ISSN 0208-7774 T R I B O L O G I A 2/2022 p. 79–88
DOI: 10.5604/01.3001.0015.9727

Piotr SZCZYGLAK[*], Jerzy NAPIÓRKOWSKI[**], Artur WODZYŃSKI[***]

METHOD FOR ASSESSING WINDSCREEN ABRASIVE WEAR

METODA OCENY ZUŻYCIA ŚCIERNEGO SZYB SAMOCHODOWYCH

Key words: wear, windscreen, safety.

Abstract: This study addresses safety issues surrounding windscreens use and identifies factors affecting the wear rate for windscreens and windscreen wiper blades. Moreover, it presents an original method for bench-testing the windscreen wear process. The method allows tests to be carried out under near-operational conditions. The paper also describes an automated bench equipped with an abrasive dispenser and methods for measuring windscreen wear. Tests were conducted for the effects of quartz sand, marine sand and electro-corundum on the windscreen. It was demonstrated for marine sand and electro-corundum that even the short-term effect of these forcings on the windscreen reduced light penetration to a level of 70%, i.e., a critical value for windscreens. The change in the roughness R_a value during the impact of quartz sand on the pane was characterised by a much greater variability compared to the interaction of marine sand and electro-corundum. It was also demonstrated that the condition of wiper blades was related to the roughness of the windscreen. The summary presents conclusions concerning the research method described and the study results.

Słowa kluczowe: zużycie, szyba samochodowa, bezpieczeństwo.

Streszczenie: W pracy omówiono problemy dotyczące bezpieczeństwa użytkowania szyb samochodowych. Zidentyfikowano czynniki wpływające na intensywność zużycia szyb i piór wycieraczek. Przedstawiono autorską metodę stanowiskowego badania procesu zużycia szyb samochodowych. Metoda pozwala na prowadzenie testów w warunkach zbliżonych do eksploatacyjnych. Opisano zautomatyzowane stanowisko wyposażone w dozownik materiału ściernego, a także sposoby pomiaru zużycia szyby. Przeprowadzono badania dla oddziaływania na szybę piasku kwarcowego, morskiego i elektrokorundu. W przypadku piasku morskiego i elektrokorundu wykazano, że nawet krótkotrwałe oddziaływanie na szybę tych wymuszeń powodowało spadek przenikalności światła do wartości 70%, co dla szyb samochodowych jest wartością krytyczną. Zmiana wartości chropowatości Ra w czasie oddziaływania na szybę piasku kwarcowego charakteryzowała się znacznie większą zmiennością w porównaniu do oddziaływania piasku morskiego i elektrokorundu. Wykazano także, że stan piór wycieraczek ma związek, z chropowatością szyby. W podsumowaniu przedstawiono wnioski dotyczące opisanej metody badawczej i wyników badań.

INTRODUCTION

The safe operation of a vehicle is largely determined by its technical conditions. Many of its components are subject to sudden or natural wear and tear, which necessitated the development of both new and rapid methods for assessing their technical condition. For example, for the vehicle braking system **[L. 1]** or suspension system **[L. 2]**, the methods developed to enable an unambiguous determination of the technical condition of these components to determine a vehicle's roadworthiness. Regarding

* ORCID: 0000-0002-8218-1540. University of Warmia and Mazury in Olsztyn, Department of Vehicle and Machine Design and Operation, M. Oczapowskiego 11 Street, 10-719 Olsztyn, Poland, email: piotr.szczyglak@uwm.edu.pl.
** ORCID: 0000-0003-2953-7402. University of Warmia and Mazury in Olsztyn, Department of Vehicle and Machine Design and Operation, M. Oczapowskiego 11 Street, 10-719 Olsztyn, Poland, email: jerzy.napiorkowski@uwm.edu.pl.
*** University of Warmia and Mazury in Olsztyn, M. Oczapowskiego 11 Street, 10-719 Olsztyn, Poland, email: artur.wodzynski@student.uwm.edu.pl.

windscreens, there are not clearly defined and commonly applied methodologies for assessing the technical condition. According to legislation applicable in many countries, a vehicle participating in road traffic must be constructed, equipped and maintained in such a manner to ensure a sufficient field of driver's vision.

Moreover, quantitative measures of the light penetration coefficient values are formulated for windscreens, with the coefficient required to be at least 70% for both the windscreen and other car windows. Under the previously existing regulations, the vehicle's windscreen had to exhibit a light penetration coefficient of at least 75%. Therefore, the requirements for windscreen transparency appear to have been formally reduced. Windscreens with a less than 70% light penetration coefficient should be replaced or repaired.

The occasionally improper synchronisation of fluid supply with the wiper movement and operating conditions connected with the dustiness of the environment may result in windscreens being subject to an intensive wear process during their operation. As the vehicle is moving, moving air masses force dust to move from the road surface to the windscreen. The main components of road dust include silica (SiO_2) and corundum (Al_2O_3), whose proportions range from 60% to 95%. Since these are compounds which, on the Mohs scale, have a hardness of 7 for silica and 9 for corundum, they are harder than glass and are able to scratch it. Apart from these compounds, road dust may also contain iron oxides (Fe_2O_3) at 1.18%–11.5%, calcium oxide (CaO) at 0.5–6.75% and magnesium oxide (MgO) at 0.35–2.83%. Dust grains are irregular in shape and have numerous sharp edges. In the process of windscreen use, the driver is forced to use wipers due to windscreen pollution. Their movement forces the movement of road dust grains in relation to the windscreen, and this is when intensive abrasive wear of the vehicle's windscreen occurs. An important factor affecting the rate of this process is the degree of windscreen wetting **[L. 3]**.

Many institutes in Poland and abroad conduct research to improve the visibility from the driver's seat or determine its level. A study by Sumarna **[L. 4]** presents a model allowing the windscreen cleaning efficiency factor to be estimated. Parameters characterising the wiper mechanism and windscreen sprinkling system were adopted as input data. The results presented are for calculations made for a Toyota Kijang KF80 vehicle. The determined cleaning efficiency was 63.92%. A study by Fagervail M. and Nyman M. **[L. 5]** also presents the results of testing for the efficiency of windscreen cleaning using wipers. The tests were conducted at a PLC-controlled bench.

Kajioka et al. **[L. 6]** were among the first to develop and implement an automatic windscreen wiper that detects raindrops using an optical rain sensor and controls the wiper operation frequency. The system can identify snow or ice on the windscreen and switch to manual control mode to protect the wiper blades. The presented wiper control system enables adjustment to atmospheric conditions and the degree of windscreen wetting to increase the life of the windscreen and the wiper blade due to the minimisation of the number of work cycles completed.

Automatic wiper control systems have been developed to date, as evidenced by a study by Alazzawi & Chakravarty **[L. 7]**. Compared to the first systems of this type, the changes are primarily oriented towards the application of more efficient control algorithms, which are often based on artificial intelligence (in this case, fuzzy logic). Similar systems were presented in studies by Abhilash Reddy P. et al. **[L. 8]**, Naresh P. and Hari Babu A.V. **[L. 9]**, Otchere P.K. et al. **[L. 10]**, and Nishant, K. et al. **[L. 11]**.

Windscreen strength tests are often carried out to confirm compliance with the applicable standards (UN Global Technical Regulation No 6 **[L. 12]**). An example of testing of this type is a paper by Kwang-bum L. et al. **[L. 13]**. Research work is also underway to determine the strength of windscreens exposed to extreme loads, and this issue was addressed by Spathonis J. **[L. 14]**. Another study by Pereverzev A.S. and Semenikhin B.A. **[L. 15]** presents the results of tests on windscreens protected against damage with pads. The authors demonstrated the effectiveness of this solution and a method for selecting the protection measure.

Moreover, tribological bench tests of wiper blades are also being carried out with a view to introducing new materials into their manufacture. A study by Bielawski D.M. et al. **[L. 16]** presents an example of this type of testing. It was demonstrated that the tribological properties of polymeric materials were not only determined by mechanical and rheological properties but also by their composition and structure.

Pronk et al. compiled a report presenting the results of studies carried out in various centres worldwide. They focused on demonstrating the relationship between windshield degradation and road safety. The work identifies glass damage caused by various factors. The relationship between glass degradation and the driver's perception has been demonstrated **[L. 17]**.

The presented analysis of the issue shows that several studies have been devoted to the issues of interaction between wipers and the windscreen, primarily in controlling the system to ensure adequate windscreen transparency. No studies have been found to describe the effect of environmental pollution with minerals on the abrasive wear course. Therefore, there is a need to develop a consistent method for assessing the degree of windscreen wear depending on the intensity of pollutant impact. The work aims to present a new method of testing the abrasive wear of car windows with the use of a prototype stand.

RESEARCH METHODOLOGY

The subject of the study was a regular, multilayer, laminated windscreen used in the Volkswagen vehicle Passat B5 (**Table 1**). The glass was melted at a temperature of approx. 1,000°C from components (sand at approx. 72%, sodium carbonate at approx. 13%, limestone at approx. 8%, dolomite at approx. 4%, aluminium oxide at approx. 1%, other additives at approx. 2%).

The windscreen interacted with an articulated wiper with a blade length of 0.28 m. The wiper blade was coated with a thin layer of graphite to increase its durability (reduction of friction between the windscreen and the blade). During the study, an active experiment option was adopted. The windscreen and the wiper blade as the subject of the study are presented in **Figure 1**.

Table 1. Specification of the tested glass
Tabela 1. Specyfikacja badanej szyby

No.	Parameters description		Description
1	Glass type		Windshield type (AS1, //) plain glass laminated front
2	Type of construction		M423
3	Homologations		E20, 43R-00340
4	Added properties of the glass	heat absorbing	No
		reflecting heat	No
		acoustic	No
		anti-glare	No
		hydrophore	No
		electrochromic	No

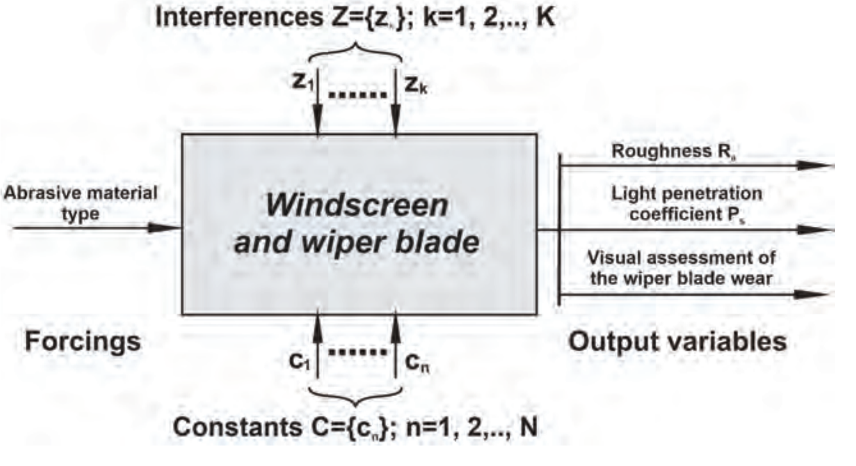


Fig. 1. Windscreen and wiper blade as the subject of the study
Rys. 1. Szyba i pióro jako przedmiot badań

The type of abrasive material fed gravitationally from the dispenser onto the windscreen was adopted as the forcing. The tests were conducted for three abrasives:

- quartz sand – the main component: quartz SiO_2, resistant to the effects of chemical and mechanical factors, with a high sintering point of 1200–1400°C, graining 0–0.5 mm, globular grain shape (**Fig. 2a**);
- marine sand – quartz SiO_2 with a sintering point exceeding 1710°C, sharp-edged shaped, graining 0.4-0.5 mm, globular and irregular grain shape (**Fig. 2b**);
- electro-corundum – chemical composition: Al_2O_3 – 94.5–96% and additives of TiO_2, SiO_2, FeO, CaO, MgO, graining 0.4-0.5 mm, sharp-edged shaped and polyhedral (**Fig. 2c**).

During the testing, the following output variables were observed:

- windscreen roughness R_a (mean arithmetic deviation from the mean line),
- light penetration coefficient P_s determined for the windscreen,
- wiper blade surface condition (the view of the surface magnified 200 times).

The set of constants during the testing included:

- c_1 – wiper blade length (l_p = 0.28 m),
- c_2 – wiper blade arm length (l_r = 0.53 m),
- c_3 – average set wiper mechanism operating speed ($v_r = 1.5$ cycles $\cdot$ s^{-1}),
- c_4 – average wiper blade linear speed set (v_p = 2.5 m $\cdot$ s^{-1}),
- c_5 – number of work cycles during which observations were made (i = 0, i = 1000, i = 2000, i = 3000, i = 4000, i = 5000),
- c_6 – control cycle time (t_c = 30 s),
- c_7 – abrasive feed time (t_s = 30 s),
- c_8 – washing-down water feed time (t_w = 15 s),
- c_9 – average abrasive feed rate (V_s = 0.2 $cm^3 \cdot cycle^{-1}$),
- c_{10} – average wash-down water feed rate (V_w = 1 $cm^3 \cdot cycle^{-1}$).

During the tests, the following disturbances occurred:

- z_1 – change in wiper mechanism operating speed due to varying resistance to the blade's movement,
- z_2 – abrasive feed irregularity,
- z_3 – wash-down water feed irregularity,
- z_4 – variable temperature and humidity in the room.

Fig. 2. A view of abrasives: (a) quartz sand, (b) marine sand, (c) electro-corundum
Rys. 2. Widok materiałów ściernych: a) piasek kwarcowy, b) piasek morski, c) elektrokorund

The windscreen was mounted in a tubular fram equipped with a wiper mechanism (**Fig. 3**). In order to improve the stability of blade movement in relation to the windscreen, one wiper arm was removed, and a blade shorter than that used for this windscreen model was applied, which allowed a significant power reserve of the entire drive system to be obtained. A CD motor controller with manual power output control was used to change the wiper blade movement speed.

During the tests, the abrasive was fed using a dispenser. It was equipped with a rotating diaphragm, which periodically blocked the discharge of abrasives from the dispenser basket. The dosing capacity was regulated by changing the rotational speed of the DC motor driving the shutter. The abrasive was thrown onto the glass by gravity at a location 5 cm above the place where the light transmittance and roughness coefficient were measured (**Fig. 3**). The material was sliding along the vertical axis of symmetry of the glass, which was inclined at an angle of 65° to the ground.

On the other hand, the water was fed using a pump with a fixed delivery rate (timer control from the master controller level). The control system was equipped with a master controller with an

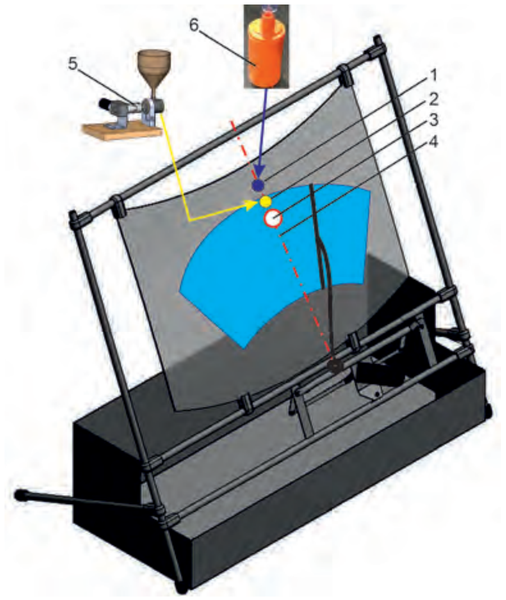


Fig. 3. A view of a model bench for windscreen testing: 1 – the place where the water is fed, 2 – place where the abrasive is fed, 3 – place of taking measurements, 4 – vertical axis of symmetry of the glass, 5 – abrasive dispenser, 6 – water pump

Rys. 3. Widok modelu stanowiska do badania szyb samochodowych: 1 – miejsce podawania wody, 2 – miejsce podawania ścierniwa, 3 – miejsce wykonywania pomiarów, 4 – pionowa oś symetrii szyby, 5 – dozownik ścierniwa, 6 – pompa wody

ATMega2560 processor interacting with an OLED display and a keyboard. Its task was to temporarily start the pump and the abrasive feeder and control the number of work cycles (after the completion of the declared number of cycles, the drive system was automatically stopped). The wiper drive system generated large amounts of heat (due to the lack of motor cooling airflow as found in a vehicle). For this reason, the control system was equipped with three temperature sensors operated by a software thread that prevents the system from overheating (temporarily pausing the bench operation). An incremental decoder was used to determine the wiper blade momentary speed (400 imp · revs^{-1}) and a Hall sensor to count the number of cycles. The system also has the capability to measure the current drawn by the wiper drive motor and to record selected process parameters on an SD memory card. The master controller can also transmit data to mobile devices, e.g., tablet or smartphone, via a Bluetooth module. **Figure 4** presents the structure of the testing process control system.

The control system was set to repeat the control cycle every 30 seconds. During this time, the abrasive dispenser operated continuously, and the wash-down water feeding pump was activated for

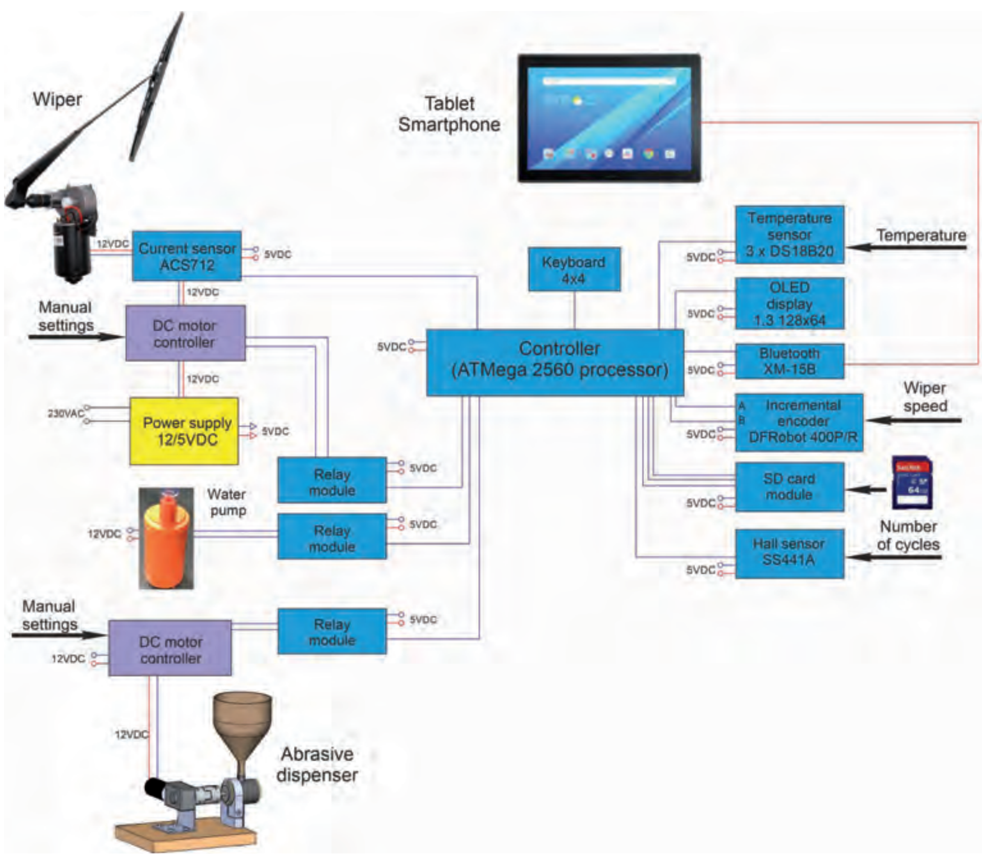


Fig. 4. The structure of the testing process control system

Rys. 4. Struktura układu sterowania procesem badania a period of 15 seconds during each control cycle. Prior to commencing tests for a particular abrasive type, the windscreen was ground with cerium oxide to achieve the same glass surface condition each time.

On the glass 5 cm below the upper edge of the wiper working area, a circle is drawn on the inside with a diameter slightly larger than that of the head for measuring the light transmission coefficient (**Fig. 3**). The vertical axis of symmetry of the circle coincides with the vertical axis of symmetry of the glass. The light transmission coefficient and roughness measurements were made in the same place (the centre of the defined circle). The measurement site was at the point where the glass was flattest.

Roughness R_a was measured using a Hommelwerke T1000 surface analyser, allowing roughness to be measured by the tracer method. The light penetration coefficient for the windscreen was measured using an AMX 710 glass transparency meter which is designed for car windows, including laminated ones. During the visual inspection of the wiper blade surface condition, an MDA1300W mobile digital microscope was used (magnified 200 times). The testing plan is presented in **Table 2.**

Table 2. Testing plan
Tabela 2. Plan badania

Item	Forcing	Number of work cycles completed	Measurements and analyses conducted		
			Roughness R_a	Light penetration coefficient P_s	Wiper blade surface condition
1	Quartz sand	0	x	x	x
		1000	x	–	–
		2000	x	–	–
		3000	x	–	–
		4000	x	–	–
		5000	x	x	x
2	Marine sand	0	x	x	x
		1000	x	–	–
		2000	x	–	–
		3000	x	–	–
		4000	x	–	–
		5000	x	x	x
3	Electro–corundum	0	x	x	x
		1000	x	–	–
		2000	x	–	–
		3000	x	–	–
		4000	x	–	–
		5000	x	x	x

EXPERIMENTAL TESTING AND RESULT ANALYSIS

The roughness values measured during the testing are presented in **Table 3**, and their graphical interpretation is in **Figure 5**. During the testing, changes in roughness were observed for subsequent measurements. For quartz sand, the initial roughness was 33% higher than the value measured for the maximum number of completed cycles. As for marine sand and electro-corundum, the situation was the opposite. For marine sand, roughness increased by 266%, and for electro-corundum, it increased by 14%. In all cases considered, the roughness initially increased and then decreased to a value below 12µm after reaching the maximum. Only for quartz sand, an almost eight-fold increase in roughness was noted, with a mean deviation for the results obtained of 0.18 µm. For marine sand and electro-corundum, the rate of changes was much lower, and the mean deviations obtained were 0.026 µm and 0.011 µm, respectively.

The values of the coefficient of light penetration through the windscreen measured during the tests are presented in **Table 4** with their graphical interpretation in **Figure 6**. Observation of the light penetration coefficient showed its decrease in all cases. The lowest decrease value was noted for quartz sand. In this case, the lowest roughness value was also noted after completing the maximum number of work cycles. As for marine sand and electro-corundum, the light penetration coefficient value decreases were at the same level (approx. 5%).

It should be noted that the light penetration coefficient for the windscreen should be at least 70%. Therefore, in all cases considered, the windscreen met this requirement, and after the completion of the maximum number of cycles, the reserve of this coefficient value was at a safe level only for quartz sand. In two other cases, these values are dangerously approaching the limit beyond which the windscreen should be either replaced or repaired.

Table 3. Roughness R_a values measured
Tabela 3. Zmierzone wartości chropowatości R_a

Item	Forcing	Number of work cycles completed					
		0	1000	2000	3000	4000	5000
1	Quartz sand	0.06 µm	0.40 µm	0.55 µm	0.11 µm	0.06 µm	0.04 µm
2	Marine sand	0.03 µm	0.05 µm	0.07 µm	0.08 µm	0.12 µm	0.11 µm
3	Electro-corundum	0.07 µm	0.07 µm	0.09 µm	0.10 µm	0.10 µm	0.08 µm

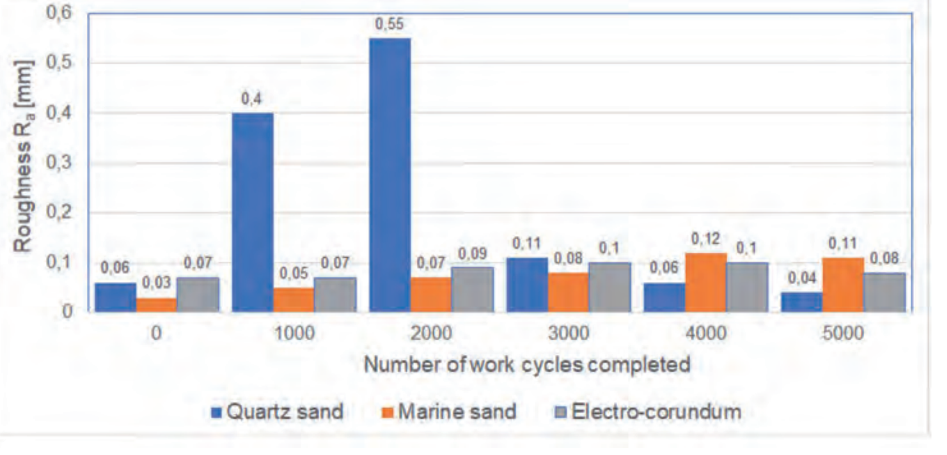
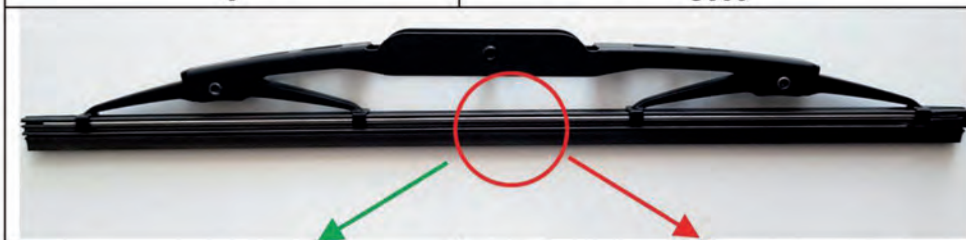
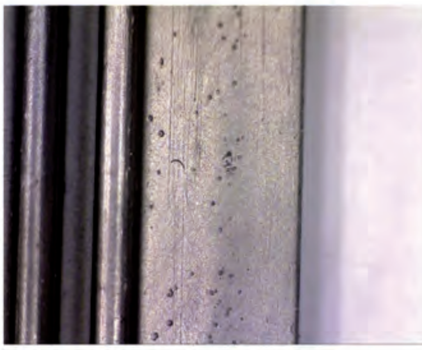
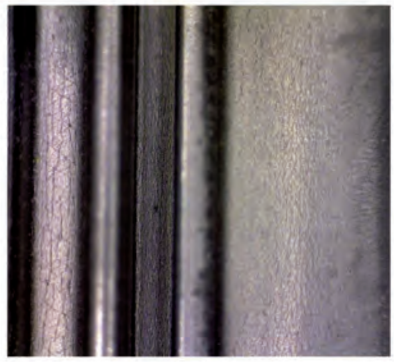
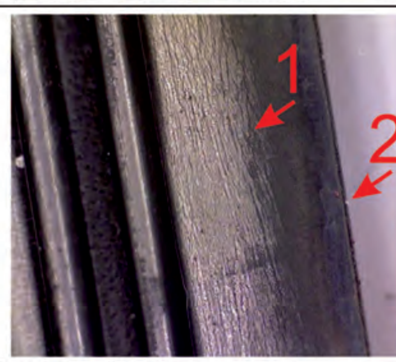


Fig. 5. Graphical interpretation of the roughness R_a values measured
Rys. 5. Interpretacja graficzna zmierzonych wartości chropowatości R_a

Table 4. The values of the coefficient of light penetration through the windscreen P_s
Tabela 4. Zmierzone wartości współczynnika przenikania światła przez szybę P_s

Forcing	Number of work cycles completed		Difference
	0	5000	
Quartz sand	75.80%	75.20%	0.60%
Marine sand	75.80%	70.50%	5.30%
Electro-corundum	75.30%	70.30%	5.00%

Table 5. Specification of views of wiper blades magnified 200 times
Tabela 5. Zestawienie widoków piór wycieraczek powiększonych 200 razy

Item	Forcing	Number of work cycles completed	
		0	5000
			
1	Quartz sand		
2	Marine sand		
3	Electro-corundum		
1 – local scratches 2 – grains stuck into the edges of the wiper blade 3 – local cavities 4 – grains stuck in the wiper blade			

Photographs of wiper blades taken during the tests at 200 times magnification are presented in **Table 5**. A visual inspection of the wiper blades showed that only for quartz sand had the graphite coating of the blade not been significantly damaged (minor wear marks on the edge). For marine sand and electro-corundum, significant damage occurred. The graphite coating wore down from the blade edge towards the joint, and the coating loss amounted to approx. 50% of its surface. For

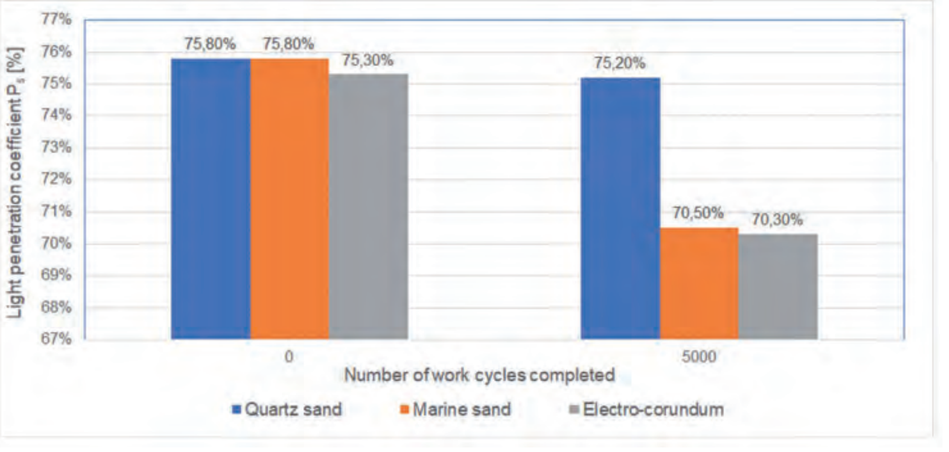


Fig. 6. Graphical interpretation of the light penetration coefficient P_s values
Rys. 6. Interpretacja graficzna zmierzonych wartości współczynnika przenikania światła P_s

quartz sand, the blade initially held the abrasive significantly more poorly. A more frequent exchange of grains resulted in the windscreen being scratched by new sharp-edged particles.

For this reason, there was a significant increase in windscreen roughness. As the blade wore down, the quartz grains were held more efficiently; therefore, the blunting of sharp edges and the grinding-in of the windscreen occurred. For marine sand and electro-corundum, the wiper blade wear was more intensive, and the increase in holding the abrasive occurred much sooner.

The wear of the wiper blade took the following forms:

- uartz sand – smoothing the surface, no grains that have stuck to the surface of the feather.
- Marine sand – smoothing the surface and its local drawing (**Tab. 5/1**), a few visible grains stuck into the surface of the feather, mainly located on its edge (**Tab. 5/2**).
- Electro-corundum – smoothing the surface of the wiper and local losses after tearing out the nested grains (**Tab. 5/3**), numerous visible grains stuck into the entire surface of the blade (**Tab. 5/4**).

SUMMARY

This study proposes an original bench for testing windscreen abrasive wear. This enabled an analysis of the wear process of windscreens used under dusty conditions (dirt roads) or under conditions where the fluid is not applied prior to the wipers' movement. Based on the results obtained, it was found that the wear rate for windscreens is primarily affected by the type of abrasive that enters between the wiper blade and the windscreen, the condition of the wiper blades and the degree of windscreen wetting.

The tests conducted allowed the following conclusions to be drawn:

- The effects of various abrasives result in different courses of the windscreen wear process.
- The effect of quartz sand, commonly found on roads, on the wear of the windscreen occurs with particular intensity in the initial period of windscreen wiper use (up to 2000 cycles). The process of significant roughness reduction follows this. This indicates the completion of the process of grinding-in of the "wiper – windscreen" tribological system. Therefore, the use of new wipers is each time associated with the performance of the grinding-in process.
- The significant effect of sharp-edged marine sand and electro-carborundum on the windscreen results in a gradual increase in the windscreen roughness up to 3000 cycles. The stabilisation of roughness follows this at a significantly lower level than for quartz sand. It also contributes to a reduction (in the short term) of light penetration coefficients to a level approaching 70%, which is a critical value for windscreens.
- The decrease in roughness after 2,000 cycles was caused by intensive wear as a result of the running-in process of the tribological system of the wiper-car window. In the initial phase, the protective coating applied to the pen mainly

held the sharp-edged grains, which, acting on the glass, caused an increase in roughness as a result of wear by scratching and micro-cutting. At a later stage, the process of overlapping drawing and cutting and cutting unevenness (smoothing) takes place, leading to a reduction in roughness.

- The rapid wear of the wipers in the case of electro-corundum and marine sand is related to the shape of the grains. Quartz sand had the most regular and similar oval grains, which resulted in rolling the grains along the glass and their partial slip; in the case of other abrasives, the rolling phenomenon was much less frequent in favour of sliding.

REFERENCES

1. Kuliś E., Żółtowski B.: Badania układów hamulcowych. Studies & Proceedings of Polish Association for Knowledge Management 2011, no. 47, pp. 126–140.
2. Gardulski J.: Metody badań amortyzatorów samochodów osobowych. Diagnostyka 2009, 3(51), pp. 93–100.
3. Dziubak T.: Zanieczyszczenia płynów eksploatacyjnych i ich wpływ na zużycie elementów silnika spalinowego pojazdu mechanicznego. Wojskowa Akademia Techniczna. Archiwum Motoryzacji 2016, 72(2), pp. 43–72.
4. Sumarna N.: Evaluation of the performance of front winshield wipers on land transport safety. International Refereed Journal of Engineering and Science (IRJES) 2013, vol. 2, issue 4 (April 2013), pp. 07–14.
5. Fagervail M., Nyman M.: Optimal windshield cleaning performance. Master's Thesis. 2000, 49. ISSN: 1402-1617.
6. Kajioka H., Fujimura K., Fujita Y.: Automatic wiper controller using optical rain sensor. FUJITSU TEN Tech. J. 1989, no. 2, pp. 69–79.
7. Alazzawi L., Chakravarty A.: Design and implementation of a reconfigurable automatic rain sensitive windshield wiper. International Journal of Engineering & Technology Sciences, April 2015, pp. 73–82.
8. Abhilash Reddy P., Sai Prudhvi G., Surya Sankar Reddy P.J., Subashka Ramesh S.S.: Automatic rain sensing car wiper. International Journal of Advance Research. Ideas and Innovations in Technology 2018, vol. 4, issue 5, pp. 657–661.
9. Naresh P., Hari Babu A.V.: Automatic rain-sensing wiper system for 4-wheeler vehicles. Journal Of Advancement In Engineering And Technology 2015, vol. 3, issue 4, pp. 1–5.
10. Otchere P.K., Owusu D.K., Otchere A.A.: Design and implementation of automatic rain sensing car wiper. International Journal of Emerging Technology and Innovative Engineering 2016, vol. issue 11, pp. 407–433.
11. Nishant K., Mohit K., Amit S., Vipul P.: Automatic rain operated wiper system in automobile: a review. International Journal for Scientific Research & Development 2015, vol. 3, issue 02, pp. 121–123.
12. UN Global Technical Regulation No. 6. Safety glazing materials for motor vehicle and motor vehicle equipment, 12 March 2008.
13. Kwang-bum L., Hae-boung K., Ho-soon A., Sang-woo J.Y., Young-sam S.: A study on toughened glass used for vehicles and its testing methods 2015, Paper Number 15-0152, pp. 1–8.
14. Spathonis J.: Report on testing to determine impact resistance of vehicle windscreens-overpass screening project. The State of Queensland. Department of Main Roads 2001.
15. Otchere P.K., Owusu D.K., Otchere A.A.: Design and implementation of automatic rain sensing car wiper. International Journal of Emerging Technology and Innovative Engineering 2016, vol. 2, issue 11, pp. 407–433.
16. Bielinski D.M., Glab P., Slusarski L.: New approach to study tribological properties of polymer materials. A case of car windshield wipers. Journal of Achievements in Materials and Manufacturing Engineering 2006, vol. 15, issue 1-2 March-April 2006, pp. 71–78.
17. Pronk N., Files B., Lenne M., Truedsson N., Olsson T.: Windscreens and Safety: A Review. Monash University Accident Research Centre – Report No. 183, 2001.