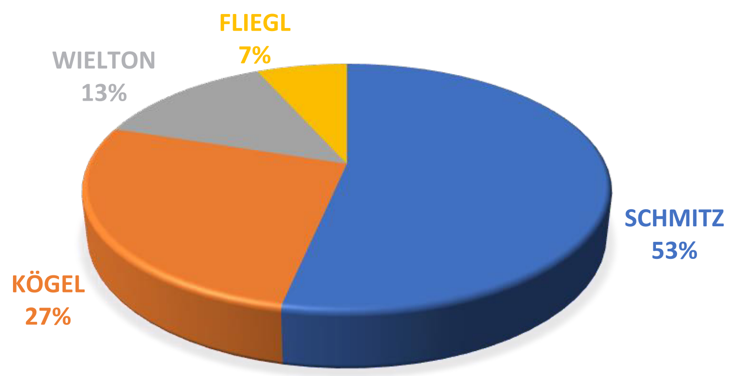


Fig. 9. Percentage share of individual makes of semi-trailers in the category II sample



Source: Own study

Among the semi-trailers, the main type of body was the tipper. This subgroup consisted of nine vehicles in the total number of fifteen vehicles in the examined sample. The second subgroup consisted of universal type bodywork (six cars). The listed types of semi-trailers had a liftable first axle, with a total of three axles. The first axle in semi-trailers is lowered when transporting a load and when parked.

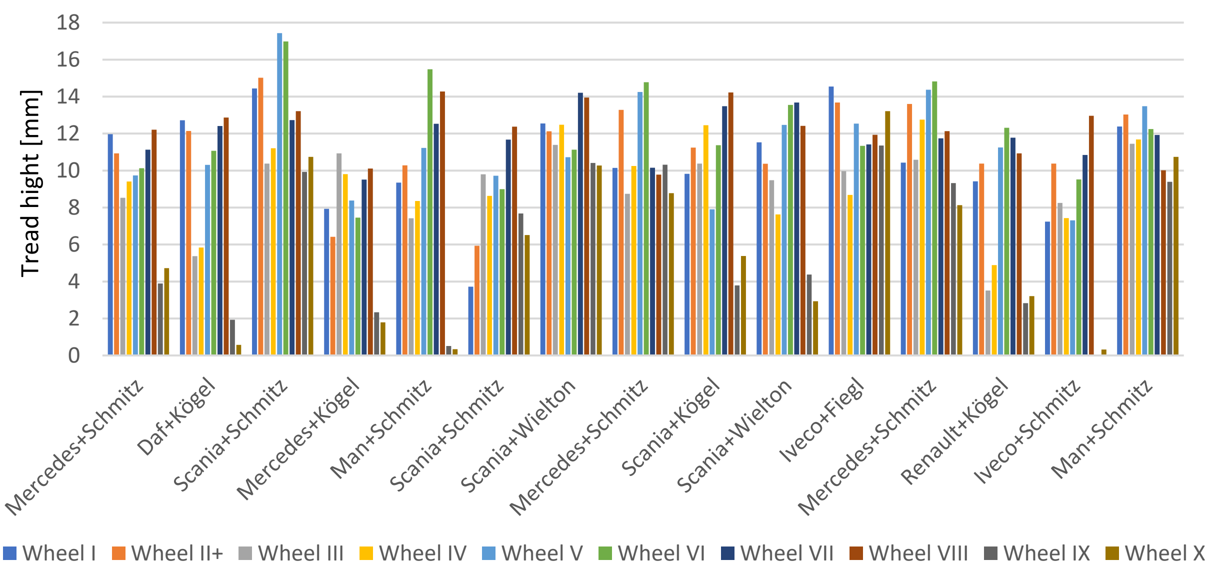
As stated in Table 3, the average mileage of tractors in the category II sample was about 706,000 km kilometres, with the average age of the vehicle being 11 years. The age of the trailer was 10 years.

Tab. 3. List of tested vehicles in the category II sample (set – truck tractor with semi-trailer)

No.	Vehicle make	Production year	Vehicle's mileage	No. of axles	Semi-trailer make	Production year	No. of axles	Type of bodywork
1.	MERCEDES	2011	527 467	2	SCHMITZ	2010	3	Tipper
2.	DAF	2012	758 931	2	KOGEL	2012	3	Universal
3.	SCANIA	2005	525 941	2	SCHMITZ	2013	3	Tipper
4.	MERCEDES	2013	508 451	2	KOGEL	2011	3	Tipper
5.	MAN	2007	654 437	2	SCHMITZ	2014	3	Tipper
6.	SCANIA	2010	848 279	2	SCHMITZ	2014	3	Tipper
7.	SCANIA	2011	794 853	2	WIELTON	2015	3	Universal
8.	MERCEDES	2012	697 557	2	SCHMITZ	2009	3	Tipper
9.	SCANIA	2004	917 432	2	KOEGEL	2013	3	Tipper
10.	SCANIA	2007	732 429	2	WIELTON	2007	3	Tipper
11.	IVECO	2012	341 158	2	FIEGL	2005	3	Universal
12.	MERCEDES	2007	842 398	2	SCHMITZ	2007	3	Universal
13.	RENAULT	2011	878 924	2	KOGEL	2009	3	Universal
14.	IVECO	2009	832 154	2	SCHMITZ	2011	3	Tipper
15.	MAN	2010	743 529	2	SCHMITZ	2012	3	Universal
Average	-	2009	706 929	2	-	2010	3	-

Source: Own study

Fig. 10. Comparison of tread height in a sample of category II vehicles



Source: Own study

Table 4 and Figure 10 show the average values of the tread height broken down by vehicle type and axle number.

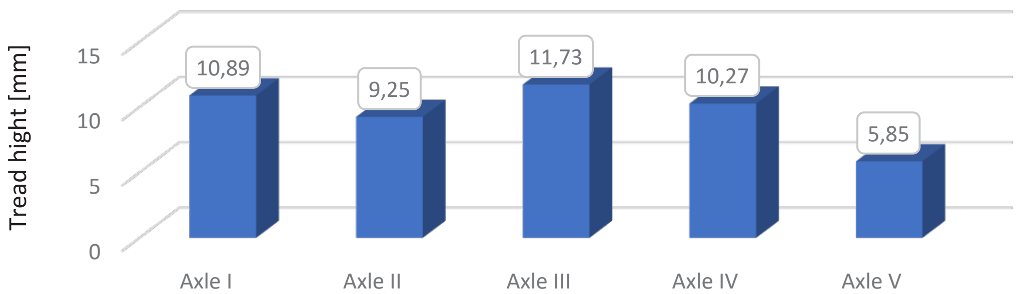
Analysing the measurement results in Table. 4 and Figure 10, it should be stated that the vehicle No. 3 on the third axle of the left wheel had the highest tread height, 17.43mm. The lowest tread height was found on the fifth axle of the left wheel of vehicle No. 14, 0.00 mm. The carcass of the tire was visible.

Tab.. 4. The results of tread height measurements in a sample of category II vehicles

No.	Vehicle make	Average tyre tread height [mm]											
		Truck tractor				Semi-trailer make		Semi-trailer					
		Axle I		Axle II				Axle III		Axle IV		Axle V	
		Wheel I	Wheel II	Wheel III	Wheel IV		Type of bodywork	Wheel V	Wheel VI	Wheel VII	Wheel VIII	Wheel IX	Wheel X
1.	MERCEDES	11,97	10,93	8,53	9,41	SCHMITZ	Tipper	9,74	10,13	11,13	12,21	3,89	4,72
2.	DAF	12,72	12,14	5,37	5,84	KÖGEL	*U/ Tarpaulin	10,31	11,07	12,41	12,87	1,93	0,57
3.	SCANIA	14,44	15,02	10,38	11,21	SCHMITZ	Tipper	17,43	16,98	12,73	13,21	9,93	10,74
4.	MERCEDES	7,93	6,42	10,93	9,81	KÖGEL	Tipper	8,38	7,45	9,51	10,11	2,34	1,79
5.	MAN	9,35	10,28	7,42	8,35	SCHMITZ	Tipper	11,22	15,48	12,53	14,28	0,51	0,34
6.	SCANIA	3,72	5,93	9,8	8,63	SCHMITZ	Tipper	9,72	8,99	11,67	12,37	7,68	6,51
7.	SCANIA	12,55	12,12	11,39	12,48	WIELTON	*U/ Tarpaulin	10,72	11,13	14,21	13,95	10,41	10,27
8.	MERCEDES	10,14	13,28	8,74	10,25	SCHMITZ	Tipper	14,25	14,78	10,15	9,78	10,32	8,78
9.	SCANIA	9,82	11,24	10,38	12,45	KÖGEL	Tipper	7,90	11,37	13,48	14,22	3,79	5,38
10.	SCANIA	11,53	10,37	9,48	7,63	WIELTON	Tipper	12,47	13,55	13,68	12,42	4,38	2,93
11.	IVECO	14,54	13,68	9,97	8,68	FLIEGL	*U/ Tarpaulin	12,54	11,34	11,41	11,93	11,35	13,21
12.	MERCEDES	10,43	13,60	10,58	12,75	SCHMITZ	*U/ Tarpaulin	14,37	14,82	11,74	12,13	9,32	8,13
13.	REANULT	9,42	10,38	3,51	4,89	KÖGEL	*U/ Tarpaulin	11,25	12,31	11,78	10,93	2,83	3,21
14.	IVECO	7,24	10,38	8,25	7,43	SCHMITZ	Tipper	7,31	9,52	10,84	12,96	0,00	0,32
15.	MAN	12,38	13,03	11,45	11,68	SCHMITZ	*U/ Tarpaulin	13,48	12,24	11,92	10,01	9,39	10,74
Average		10.,54	11,25	9,07	9,43			11,40	12,07	8,05	12,49	5,87	5,84
*Universal/Tarpaulin													

The results of the measurements in test II were grouped according to the axle numbers of the tested vehicle sets (5 axles). The average values of the tread height in each group were calculated. The results of the calculations are shown in Figure 11. The greatest tire wear was found on the fifth axle of the set, i.e. the third axle of the semi-trailer (tread height 5.85 mm). Increased tire wear was also noted on the second axle of the set, i.e. the drive axle of the tractor (tread height 9.25 mm).

Fig. 11. The average height of the tread with a division into the axles of vehicles in a sample of category II



Source: Own study

Another group of tested vehicles was a category III sample consisting of a truck with a trailer (Table 5). The research covered fifteen inspected vehicle combinations. In order to standardize the tests, the measurements were carried out on trucks with two axles, where the first axle was the steering axle and the second one was the driving axle. All trailers in the tested units had two axles, the first of which was a steering axle. The percentage share of individual makes of the tested trucks in category III vehicle combinations is shown in Figure 12, while the percentage share of trailer makes is shown in Figure 13.

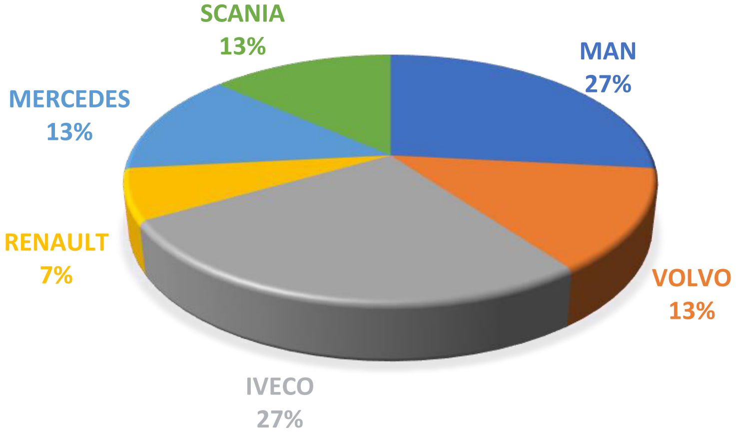
Tab. 5. List of tested category III vehicles (set – truck with trailer)

No.	Vehicle make	Production year	Vehicle's mileage	No. of axles	Trailer make	Production year	No. of axles	Type of bodywork
1.	MAN	2008	452 328	2	SCHMITZ	2009	2	Universal
2.	VOLVO	2011	392 653	2	MOESLEN	2015	2	Universal
3.	MAN	2012	428 625	2	KRONE	2014	2	Hook
4.	VOLVO	2009	631 298	2	WIELTON	2014	2	Universal
5.	IVECO	2011	451 283	2	SCHMITZ	2011	2	Hook
6.	MAN	2007	732 451	2	SCHMITZ	2017	2	Hook
7.	RENAULT	2010	578 103	2	SCHMITZ	2013	2	Universal
8.	MERCEDES	2009	479 382	2	SCHMITZ	2013	2	Universal
9.	MAN	2006	842 506	2	WIELTON	2014	2	Universal
10.	MERCEDES	2007	658 427	2	MEILLER	2013	2	Hook
11.	IVECO	2013	343 357	2	FIEGL	2015	2	Universal
12.	SCANIA	2007	754 293	2	ZASŁAW	2017	2	Hook
13.	IVECO	2012	328 462	2	FIEGL	2014	2	Universal
14.	SCANIA	2009	427 389	2	SCHMITZ	2013	2	Universal
15.	IVECO	2009	458 294	2	ZASŁAW	2015	2	Universal
Average	-	2009	530 590	2	-	2013	2	-

Source: Own study

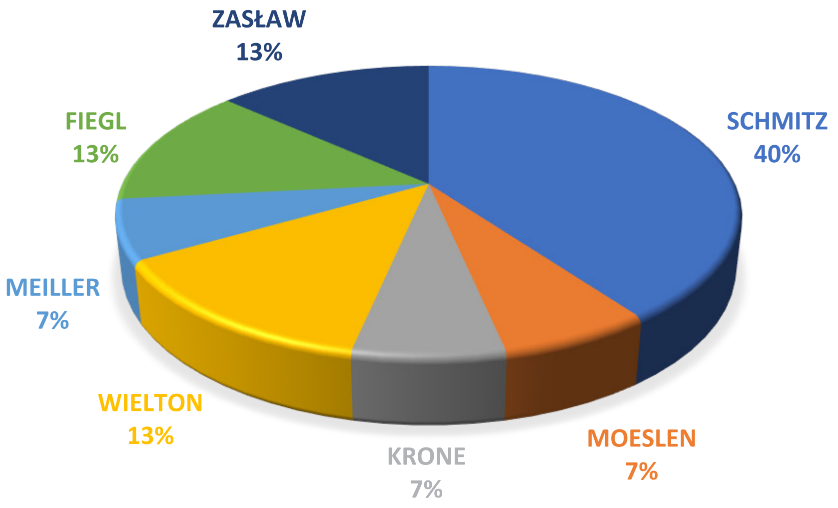
In the sample of category III vehicles, six makes (Figure 12) and seven makes of truck trailers (Figure 13) were tested.

Fig. 12. Percentage share of individual makes of trucks in the sample of category III vehicles



Source: Own study

Fig. 13. Percentage share of individual makes of truck trailers in the category III sample



Source: Own study

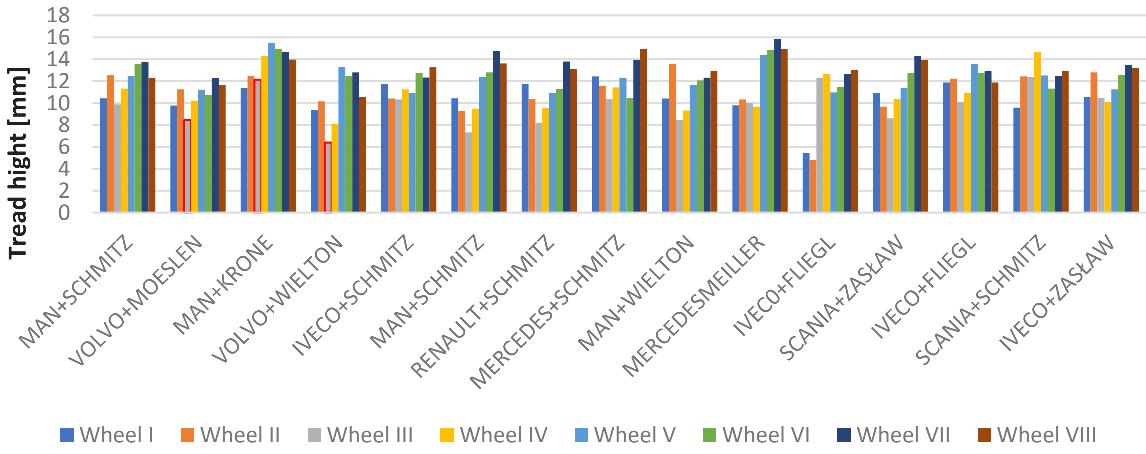
Table 6 and Figure 14 show the average values of the tire tread height of each wheel of the tested trucks and trailers in test III.

Tab. 6. The results of tread height measurements in a sample of category III vehicles

No.	Vehicle make	Type of bodywork	Average tyre tread height [mm]								
			Truck tractor				Trailer make	Trailer			
			Axle I		Axle II			Axle III		Axle IV	
			Wheel I	Wheel II	Wheel III	Wheel IV		Wheel V	Wheel VI	Wheel VII	Wheel VIII
1.	MAN	*Universal	10,43	12,53	9,87	11,32	SCHMITZ	12,48	13,57	13,74	12,32
2.	VOLVO	* Universal	9,77	11,24	8,44	10,21	MOESLEN	11,21	10,73	12,27	11,65
3.	MAN	Hook	11,37	12,48	12,13	14,27	KRONE	15,48	14,93	14,63	13,97
4.	VOLVO	* Universal	9,38	10,15	6,39	8,12	WIELTON	13,29	12,46	12,79	10,54
5.	IVECO	Hook	11,76	10,42	10,32	11,25	SCHMITZ	10,92	12,72	12,33	13,26
6.	MAN	Hook	10,43	9,28	7,32	9,49	SCHMITZ	12,38	12,79	14,76	13,62
7.	RENAULT	* Universal	11,76	10,39	8,21	9,54	SCHMITZ	10,92	11,31	13,79	13,11
8.	MERCEDES	* Universal	12,43	11,58	10,39	11,42	SCHMITZ	12,31	10,47	13,94	14,92
9.	MAN	* Universal	10,42	13,58	8,45	9,32	WIELTON	11,65	12,07	12,31	12,94
10.	MERCEDES	Hook	9,78	10,32	10,02	9,67	MEILLER	14,37	14,82	15,87	14,92
11.	IVECO	* Universal	5,43	4,80	12,31	12,65	FLIEG	10,97	11,45	12,65	13,02
12.	SCANIA	Hook	10,92	9,67	8,60	10,37	ZASŁAW	11,39	12,75	14,32	13,95
13.	IVECO	* Universal	11,88	12,23	10,12	10,93	FLIEGL	13,54	12,74	12,92	11,87
14.	SCANIA	* Universal	9,58	12,43	12,38	14,67	SCHMITZ	12,52	11,32	12,48	12,93
15.	IVECO	* Universal	10,53	12,79	10,48	10,09	ZASŁAW	11,24	12,58	13,49	13,21
Average			**10,37**	**10,92**	**9,69**	**10,88**	-	**12,30**	**12,42**	**13,48**	**13,02**
* Universal/Tarpaulin											

Source: Own study

Fig. 14. Comparison of tire tread height in a sample of category III vehicles

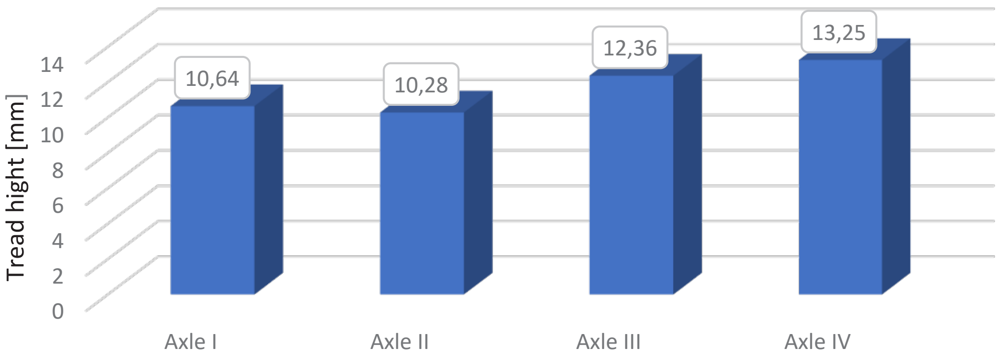


Source: Own study

Analysing the measurement results presented in Table. 6 and Figure 14, it should be noted that the greatest height of the tread had vehicle no. 10 on the fourth vehicle axle of the left wheel, 15.87 mm. The lowest value of the tread height, 4.80 mm, was found on the first axle of the right wheel in vehicle no. 11. From the data presented in Figure 15, it can be shown that the greatest wear occurs on the second axle of the car in the set. This is the drive axle. The difference in the tread height of the first axle to the second axle is 0.36 mm. In truck trailers, out of the two axles, the greatest wear occurs on the first axle, which is the steering axle of the vehicle. The difference with the second axle is 0.89 mm.

The results of the measurements in test III were grouped according to the axle numbers of the vehicle sets (4 axles). The average values of the tread height in each group were calculated. The calculation results are shown in Figure 15.

Fig. 15. The average height of the tread with a division into the axles of vehicles in the category III sample



Source: Own study

3.2. Operational damage forms

An organoleptic evaluation of the used tires was carried out. The following types of damage were distinguished:

1) external mechanical damage to the tread – cut
2) external mechanical damage to the tread – tear
3) external mechanical damage to the tire sidewall
4) mechanical structural damage – delamination of the structure
5) fatigue and aging damage to the structure
6) excessive wear of the tread – the conventional measure of limit wear means tread height ≤ 7 mm
7) uneven tread wear

Fig. 16. Examples of tread block cuts

Source: Own study

Fig. 17. Examples of cuts to the tread ribs

Source: Own study

Figures 16 and 17 show examples of cuts to the blocks and tread ribs caused by the use of tires on a stony surface or hitting a sharp object.

Figure 18 shows examples of tire sidewall damage caused by sharp edges of random objects on the road or by contact with elements of road infrastructure (kerbs).

Fig. 18. Examples of tire sidewall damage

Source: Own study

Figure 19 shows the places of the torn off tread fragments. They are probably the result of rapid starts and accelerations of a loaded vehicle leading to wheel slipping against the road surface.

Fig. 19. An example of tearing off a tread fragment

Source: Own study

Figure 20 shows an example of damage involving delamination of the tread. The cause of tread delamination is the use of a tire with too little pressure or with an excessive load. Another cause may be oxidization of the metal and rubber structural elements of the tyre.

Fig. 20. Example of delamination of the tread layer

Source: Own study

Figure 21 shows an example of fatigue and aging cracking of a tire after a long period of operation. Such damage can be accelerated by using too high a tire pressure or by not adjusting the vehicle load to the tire load index.

Fig. 21. An example of fatigue and aging cracks in a tire after long-term use

Source: Own study

Figures 22-24 show examples of emergency and uneven tread wear. Emergency wear (Figure 22) is understood as the size of the operational tread height loss, which exceeds the contractually or legally defined limit and is a wear that directly threatens road safety

Fig. 22. Examples of emergency tread wear

Source: Own study

Examples of uneven wear are shown in Figure 23 and Figure 24. Uneven tread wear can be caused by incorrect wheel geometry, faulty car suspension or incorrect tire pressure caused by overloading the vehicle or poor operator handling.

Fig. 23. Example of uneven tread wear

Source: Own study

Fig. 24. Example of uneven tread wear

Source: Own study

4. Discussing the research results

In total, the operational wear and tear of tires of 45 vehicles were analysed, including 15 single-segment vehicles with integrated bodies, 15 sets coupled with semi-trailers and 15 sets coupled with trailers.

The average results of tire tread height measurements in the three tested categories are presented in Table 7. The minimum allowable tread height of 1.6 mm is also marked.

Tab. 7. Average tire tread height by vehicle categories and axle number

Vehicles' category	Average tire tread height by category of individual vehicle groups (axle number) [mm]														
	Axle I			Axle II			Axle III			Axle IV			Axle V		
	Wheel I	Wheel II	Average	Wheel III	Wheel IV	Average	Wheel V	Wheel VI	Average	Wheel VII	Wheel VIII	Average	Wheel IX	Wheel X	Average
FIRST	12,36	12,53	12,44	9,78	10,08	9,33	13,41	13,24	13,32	11,66	12,21	11,93	-	-	
SECOND	10,54	11,25	10,89	9,07	9,43	9,25	11,40	12,07	11,73	8,05	12,49	10,27	5,87	5,84	5,85
THIRD	10,37	10,92	10,64	9,69	10,88	10,28	12,30	12,42	12,36	13,48	13,02	13,25	-	-	

Source: Own study

Based on the results presented in Table 7, it should be stated that the greatest wear occurs in the tires of the second and fifth axles in the groups of category II vehicles. The second axle is the driving axle. Also in the vehicles of category I, the second axle, which is the driving axle, is characterized by high tire wear. Similarly, in group III, the wear of the wheels of the second (driving) axle stands out. The lowest average value of the tread height, i.e. the highest tire wear, was found on the wheels of the fifth axle of vehicles, occurring only in semi-trailers, i.e. in the category II group. The average tread height of the fifth axle was 5.85 mm. This result may have been due to tire sideways slip under heavy load conditions. The highest value of their tread height (the lowest wear) is characteristic of the wheels on the third axle. Average wear values were 13.32 mm; 11.73mm; 12.36 mm – respectively for the group of vehicles of categories I, II and III. The reason for the low wear could be the low load on the third axle. It is worth noting that in vehicles of category II, the third axle was a liftable axle.

The next analysed issues were the type of damage and statistical indicators of damageability. The type of damage was evaluated organoleptically. In total, seven types of tire damage were distinguished (Table 8), according to the classification described in section 3.2. The percentage breakdown of the individual types of damage is shown in Figure 26. Table 8 also gives the values of the damage factor F_u calculated according to the formula (1) [8].

$$F_u = \frac{m}{n} \times 100\% \qquad (1)$$

where:
m is the number of damaged tires in the test sample (group)
n is the number of all tires in the test sample (group)

Tab. 8. List of types of damage and tire damage indicators

No.	Type of damage	Category I		Category II		Category III		In total		
		Number of damages m	Damageability F_u	Number of damages m	Damageability F_u	Number of damages m	Damageability F_u	Number of damages m	Damageability F_u	Division of damage types
		pcs.	%	pcs.	%	pcs.	%	pcs.	%	%
1.	Tread block/rib cut	16	14,3	9	6,0	3	2,5	28	7,3	30
2.	Tread element tearing	3	2,7	-	-	-	-	3	0,8	3
3.	Mechanical damage to the tire sidewall	1	0,9	-	-	2	1,7	3	0,8	3
4.	Tread delamination	2	1,8	-	-	-	-	2	0,5	2
5.	Fatigue and aging failure	-	-	-	-	2	1,7	2	0,5	2
6.	Excessive tread wear	7	6,3	23	15,3	2	1,7	32	8,4	35
7.	Uneven tread wear	5	4,5	11	7,3	6	5,0	22	5,8	25
	Total number of damages	34	30,5	43	28,6	15	12,6	92	24,1	100
	Number of tires tested n	112		150		120		382		

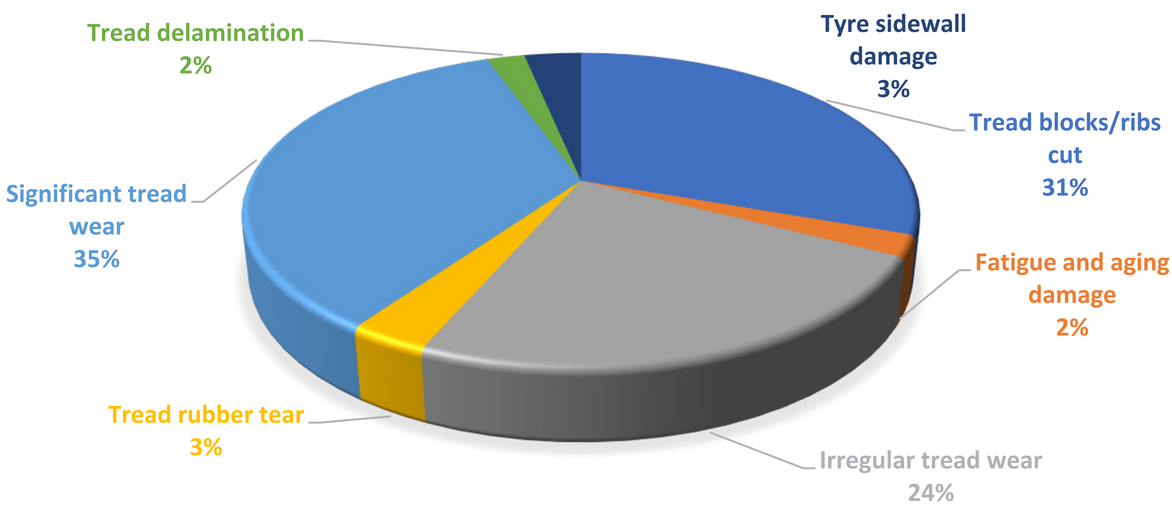
Source: Own study

The overall damageability was F_u = 24.1% with F_u (I) = 30,5% in the sample of category I vehicles (trucks with an integrated body), in the category II sample (tractors with a semi-trailer) F_u (II) = 28.6%. On the other hand, in the category III sample (lorries with a trailer), tire damageability was more than twice lower, F_u (III) = 12.6%. The reason for this difference may have been the severe operating conditions of category I and II vehicles (construction works).

The most common tire damage (Figure 25) was excessive tread wear – 35% of all damages. The highest damageability of this type occurred in the second category of vehicles F_u (II,6) = 15.3%, due to long-distance routes of vehicles with heavy loads. The second most frequent type of damage was cutting a block or tread rib (No. 1) – 28 cases, i.e. 30% of total damages. The third most common was uneven tire tread wear (No. 7). This damage occurred in 22 tires, i.e. 24% of the total number. It was probably caused by incorrect tire pressure or bad suspension geometry. The share of each of the other types of damage did not exceed 3% of the total number of damaged tires.

Irregular tread wear 24%

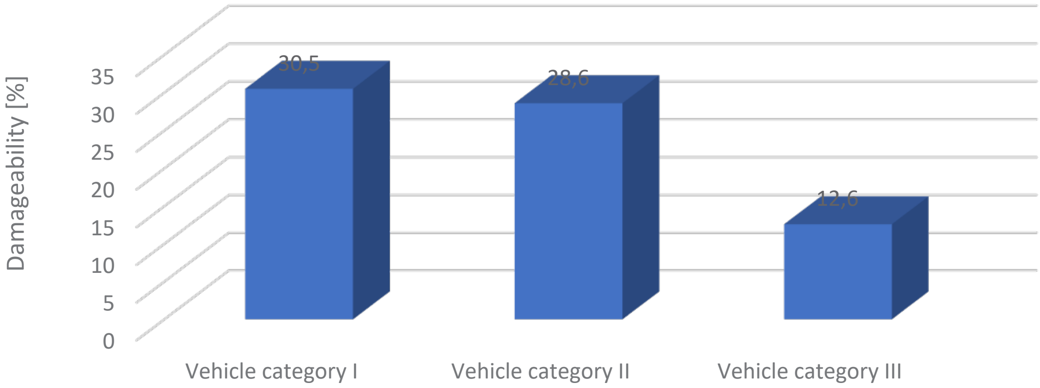
Fig. 25. Breakdown of tire damage types



Source: Own study

Figure 26 shows the damageability (failure rate) of tires in particular groups of vehicles covered by the tests. The highest failure rate F_u = 30.5% was recorded in the group of the first category in the sample of cars with an integrated body. The second group of vehicles was ranked second in terms of damageability F_u = 28.6%. In the third group of vehicles, which included a set of a truck with a trailer, a significantly lower failure rate F_u = 12.6% was registered.

Fig. 26. Diagram of tire damageability for individual vehicle categories



Source: Own study

5. Conclusions

Based on the experimental studies conducted, the following conclusions were formulated:

The most common type of damage to the truck tires in the examined groups of vehicles in general is excessive tread wear (35% of all damages). The next places in the damage frequency ranking are cuts in the tread (30%) and uneven wear of the tread (24%).

There is a large variation in the damageability of tires depending on the category of vehicles and their operating conditions. The highest failure rate F_u = 30.5% was found in the group of vehicles of category I, i.e. with an integrated body (mostly of the tipper type), performing transport on short routes related to construction works in respect to the number of kilometres driven by truck tractors with closed semi-trailers. A similarly high failure rate F_u = 28.6% was characteristic for vehicles of category II, i.e. tractor-semi-trailer combinations, mainly of the dumper type, performing transport on medium routes with heavy loads. In the first case, damage of the “cutting of the tread” type was dominant, in the second case, damage of the “excessive abrasion wear of the tread” type was dominant.

The damage rate of tires in the third group of vehicles engaged in long-distance transport of goods on smooth roads (sets – truck – universal trailer) was more than twice lower, F_u = 12.6%, than in the other groups.

The largest tire tread wear can be observed in multi-unit vehicles consisting of a truck tractor and a semi-trailer. This is due to long-distance transport, which translates into higher tire work intensity.

The test results showed that in semi-trailers with three axles, the third axle is the most exposed to tread wear. This is due to the sideways slip of the tire relative to the ground while rolling, causing rolling and sliding friction at the same time. In order to avoid this phenomenon a third steering axle in semi-trailers is used

Bibliography:

1. Bęczkowska S., Korzeb J., Koziak S., Opala M., Weyssenhoff A.: Niejednorodność i wady materiałowe opon samochodów osobowych, Zagadnienia Wybrane, Politechnika Warszawska, Wydział Transportu, 2018.
2. Chomka G., Chudy J., Kasperowicz M., Techniczne aspekty regeneracji opon samochodowych, Wyd ITE-PIB Radom 2012, s. 1-3.
3. Fedorko G., Molnar V., Dovica M., Toth T, Soos L, Fabianova J., Pinosova M., Failure analysis of irreversible changes in the construction of car tyres, Engineering Failure Analysis, Volume 104, 2019, Pages 399-408, ISSN 1350-630].
4. Fedujwar R. R., Sahoo U. Ch., Pavement responses under wide base tyres subjected to moving loads, International Journal of Transportation Science and Technology, 2022, ISSN 2046-0430, https://doi.org/10.1016/j.ijtst.2022.05.006.
5. Gorzelańczyk P.: Charakterystyka zużycia opon autobusów komunikacji miejskiej w mieście Piła, AUTOBUSY 12/2017.
6. Haq M. T., Zlatkovic M., Ksaibati K, Assessment of tire failure related crashes and injury severity on a mountainous freeway: Bayesian binary logit approach, Accident Analysis & Prevention, Volume 145, 2020, 105693, ISSN 0001-4575,].
7. Kamiński T. (red.) Polski transport samochodowy rzeczy. WKiŁ, Warszawa 2020.
8. Migdalski J. (red.) Poradnik niezawodności. Podstawy matematyczne. Wyd. Przemysłu Maszynowego WEMA, Warszawa 1988.
9. Niziński S., Michalski R. Diagnostyka obiektów technicznych. Wyd. ITE, Radom 2002.
10. Osiński J., Żach P. Wybrane zagadnienia recyklingu samochodów. WKŁ, Warszawa 2006.
11. PN-ISO 4000-1: Opony i obręcze do samochodów osobowych, Część 1, 2005.
12. Ustawa z dnia 20 Czerwca 1997 r. Prawo o ruchu drogowym (Dz.U.2020.0.110).
13. https://bcpw.bg.pw.edu.pl/Content/1456/Techniczny_poradnik_samochodowy_cz1_str632_Mechanika_pojazdow.pdf (dostęp 25.01.2021).
14. Zeng H, Xu W., Zang M., Experimental investigation of tire traction performance on granular terrain, Journal of Terramechanics, Volume 104, 2022, Pages 49-58, ISSN 0022-4898].

Piotr Cieślak
piotr.cieślak@ksp.policja.gov.pl
Warsaw Police Headquarters, Road Traffic Department

Daniel Pieniak
daniel.pieniak@wsei.lublin.pl
University of Economics and Innovation in Lublin, Faculty of Transport and Computer Science

Leszek Gil
leszek.gil@wsei.lublin.pl
University of Economics and Innovation in Lublin, Faculty of Transport and Computer Science

Artur Dmowski
artur.dmowski@wsei.lublin.pl
University of Economics and Innovation in Lublin, Faculty of Transport and Computer Science

Andrzej Niewczas
andrzej.niewczas@its.waw.pl
Motor Transport Institute

Attachments:

Attachment 1

TEST REPORT

Quantitative and qualitative assessment of the operational tire damage and wear on trucks.

Vehicle categories:
□ truck
□ truck tractor + semi-trailer
□ truck + trailer

Motor vehicle:

Make of motor vehicle -
Mileage -
Vehicle production year -
Number of axles - Number of steering axles - Number of driving axles -
Bodywork type -

Trailer/Semi-trailer:

Trailer/semi-trailer make -
Year of production -
Number of axles - Number of steering axles - Number of liftable axles -
Bodywork type –

Average tire tread height of motor vehicle/trailer (vehicle combination):

Average tire tread height on axle I:
– 1…………… 2…………….
Average tire tread height on axle II:
– 3…………… 4…………….
Average tire tread height on axle III:
– 5…………… 6…………….
Average tire tread height on axle IV:
– 7…………… 8…………….
Average tire tread height on axle V:
– 9…………… 10…………….
Average tire tread height on axle VI:
– 11………..… 12…………….
Average tire tread height on axle VII:
– 13…………. 14…………….

Description of the tire damage:
……
……
……
……
……
…………………………