Evaluation of the protective and ergonomic properties of polymer gloves under conditions of exposure to chemicals

Klaudia Halicka[1), *)] (ORCID ID: 0009-0005-1346-8651), **Julia Jakubaszek**[2)], **Emilia Irzmańska**[1)] (0000-0001-8138-5552), **Magdalena Płocińska**[1)] (0000-0003-2335-2490)

DOI: https://doi.org/10.14314/polimery.2025.7.7

Abstract: This study evaluated the protective and ergonomic properties of three types of polymer gloves — chloroprene-latex (C I), chloroprene (C II), and nitrile (N) — under exposure to methanol. Tests included chemical permeation, chemical degradation resistance, bending stiffness, thickness measurements, and scanning electron microscopy (SEM). Results showed notable differences in normalized breakthrough time (NBT) between materials: C II exhibited the highest resistance (70 min), C I – 25 min, and N – 15 min. Degradation testing revealed an increase in hardness for C I, while C II and N experienced mechanical weakening, most pronounced in nitrile gloves. All gloves displayed increased stiffness after methanol exposure, potentially impairing user comfort and dexterity. SEM analysis revealed micropores and microcracks undetectable macroscopically but capable of enabling chemical penetration. Chloroprene gloves (C II) offered the best balance between chemical resistance and mechanical durability, with a recommended safe use time of approximately 70 minutes. The findings emphasize the need for integrated assessment of permeation and degradation parameters under realistic workplace conditions.

Keywords: polymer gloves, chemical exposure, degradation against chemicals, protective gloves.

Ocena właściwości ochronnych i ergonomicznych rękawic polimerowych w warunkach narażenia chemicznego

Streszczenie: Celem pracy była ocena właściwości ochronnych i ergonomicznych trzech typów rękawic polimerowych — chloroprenowo-lateksowych (C I), chloroprenowych (C II) oraz nitrylowych (N) — w warunkach kontaktu z metanolem. Badania obejmowały testy przenikania ciekłych sustancji chemicznych, odporności na degradację chemiczną, pomiary sztywności na zginanie, zmian grubości oraz analizę mikrostruktury za pomocą SEM. Wykazano istotne różnice w czasie przebicia (NBT) pomiędzy materiałami: C II cechowały się najwyższą odpornością (70 min), C I – 25 min, a N – 15 min. Testy degradacji ujawniły zwiększenie twardości w przypadku C I oraz osłabienie mechaniczne C II i N, szczególnie widoczne w rękawicach nitrylowych. Wszystkie materiały wykazywały wzrost sztywności po ekspozycji, co może pogarszać ergonomię użytkowania. Analiza SEM ujawniła mikropory i mikropęknięcia, które nie były widoczne makroskopowo, ale mogą stanowić drogi przenikania substancji chemicznych. Najlepszą równowagę między odpornością chemiczną a trwałością mechaniczną wykazały rękawice C II, przy zalecanym maksymalnym czasie użytkowania ok. 70 minut. Wyniki podkreślają konieczność łącznej oceny parametrów przenikania i degradacji w realnych warunkach pracy.

Słowa kluczowe: rękawice polimerowe, narażenie chemiczne, środki ochrony rąk, degradacja chemiczna.

Chemical exposure poses significant risks in the workplace, often due to improperly selected protective measures. Inadequate protection may cause serious health effects [1]. While technical and organizational solutions should take precedence, personal protective equipment (PPE), including gloves, serves as a necessary complement when full hazard elimination is not feasible [2]. Protective gloves are among the most widely used PPE against harmful chemicals, and their effectiveness depends on the material's resistance to chemical permeation [3–5]. Common glove materials include natural rubber, neoprene, nitrile, butyl, Viton, PVC, and multi-

---

[1)] Central Institute for Labor Protection – National Research Institute, ul. Czerniakowska 16, 00-701 Warszawa, Poland.

[2)] Faculty of Chemistry, University of Lodz, ul. Tamka 12, 91-403 Łódź, Poland.

[*)] Author for correspondence: klaha@ciop.lodz.pl

layer laminates. While thicker gloves offer better chemical resistance, they may compromise dexterity and ergonomics, increasing accident risk [2].

Ergonomic comfort is essential for effective glove use. Regular assessment of both protective and functional properties supports workplace safety [6]. However, laboratory tests often fail to replicate real-use conditions, where gloves are simultaneously exposed to heat, moisture, mechanical stress, and diverse chemicals, including sweat and complex mixtures. Despite the relevance of this issue, few studies evaluate glove performance under multifactorial, real-world exposures [7]. This gap highlights the need for research into glove durability and protective efficiency in practical settings.

Chemical degradation of polymeric materials involves structural and physicochemical changes that impair performance in hazardous environments [8]. Irzmańska et al. [9] demonstrated varied glove performance against inorganic compounds. While most materials effectively resisted sodium hydroxide and sulfuric acid (VI), degradation was more pronounced with hydrogen peroxide, especially in latex and neoprene. Polyacrylonitrile gloves offered the least protection. Mechanical integrity was unaffected by sodium hydroxide exposure, and no significant surface degradation was observed.

A key protective parameter is breakthrough time - the duration before a chemical permeates glove material, typically evaluated in accordance with EN ISO 374 standard. These tests are conducted at room temperature with continuous exposure to a defined substance. However, they do not reflect real conditions such as elevated temperatures or mechanical stress, which may accelerate permeation. Additionally, variations in glove composition even among similarly labeled materials affect resistance. Notably, chemical migration may continue after exposure ends, extending the risk [4].

Nelson and Phalen [10] discuss the selection and properties of protective gloves with respect to chemical resistance and emphasize that the resistance of gloves is strongly dependent on the composition of the polymer and the type of chemicals, and that permeation tests are usually conducted only with selected representative substances from each group. They point out errors in use, e.g., using the wrong gloves, exceeding the permeation time, and the imperfection of current testing standards.

Phalen and Wong [11] conclude that simulated hand movement significantly accelerates chemical permeation through disposable nitrile gloves, highlighting the importance of considering dynamic conditions in glove selection and testing. The variability among different glove products underscores the necessity for careful evaluation of glove performance under realistic usage scenarios.

In practice, defining safe glove usage duration is critical. Studies confirm that combined chemical and mechanical stress significantly reduces glove longevity [12, 13]. Effective glove selection should consider chemical concentration, exposure form, duration, and mechanical risks [13, 14].

Given these limitations, this study presents preliminary findings on the behavior of neoprene and nitrile gloves exposed to methanol, aiming to inform future research on glove performance in realistic, multifactorial conditions.

EXPERIMENTAL PART

Materials

The study was conducted on commercially available protective glove materials made of polychloroprene rubber (neoprene) and polyacrylonitrile rubber (nitrile). Detailed material specifications are presented in Table 1.

For the permeation, determination of resistance to degradation by chemicals and determination of bending stiffness, methanol (CH_3OH) (Chempur, Piekary Śląskie, Poland) was used.

Table 1. Description of materials used in the preparation of protective gloves

Material	Characteristics
Chloroprene + latex (C I)	Reusable protective gloves Composite material: chloroprene rubber (neoprene) and natural rubber latex, flocked Manufacturer: Nitras Safety, Germany
Chloroprene (C II)	Reusable protective gloves Composite material: chloroprene rubber, lined with velour Manufacturer: Nitras Safety, Germany
Nitrile (N)	Disposable protective gloves Composite material: polyacrylonitrile rubber Manufacturer: AMPri, Germany

Methods

Open-loop chemical permeation testing

Chemical permeation tests were performed according to EN 16523-1:2015+A1:2018 using an open system with gas chromatography and flame ionization detection (GC-FID). The setup included a nitrogen generator (NG 2081, Alltech), air compressor, and hydrogen generator (SPE 300HC, Union Space International, Ltd.) to operate the FID. Gas flow was controlled by a precision rotameter (33–833 cm^3/min).

The central measuring unit was a LABC.de permeation cell, with liquid dosing via a Thermo Scientific ORION M365 syringe pump. System calibration was done using a 10 mm^3 Hamilton microsyringe. Chromatographic analyses were conducted with an ATI Unicam 610 Series GC-FID.

Samples were mounted in the cell to separate the chemical from the collecting medium. Permeated substance concentrations were monitored over time, with

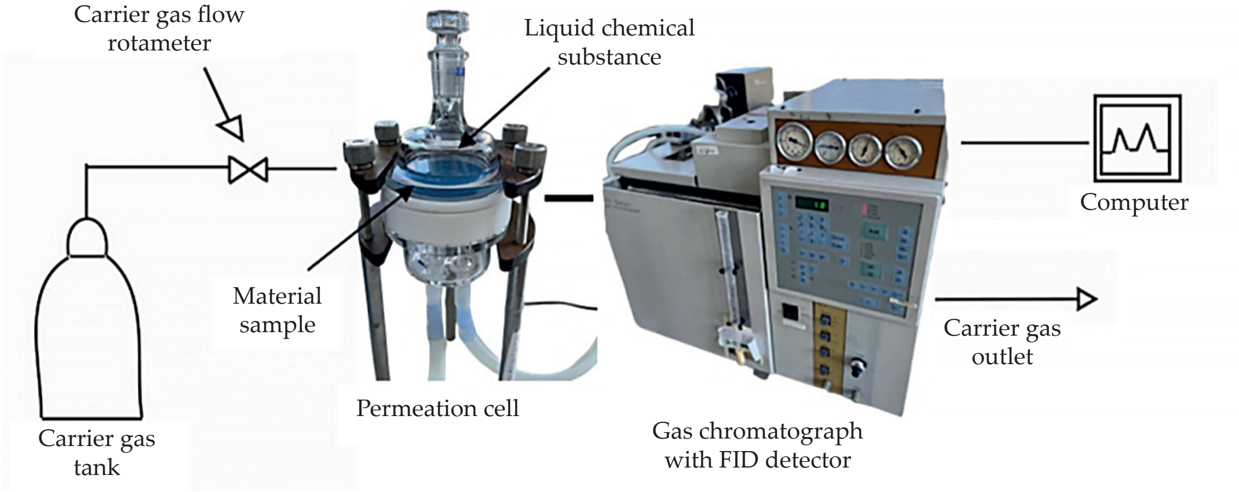


Fig. 1. Schematic diagram of the apparatus for permeation testing

breakthrough time indirectly determined by chromatographic peak height, corresponding to a permeation rate of 1 μg/(cm²·min). Based on a flow rate of 350 cm³/min and sample area of 20.42 cm², the threshold concentration was calculated as 0.058 μg/cm³ using Equation 1.

$$C = \frac{A \cdot P}{F} \tag{1}$$

where: P – permeation rate [μg/(cm²·min)], C – threshold concentration, F – flow rate of the collecting medium (350 cm³/min), A – exposed surface area of the material sample (20.42 cm²).

Tests were conducted under controlled conditions. The test substance was vaporized in an unfilled capillary at 200°C. Injector and FID temperatures were set at 200°C and 250°C, respectively. Nitrogen carrier gas flowed at 54–56 cm³/min. The FID, operated at 1 V and medium sensitivity, detected the analyte. Ambient temperature was maintained at 23±1°C, with data collected every minute. The collecting medium was air at 350 cm³/min. The schematic diagram of the apparatus is shown in Figure 1.

Study of the determination of resistance to degradation by chemicals

The PN-EN ISO 374-4:2020-03 method for assessing chemical degradation resistance involves two stages under controlled lab conditions (23±2°C). First, a 20 mm diameter glove material sample is exposed continuously for 1 hour to the test chemical inside sealed vials to prevent environmental changes. The sample is sealed with a septum

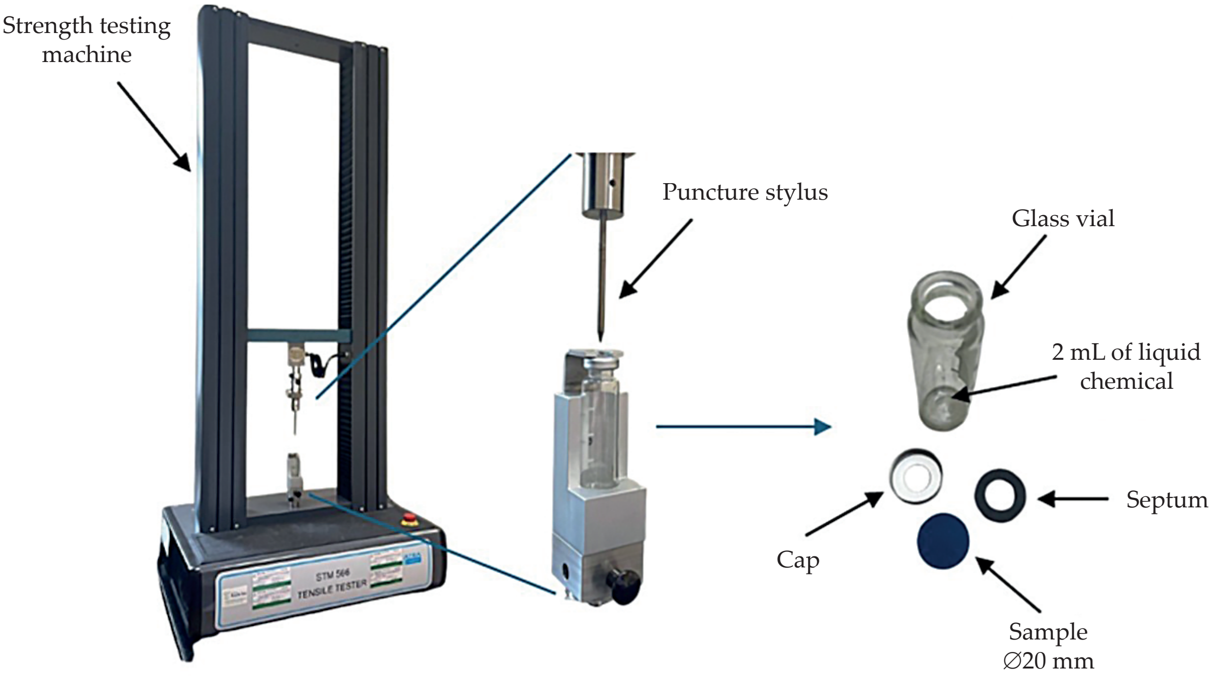


Fig. 2. Apparatus for determining resistance to degradation by chemicals

featuring a 12 mm hole. In the second stage, the puncture force of the material is measured before and after exposure using a setup with a stylus moving at 100 mm/min over a 100 mm distance. The peak force is recorded to the nearest hundredth of a newton [N]. A schematic representation of the apparatus is presented in Figure 2.

Puncture resistance testing machine

Three samples from three different gloves are tested. The change in average puncture force is calculated relative to the initial value and expressed as a percentage using Equation 2.

$$D_R = \left(\frac{OP - RP}{OP}\right)\cdot 100\,\% \qquad (2)$$

where: D_R is the degradation of the glove material against challenge chemical evaluated, OP is the average puncture force before exposure, and RP is the average puncture force after exposure.

After testing and drying, samples are visually inspected for surface changes such as shrinkage, crumbling, peeling, swelling, hardening, discoloration, cracking, or delamination.

Macroscopic observation of the surface

The surface of the chemically degraded glove material was examined using a stereomicroscope at 7× magnification (OPTA-TECH SK series, Warsaw, Poland).

Bending stiffness angle test

This study evaluated the bending stiffness of glove materials as an indicator of ergonomic performance, using the fixed-angle method based on the PN-73/P-04631 standard. Four samples per material (30×300 mm) were evaluated. Each sample was placed on the device's horizontal edge with its end aligned to an inclined plane. The metal ruler was placed on the edge of the sample and moved until the free end contacted the ramp. The overhanging length was recorded with 1 mm accuracy. The test setup is shown in Figure 3. Measurements were taken for both new and methanol-exposed gloves. Results were expressed as bending stiffness (mNm) and flexural modulus (MPa), reflecting resistance to elastic deformation, and offering a mechanical parameter linked to glove comfort and polymer flexibility over time.

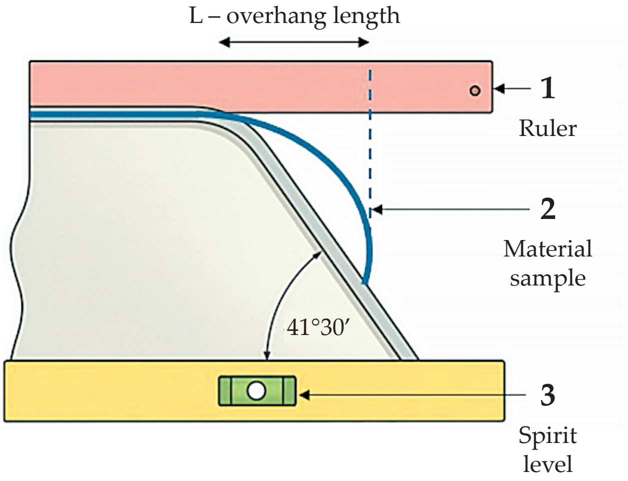


Fig. 3. Schematic diagram of the device and the bending stiffness testing procedure

Thickness

The chemical resistance of gloves made from the same material improves with increasing material thickness, as confirmed by experimental studies involving various substances [4]. Glove thickness measurements were carried out using a thickness gauge in accordance with the PN-ISO 37:2007 standard, applicable to rubber and elastomers with a hardness ≥ 35 IRHD.

Scanning electron microscopy

A Hitachi SU-8010 scanning electron microscope (SEM) was used for the observation of polymer glove materials. Glove samples were mounted on aluminum stubs using carbon adhesive and left to dry, then sputter-coated with 7 nm layer of gold using a high-vacuum sputter coater (Quorum Technologies LTD, Q150 T). For quantitative analysis, the microscope's measurement capabilities were utilized, and the measurements were performed *in situ* during observation.

RESULTS AND DISCUSSION

Permeability of chemicals using an open system

The breakthrough time of methanol through glove materials depends on the type of polymer used in their construction. Preliminary tests were also conducted using latex and butyl gloves. However, due to the observed results - complete lack of resistance in the case of natural rubber and extremely high resistance in the case of

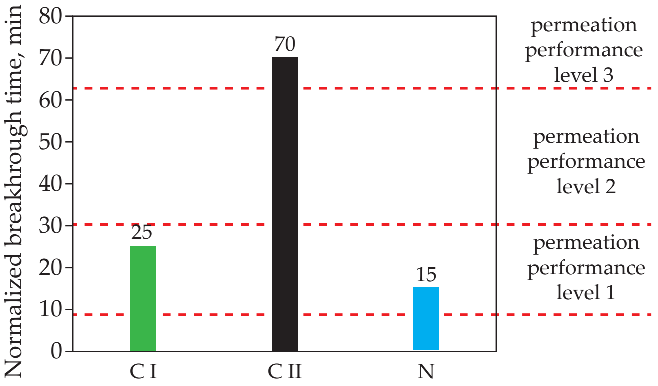


Fig. 4. Breakthrough detection time of the samples

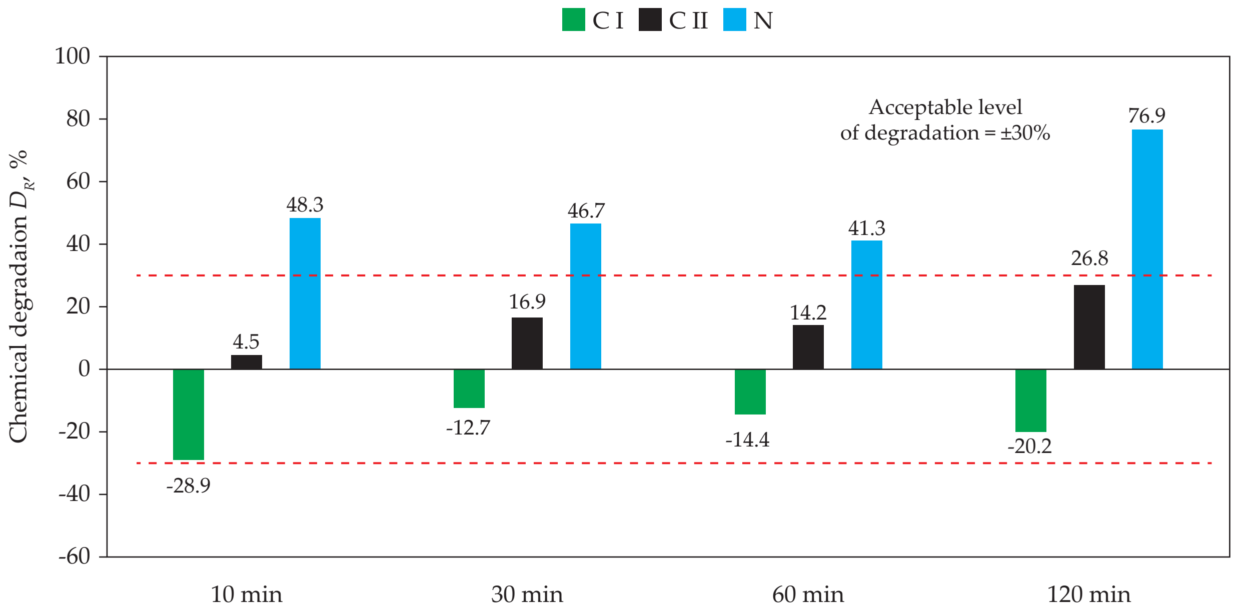


Fig. 5. Resistance to chemical degradation of glove materials exposed to methanol. Where: ±30% – the conventional threshold for acceptable degradation level established during the VG5 summit – an international group of experts working to harmonize standards and testing practices for chemical-resistant gloves and other protective materials

butyl rubber, chloroprene rubber (two glove models) and nitrile rubber (one glove model) were selected for further testing. The results obtained are presented in Figure 4.

The resistance of protective gloves to the permeation of liquid chemical substances was evaluated based on the measurement of a standardized parameter known as the normalized breakthrough time (NBT). This parameter corresponds to a normalized permeation rate (NPR) of 1 μg/(cm^2 · min). The interpretation of the obtained NBT is presented in Table 2.

The tests were conducted on samples taken from three individual gloves of each type, and the lowest determined breakthrough time was reported. Although gloves C I and C II are made of the same base material (neoprene), they exhibit different resistance to methanol permeation. The N-type gloves (nitrile) demonstrated the lowest resistance to methanol. According to Table 2, both C I and N gloves achieved level 1 of methanol permeation resistance, with breakthrough times of 25 and 15 min, respectively. In contrast, C II gloves reached level 3, with methanol breakthrough occurring after 70 min.

Table 2. Performance levels of protection against chemical penetration through the material

Measured breakthrough time, min	Permeation performance level
> 10	1
> 30	2
> 60	3
> 120	4
> 240	5
> 480	6

Chemical degradation caused by exposure to liquid chemicals

The results obtained from the chemical degradation test, with changes in relation to the test time, is presented in Fig. 5.

Gloves C I exhibited negative degradation, as the puncture force increased after methanol exposure, indicating material hardening. Although degradation remained within acceptable limits and was similar after 10 min and 2 h, permeation results suggest their safe use should not exceed 25 min. In contrast, gloves C II showed positive, time-dependent degradation, with a progressive decline in puncture resistance as exposure time increased. N-type gloves experienced the most severe degradation – nearly 50% within 10 min. Despite a permeation time of 15 min, the early loss of mechanical integrity may lead to rapid failure and increased risk of chemical penetration and skin exposure.

Macroscopic observation of the surface

The results of observation of glove material samples after puncture, before and after methanol degradation are shown in Figure 6.

Bending stiffness

Bending properties of tested gloves are presented in Table 3.

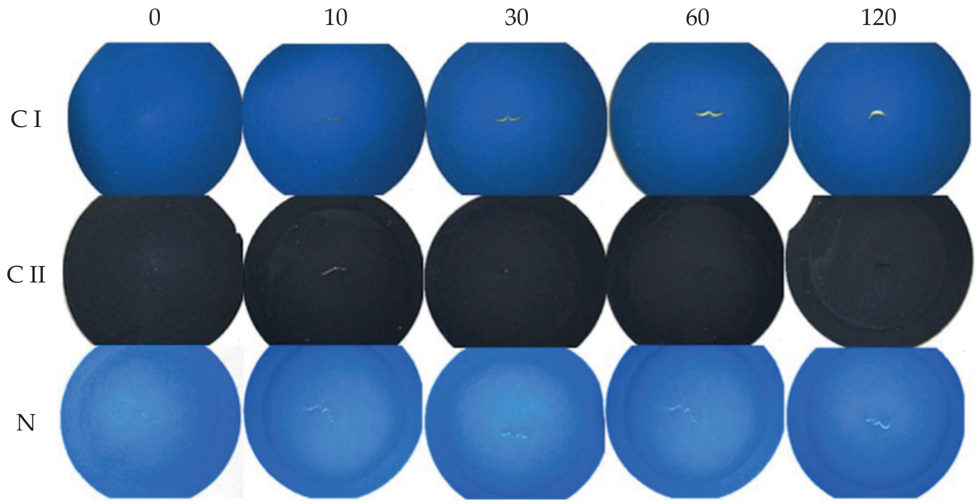


Fig. 6. Stereoscopic microscopic images of the tested samples

T a b l e 3. Bending properties of tested gloves

Sample	Methanol-induced degradation time min	Overhang length mm	Surface mass g/m^2	Bending stiffness mNm	Flexural modulus MPa
C I	0	248	614.8	11.50	270.5
	10	254	574.0	11.50	270.6
	30	366	591.9	34.50	828.0
	60	402	578.8	46.10	1202.6
	120	406	620.2	50.90	1245.9
C II	0	342	682.3	33.45	802.9
	10	368	825.4	50.40	1008.0
	30	394	889.6	61.90	1198.1
	60	412	904.6	77.54	1388.8
	120	428	936.5	90.00	1500.0
N	0	202	202.1	2.43	57.1
	10	230	184.6	2.75	366.7
	30	262	230.2	4.07	542.7
	60	262	229.6	5.06	506.0
	120	290	249.6	7.46	895.2

Thickness

Thickness of tested gloves are presented in Table 4.

T a b l e 4. Thickness of tested gloves

Sample	Methanol-induced degradation time	Thickness mm
C I	0	0.51
	10	0.51
	30	0.50
	60	0.46
	120	0.49
C II	0	0.59
	10	0.60
	30	0.62
	60	0.67
	120	0.72
N	0	0.10
	10	0.09
	30	0.09
	60	0.10
	120	0.12

SEM analysis

SEM images were captured at various magnifications. Selected images with scales of 5 μm and 100 μm are presented in Tables 5–7.

Chloroprene-latex gloves with cotton flocking

Comparative SEM analysis at ×300 and ×1000 magnifications showed no significant morphological changes after different degradation times. Large surface heterogeneities, including crack networks, were present from the initial state (0 min – Table 5). The glove's inner surface displayed fibers resembling organic materials like cellulose or cotton. Despite exposure to methanol, no changes in surface morphology, mechanical properties, or puncture characteristics were observed. SEM may not show visible degradation, but mechanical properties are changed, as confirmed by other studies in this article.

Velour-lined chloroprene gloves

SEM analysis at lower magnifications (×300 and ×1000) showed no major morphological differences over degradation times, though a slight increase in surface porosity and roughness was noted (Table 6). However, higher magnifications revealed morphological changes after 30 min. After 60 min, micropores appeared around the puncture area (Fig. 7), and after 120 min, micropores were also visible on the glove's inner surface (Fig. 8). Organic-type fibers, like those in C I gloves, were found on the inner surface.

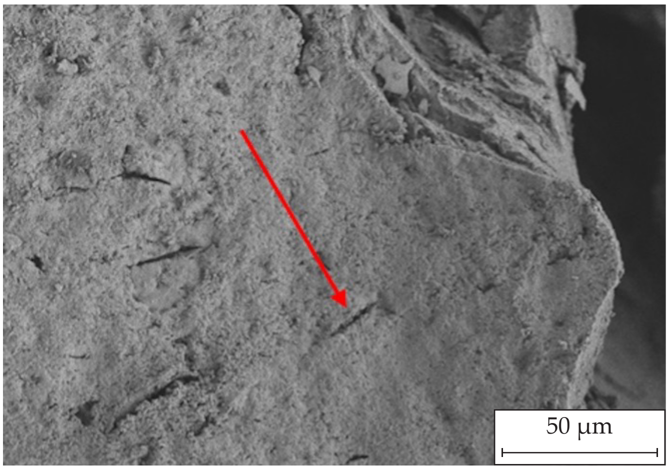


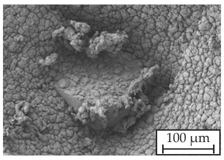
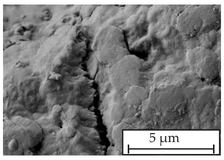
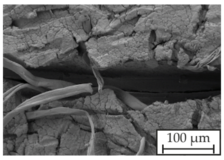
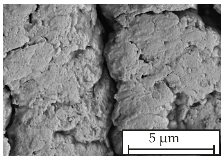
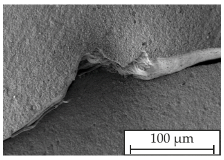
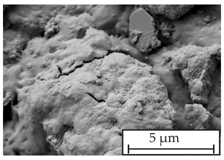
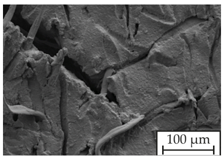
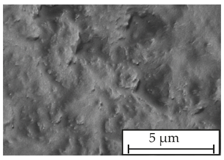
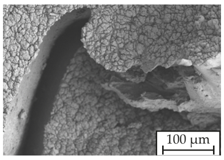
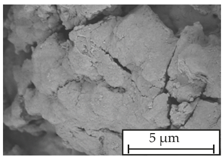
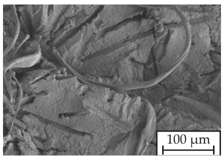
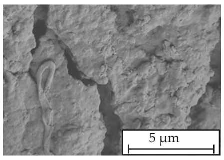
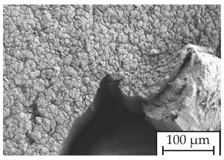
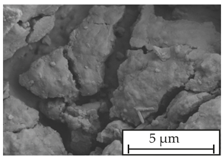
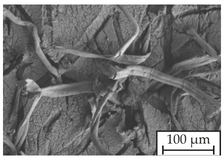
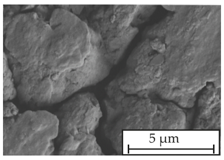
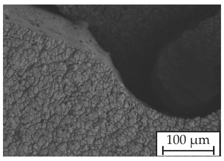
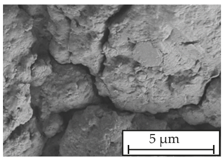
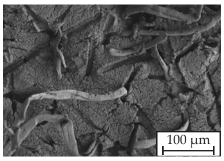
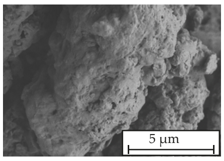
Fig. 7. Micropores within the puncture area observed by SEM at a scale of 50 μm in the outer surface of chloroprene glove material after 120 min of methanol exposure

Nitrile gloves

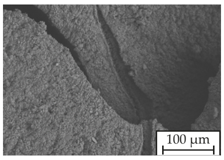
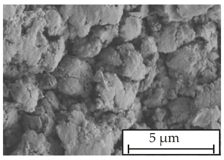
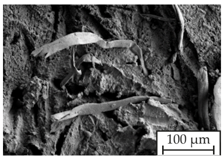
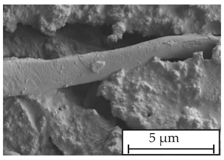
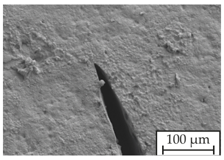
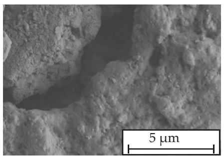
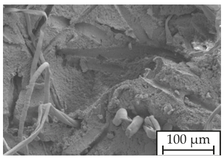
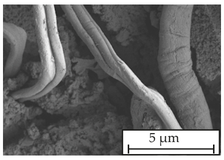
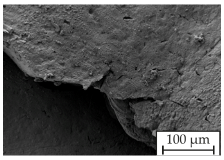
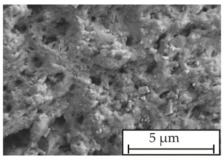
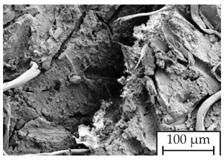
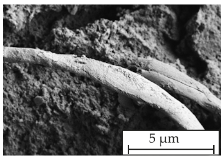
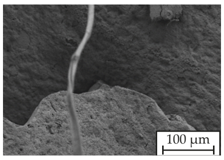
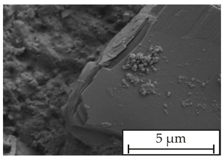
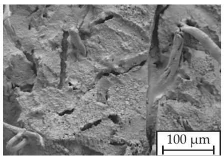
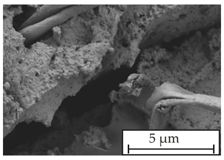
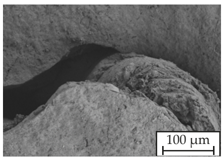
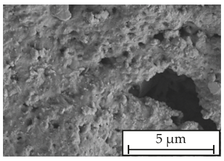
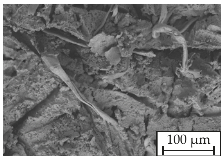
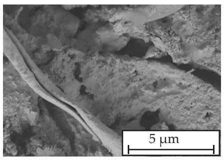
SEM images at lower magnifications (×300 and ×1000) showed no significant morphological differences after varying degradation times (Table 7). Micropores were present in the puncture zone both before (Fig. 9) and after methanol exposure (Fig. 10).

An additional cross-sectional observation using SEM was conducted for the chloroprene glove material C II. Two extreme degradation states were selected for analy-

T a b l e 5. SEM images of chloroprene and natural rubber flocked glove material at 5 μm and 100 μm scale, taken for punctured samples, unexposed (0 min) and exposed to methanol for 10–120 min

CI	Punctured			
Time, min	top		bottom	
	100 μm	5 μm	100 μm	5 μm
0				
10				
30				
60				
120				

T a b l e 6. SEM images of velour-lined chloroprene rubber glove material at 5 µm and 100 µm scale, taken for punctured, unirradiated (0 min) and methanol-treated samples for 10–120 min

CII	Punctured			
Time, min	top		bottom	
	100 µm	5 µm	100 µm	5 µm
0				
10				
30				
60				
120				

sis – both from glove surfaces where cracking had been previously observed. Fracture surface observations revealed a hybrid structure of the glove. On the outer side, an advanced porous layer was identified (Figs. 11–12). The thickness of this layer is estimated to be a few micrometers. Beneath it, two morphologically distinct layers differing in filler content were observed, each with a thickness of approximately 200 µm (Fig. 13), followed by a third layer, about 160 µm thick, containing embedded organic fibers, which constitutes the inner part of the glove.

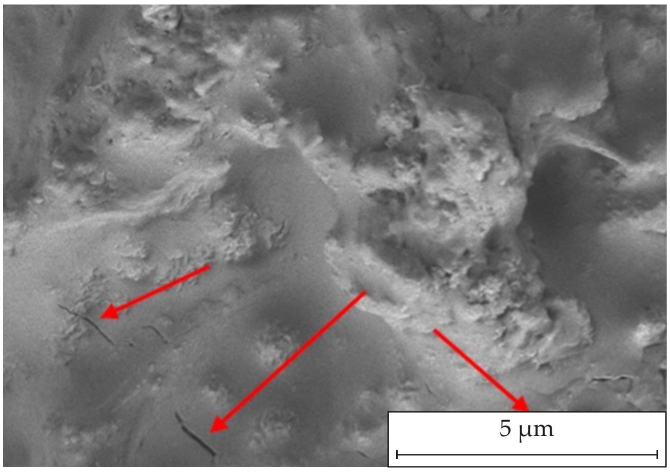


Fig. 8. Micropores within the puncture area observed by SEM at 5 µm scale in the inner surface of chloroprene glove material after 120 min of methanol exposure

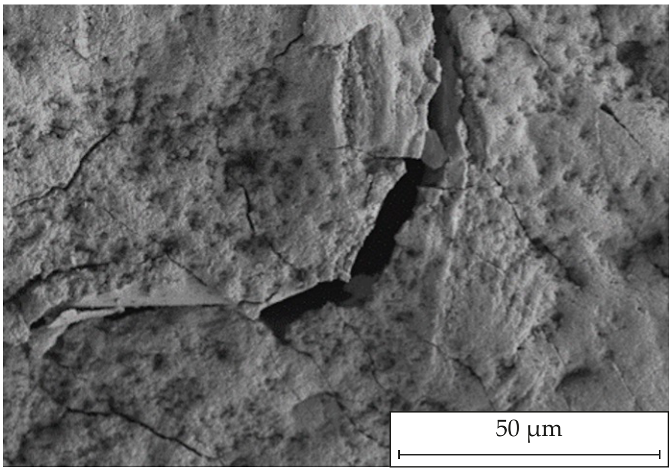
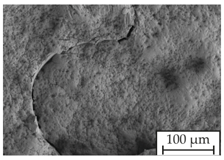
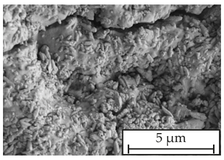
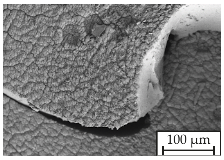
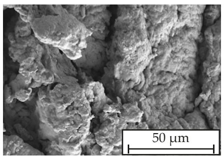
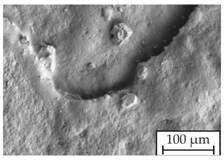
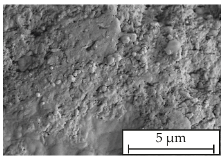
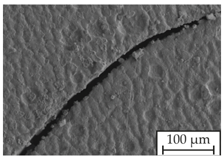
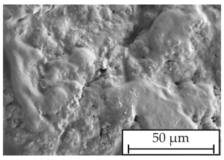
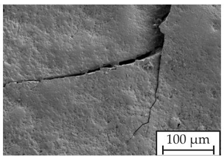
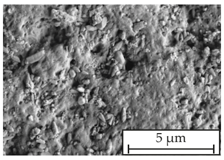
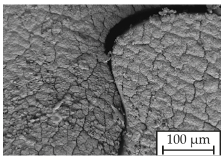
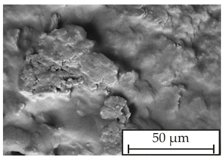
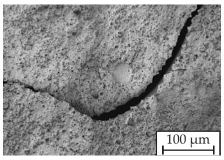
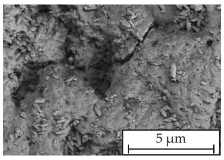
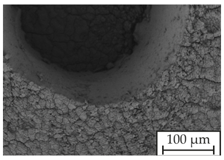
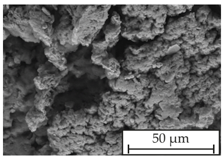
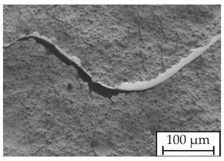
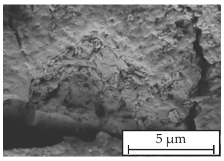
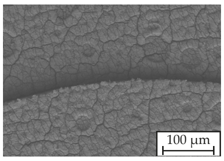
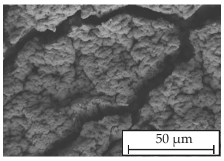


Fig. 9. Micropores within the puncture area observed using SEM at 50 µm scale in nitrile gloves in the initial state – unexposed to methanol

T a b l e 7. SEM images of acrylonitrile rubber glove material at the 5 μm, 50 μm, and 100 μm scale, taken for punctured samples, untreated (0 min) and exposed to methanol for 10–120 min

N	Punctured			
Time, min	top		bottom	
	100 μm	5 μm	100 μm	50 μm
0				
10				
30				
60				
120				

Observations revealed a slight increase in cross-sectional thickness after 120 min of degradation. Examination of the outer layer showed signs of its degradation (Fig. 14). It was significantly less visible and thinner compared to the initial state. The appearance of the remaining three layers was similar to the initial state. However, microcracks were observed both in the outermost layer and on the inner side of the glove (Fig. 15) suggesting material degradation through and through. Comparing the photos obtained at the same magnifications, a significant loss in the thickness and morphology of the surface layer was observed.

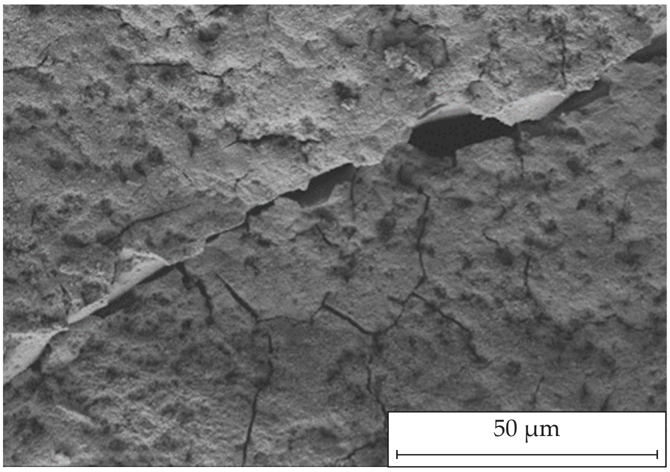


Fig. 10. Micropores within the puncture area observed using SEM at 50 μm scale in nitrile gloves after 120 min of methanol exposure

In summary, all the results reveal several noteworthy correlations. Starting with the bending stiffness test results, it reflects a material's resistance to bending (Table 3). Low values of the bending modulus mean high flexibility, while higher values indicate greater stiffness. Overhang length shows how much the sample deflects under its own weight – longer overhangs mean softer materials.

Methanol exposure increased stiffness in all tested materials over time. Material C I showed the largest increase, rising 4.6 times from 270.5 MPa to 1246.5 MPa. Material C II's stiffness grew 1.9 times after 2 hours but started with the highest initial stiffness.

Nitrile gloves (N) best retained flexibility, with modulus rising from 57.1 MPa to 895.2 MPa after 2 hours of methanol exposure. Despite this, they had the highest degradation (~48% after 10 minutes) and shortest breakthrough time (15 minutes). These findings highlight the

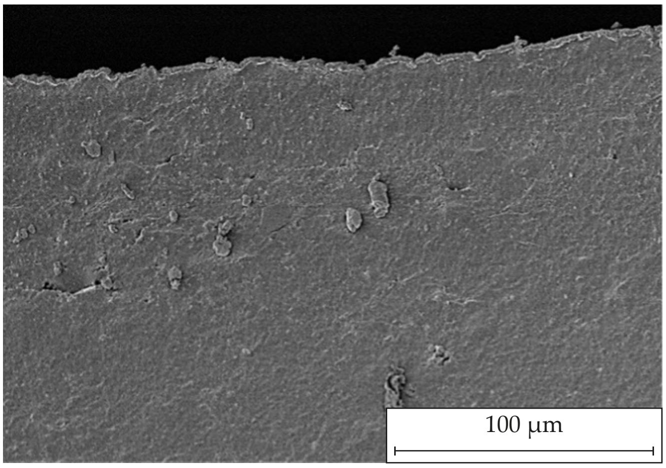


Fig. 11. Cross-sectional view of the C II glove – initial state

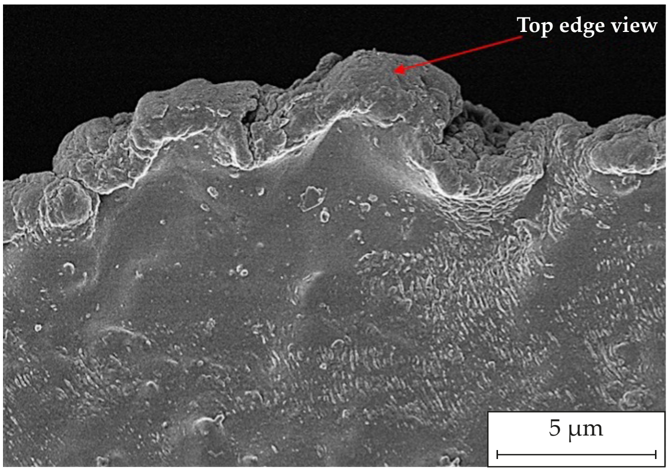


Fig. 12. Cross-sectional view of theC II glove – initial state

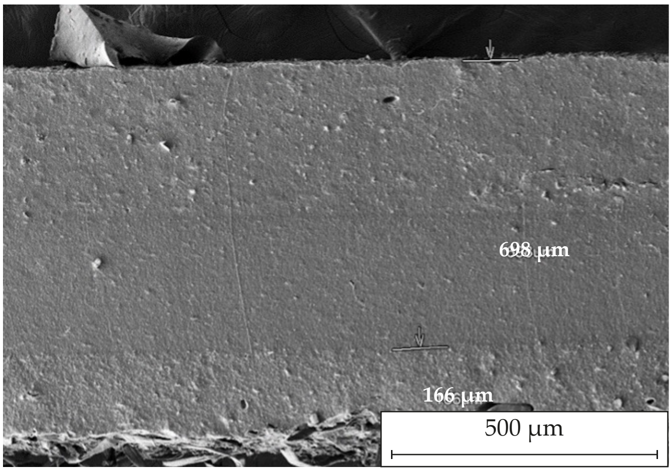


Fig. 13. Cross-sectional view of the C II glove – initial state

trade-off between chemical resistance and mechanical flexibility, a key consideration in protective glove design.

In the case of gloves C I, made of chloroprene and latex rubber, a noticeable decrease in material thickness was observed with increasing contact time with methanol (Table 8). This may suggest the leaching of substances from the material and a consequent weakening of its mechanical properties. In contrast, for chloroprene gloves C II and nitrile gloves (N), the opposite trend was noted. The material thickness increased proportionally with the duration of methanol exposure, indicating swelling of the material. These observations are supported by degradation studies.

The C I material is characterized by negative degradation values, corresponding to an increase in hardness and the force required to puncture it. Conversely, materials C II and N exhibit positive degradation values, which indicates a weakening of the mechanical properties, particularly puncture resistance. Among these, nitrile gloves showed significantly higher degradation levels, with a considerable reduction in the force required for puncture after methanol exposure.

Permeation and degradation data reveal chloroprene gloves C II offer the best methanol resistance. Although degradation stayed within ±30% after 120 minutes, their use should be limited to 70 minutes, as permeation begins beyond this point - undetectable visually but posing dermal exposure risk.

The observed variation in normalized breakthrough time and degradation across glove materials is consistent with broader literature on dynamic exposure conditions. Simulated hand movement significantly accelerates

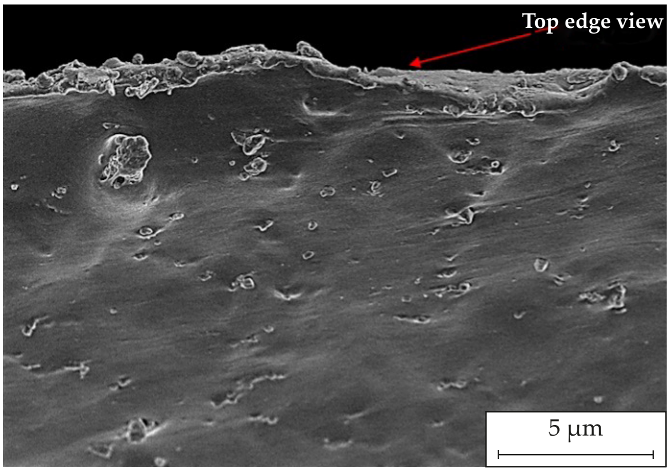


Fig. 14. Cross-sectional view of the C II glove – state after 120 min of degradation by methanol

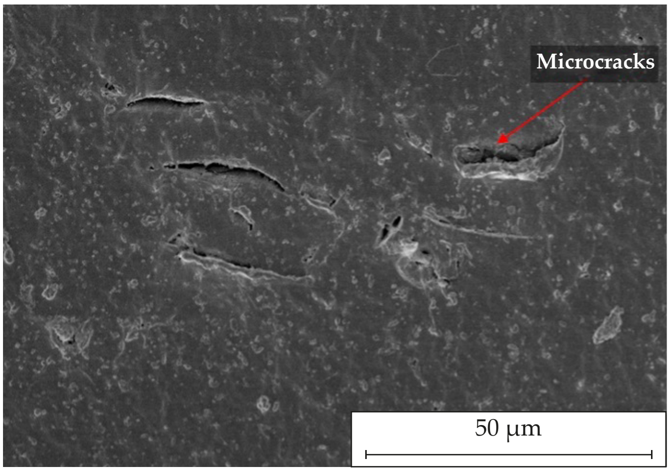


Fig. 15. Cross-sectional view of the C II glove – state after 120 min of degradation by methanol

chemical permeation in nitrile gloves. Phalen *et al.* [15] demonstrated that nitrile gloves under movement conditions exhibit a 31% reduction in NBT, a 47% increase in steady-state permeation rate (SSPR), and a 111% rise in cumulative permeation over 30 minutes (CP_{30}) compared with static testing protocols. Phalen and Wong [11] reported (across 30 nitrile glove models) an average 18% decrease in NBT, 18 % increase in SSPR, and up to a threefold increase in AUC_{30} (Area Under the Curve at 30 minutes), with strong product variability (NBT: −6 to −33 %, SSPR: +1 to +78 %).

The SEM observations in our study, particularly the micropores and surface cracks in chloroprene gloves (C II), are consistent with reports from Wang *et al.* [16], who found that nitrile gloves exposed to environmental aging conditions (UV–humidity cycling) exhibited significant surface cracking, exfoliation, and microparticle release, visible on SEM imaging. These physicochemical changes reduced surface integrity and were not always associated with macroscopic damage.

Additionally, Delgado-Nungaray *et al.* [17] observed 2.25 % weight loss in nitrile gloves during biodegradation by P. aeruginosa, accompanied by SEM-detectable cracking and microstructural erosion. This highlights how surface damage may progress invisibly under chemical or biological conditions.

Finally, cyclic fatigue under mechanical loading without chemical exposure also degrades glove durability. Kang *et al.* [18] analyzed the fatigue behavior of rubber materials and concluded that repeated flexing promotes initiation and propagation of internal cracks, leading to failure of elastomeric gloves under prolonged mechanical stress.

It is worth noting that once permeation starts, brief contact followed by cleaning does not stop it. Therefore, the glove use time is calculated from first contact with the chemical, regardless of exposure duration. Degradation changes are often invisible to the naked eye or under a stereoscopic microscope (Fig. 6), while permeation and skin exposure may already occur.

This relationship may vary for other chemicals. Visible changes, such as discoloration, do not always indicate a loss of protection. Safe glove use requires evaluation of both permeation and degradation data, detailed in certified glove use instructions, with particular emphasis on correct interpretation for hazard protection.

CONSCUSIONS

This work presents a comprehensive evaluation of the performance of three polymer glove types when exposed to methanol, considering both protective effectiveness and ergonomic comfort. The results demonstrate that standard permeation tests do not fully reflect real-use scenarios, where gloves are subjected to combined chemical, mechanical, and environmental stresses. Chloroprene gloves (C II) provided the longest methanol breakthrough time but still underwent gradual mechanical degradation and stiffness increase. Chloroprene-latex gloves (C I) hardened upon exposure, while nitrile gloves (N) suffered the most severe mechanical deterioration and the shortest protection time. SEM observations identified microstructural damage, such as micropores and cracks, invisible to the naked eye, yet correlated with chemical penetration. Based on these findings, the authors recommend limiting C II glove use to approximately 70 min from first chemical contact with methanol. The study highlights that glove selection and safety guidelines should be based on combined permeation and degradation data rather than standardized breakthrough times alone, ensuring effective protection in hazardous chemical environments.

ACKNOWLEDGEMENTS

This work is based on the results of a research task carried out as part of the 6th stage of the National Program "Government Program for Improvement of Occupational Safety and Conditions" financed by the National Center for Research and Development, task no. 1.ZS.06 entitled "Method for determining resistance to chemical degradation of polymer protective gloves, including dual-use medical gloves, taking into account the requirements of the European standard PN-EN ISO 374-4:2020-03." The main coordinator of the Program is the Central Institute for Labor Protection - National Research Institute.

The research work was partially conducted as part of research internship at the Central Institute for Labour Protection – National Research Institute, Department of Personal Protective Equipment, Laboratory of Hand and Foot Protection on December 2, 2024 – February 28, 2025.

Authors contribution

K.H. – methodology, validation, formal analysis, investigation, writing – original draft, review & editing, visualization; J.J. – investigation, visualization; E.I. – conceptualization, resources, writing – review & editing, supervision, project administration, funding acquisition, M.P – methodology, validation, formal analysis.

Funding

The research was conducted thanks to 6th stage of the National Program "Governmental Program for Improvement of Safety and Working Conditions" funded by the resources of the National Centre for Research and Development. task no 1.ZS.06.

Conflict of interest

The authors declare no conflict of interest.

REFERENCES

[1] Krzemińska S.: *Bezpieczeństwo Pracy* **2006**, *2*, 18.

[2] U.S. Department of Labor, Occupational Safety and Health Administration: *Personal Protective Equipment*, 2023.

[3] Roder M.M.: "A Guide For Evaluating The Performance Of Chemical Protective Clothing (CPC)", U.S. Department of Health and Human Services, Morgantown, West Virginia 1990.

[4] Forsberg K. *et al*.: "Quick Selection Guide to Chemical Protective Clothing", 6th Edition, John Wiley & Sons, Inc., USA 2014.

[5] Henry N.W., Stull J.O.: "Test Methods and Standards" in: *Chemical Protective Clothing* (ed. Anna D.H.), AIHA Press, Fairfax, VA 2003, p. 181.

[6] Krzemińska S., Irzmańska E.: *Journal of Testing and Evaluation* **2013**, *41 (6)*, 875, https://doi.org/10.1520/JTE20120224

[7] Park J.: *American Industrial Hygiene Association Journal* **2000**, *61*, 192, http://dx.doi.org/10.1080/15298660008984528

[8] Lendzion-Bieluń Z., Moszyński D.: "Degradacja chemiczna materiałów polimerowych stosowanych w odzieży ochronnej" in: *Postępy w inżynierii i technologii chemicznej*, Wydawnictwo Uczelniane ZUT w Szczecinie, 2023, p. 51.

[9] Irzmańska E. *et al*.: *Podstawy i Metody Oceny Środowiska Pracy* **2024**, *3*, 149, https://doi.org//10.54215/PiMOSP/5.121.2024

[10] Nelson D.I., Phalen R.N.: *ACS Chemical Health & Safety* **2022**, *29 (1)*, 39. https://doi.org/10.1021/acs.chas.1c00084

[11] Phalen R.N., Wong J.S.: *Journal of Occupational and Environmental Hygiene* **2012**, *9 (11)*, 630. https://doi.org/10.1080/15459624.2012.723584

[12] Irzmańska E., Dyńska-Kukulska K., Jurczyk-Kowalska M.: *Polimery* **2014**, *59*, 136, https://doi.org/10.14314/polimery.2014.136

[13] Irzmańska E., Stefko A.: *International Journal of Industrial Ergonomics* **2015**, *47*, 61, https://doi.org/10.1016/j.ergon.2015.02.007

[14] Irzmańska E., Dyńska-Kukulska K.: *Reviews in Analytical Chemistry* **2012**, *31(2)*, 113, https://doi.org/10.1515/revac.2011.121

[15] Phalen R.N., Le T., Wong W.K.: *Journal of Occupational and Environmental Hygiene* **2014**, *11*, 716. https://doi.org/10.1080/15459624.2014.908259

[16] Wang Z., An C., Lee K. *et al*.: *Science of The Total Environment* **2022**, *832*, 154986. https://doi.org/10.1016/j.scitotenv.2022.154986

[17] Delgado-Nungaray J.A., Grajeda-Arias D., Reynaga-Delgado E. *et al*.: *Polymers* **2024**, *16*, 1162. https://doi.org/10.3390/polym16081162

[18] Kang W., Liu J., Xiong W. *et al*.: *Reviews on Advanced Materials Science* **2022**, *61*, 587. https://doi.org/10.1515/rams-2022-0054

Received 16 V 2025.
Accepted 20 VI 2025.