

# Microscopic analysis of the FFP2 mask used to protect the respiratory system against urban pollutions

## *Analiza mikroskopowa maseczki FFP2 zastosowanej do ochrony układu oddechowego przed zanieczyszczeniami miejskimi*

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**Key words:** air pollution, anti-covid mask, PM2.5, healthcare.

**Słowa kluczowe:** zanieczyszczenie powietrza, maseczka antykowidowa, PM2.5, ochrona zdrowia.

### Abstract

**Introduction:** Disposable medical masks commonly used to protect against airborne pathogenic microorganisms have gained popularity during the SARS-CoV-2 pandemic. Until the Comirnaty vaccine was approved by the European Commission on 21 December 2020, the masks had been basically the only protection against the infection. The manufacturer guaranteeing a bacterial filtration efficiency (BFE) of 95% also states that the masks are intended for protection of the respiratory system against pollutants and dust.

**Aim of the research:** The aim of the article is to assess the suitability of the mask as a means of protecting the respiratory system against harmful dust during the periods of high PM2.5 air levels. Using the microscopic examination of individual mask layers the quantitative and qualitative composition of the material subjected to aeration in the zone affected by urban pollution was analysed.

**Material and methods:** The FFP2 mask commonly available on the market, manufactured in accordance with the EN 149:2001 + A1:2009 standard, was analysed. Observations and sample analysis was conducted by using the Energy Dispersive Spectroscopy (EDS) microanalyser in a Scanning Electron Microscopy System FEI Quanta 250 in the UJK University Environmental Testing Laboratory, Kielce.

**Results and conclusions:** The experiment confirmed the effectiveness of protection against pollution provided by the protective mask made of 5-layer polypropylene (PP) non-woven fabric with slim design intended to protect the respiratory system against pathogenic microorganisms transmitted by droplets. The microscopic imaging revealed diverse particles on the surface of individual face mask layers, including multi-element conglomerates; particles of soot, minerals and concentric spherules with predominating share of Fe, Cr, Al and Mg.

### Streszczenie

**Wprowadzenie:** Jednorazowe maseczki medyczne powszechnie stosowane do ochrony przed drobnoustrojami chorobotwórczymi przenoszonymi drogami kropelkowymi zyskały popularność podczas pandemii SARS-CoV-2. Do zatwierdzenia szczepionki Comirnaty przez Komisję Europejską były w zasadzie jedynym zabezpieczeniem przed zakażeniem. Producent, gwarantując skuteczność filtracji bakteryjnej na poziomie 95%, podaje także przeznaczenie maseczek jako ochronę układu oddechowego przed zanieczyszczeniami i pyłami.

**Cel pracy:** Celem pracy jest ocena przydatności maseczki jako środka ochrony układu oddechowego przed szkodliwymi pyłami w czasie podwyższonego stężenia PM2.5 w powietrzu. Stosując analizę mikroskopową poszczególnych warstw maseczki, przeanalizowano skład ilościowy i jakościowy materiału poddanego napowietrzeniu w strefie oddziaływania zanieczyszczeń miejskich.

**Materiał i metody:** Analizie poddano maseczkę powszechnie dostępną na rynku FFP2, wyprodukowaną zgodnie z normą EN 149:2001 + A1:2009. Analizę próbek wykonano za pomocą mikroanalizatora EDS (*energy dispersive spectroscopy*) w skaningowym mikroskopie elektronowym FEI Quanta 250 w Laboratorium Badań Środowiska Uniwersytetu Jana Kochanowskiego w Kielcach.

**Wyniki i wnioski:** Przeprowadzony eksperyment potwierdził skuteczność ochrony przed zanieczyszczeniami maski ochronnej wykonanej z włókniny polipropylenowej, pięciowarstwowej o smukłej konstrukcji przeznaczonej do ochrony układu oddechowego przed drobnoustrojami chorobotwórczymi przenoszonymi drogą kropelkową. Cechy strukturalne poszczególnych warstw maseczki wpływają na zróżnicowane właściwości absorpcyjne. Zewnętrzne warstwy maseczki (1 i 5) miały znacznie grubsze włókna i większe wolne przestrzenie między nimi w porównaniu z warstwami wewnętrznymi maseczki (zwłaszcza 3 i 4). Wewnętrzne warstwy maseczki wykorzystanej do badania cechowały znacznie większy stopień upakowania drobniejszych włókien, przez co charakteryzowały się lepszymi właściwościami absorpcyjnymi. Obrazowanie mikroskopowe uwidoczniało zróżnicowane cząstki na powierzchni poszczególnych warstw maseczki, w tym konglomeratów wielopierwiastkowych, cząstek sadzy, minerałów oraz koncentrycznych sferul z przewagą Si, Fe, Cr, Al i Mg.

## Introduction

Disposable medical masks commonly used to protect against airborne pathogenic microorganisms gained popularity during the SARS-CoV-2 pandemic [1, 2]. Until the Comirnaty vaccine was approved by the European Commission on 21 December 2020, masks had been the main element in the protection against the infection [3]. Manufacturers guaranteeing a bacterial filtration efficiency (BFE) of 95% also state that the masks are intended for protection of the respiratory system against particulate matter pollutants.

## Aim of the research

The aim of the article is to assess the suitability of the mask as a means of protecting the respiratory system against harmful dust during periods of high PM<sub>2.5</sub> air pollution levels. Using microscopic examination of individual mask layers, the quantitative and qualitative composition of the material subjected to aeration in the zone affected by urban pollution was analysed.

## Material and methods

The FFP2 mask, commonly available on the market, manufactured in accordance with the EN 149:2001 + A1:2009 standard, was analysed. Round samples (47 mm) were cut using a surgical scalpel blade and were placed in the pneumatic system of a Fidas 200 dust monitor manufactured by Palas, in the Jan Kochanowski University of Kielce (UJK) mobile laboratory equipped with an Airpointer measurement system, using accredited methods for PM<sub>2.5</sub> and PM<sub>10</sub>, Polish Centre for Accreditation – AB 1622 [4]. The measurement took place in the centre of Kielce within the UJK university campus at the Faculty of Exact and Natural Sciences (at Uniwersytecka Str. 7) and lasted 24 h. The recorded flow (4.8 dm<sup>3</sup>/min) allowed us to determine the volume pumped through the sample to 6912 dm<sup>3</sup>. The sample placed in the dust monitor outside the measurement line did not affect the 2.5 µm PM fraction measurement. During the test, weather conditions were determined using the Vaisala WXT 536 weather station integrated with the Airpointer and validated with a certified LAT sensor. Observations and sample analysis were conducted using an Energy Dispersive Spectroscopy (EDS) microanalyser in a Scanning Electron Microscopy System FEI Quanta 250 in the UJK University Environmental Testing Laboratory, Kielce. After 24 h the piece of mask installed in the dust monitor was delaminated into 5 individual fibre coatings and placed on a 12.7-mm nail-shaped sample table using copper tape and covered with a layer (10 nm) of 24-karat gold in a Leica EM SC050 sputtering device in an argon 5.0 atm. The use of electron beam scanning to sample surfaces allowed us to visualise differences in the elemental composition of individual samples in a relatively quick and simple way. Identification of ele-

ments (EDS analysis) was performed using the registration of the X-ray energy spectrum emitted by sample atoms excited by an electron beam.

## Results

The test began on 29 November 2023 at 10 p.m. and lasted 24 h. The average air temperature was –3.2°C (with a minimum of –7.8°C at 10 p.m. and a maximum of 0.3°C at 1 p.m.). There was no precipitation during the tests, and the average relative air humidity was 84.8%. The wind was blowing at an average speed of 0.5 m/s, mainly from the WSW-SSW sectors and did not exceed 1.2 m/s. The average PM<sub>2.5</sub> concentration was 44.8 µg/m<sup>3</sup>. The highest value of PM<sub>2.5</sub> concentration (86.1 µg/m<sup>3</sup>) was recorded at 11 p.m., while the lowest (26.1 µg/m<sup>3</sup>) was recorded at 3 p.m. (Figure 1). Based on 1-hour PM<sub>2.5</sub> measurement data, air quality was classified in accordance with the guidelines of State Environmental Monitoring [5]. The Air Quality Index (AQI) allowed us to qualify 9 h within the 24 h under analysis to the good class, 5 h – to moderate, 4 h – sufficient, and 2 to the bad class.

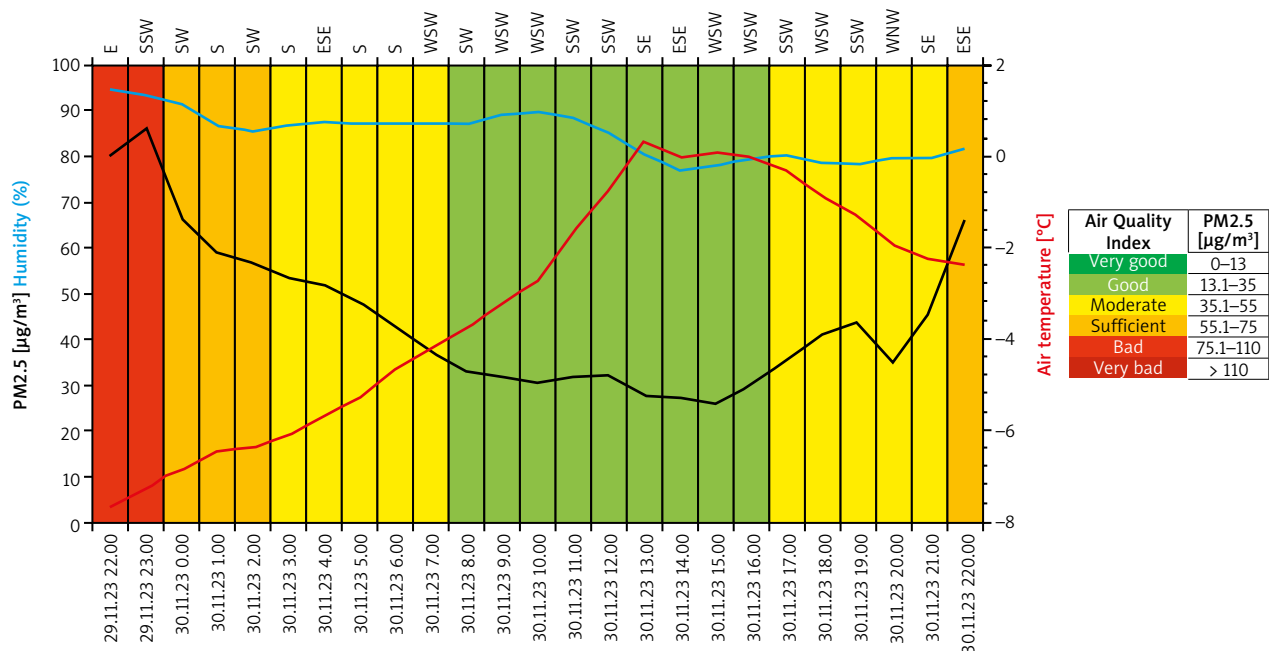
The microscopic examination (SEM) of the mask surface showed the presence of particles of various sizes and shapes on polypropylene fibres (Figure 2). However, the outer layers (1 and 5) featured the lowest compaction, but with much thicker mask fibres, acting as protection against falling out of the internal (much thinner) fibres. The particles on photographs had various sizes, but no larger than 20 µm. Their shape (round as well as sharp-edged) indicated both natural and anthropogenic origin. Spherical particles composed of Al-Si-Fe, come from high-energy combustion of fossil fuels [5], while the larger, sharp-edged structures of Ca-Mg-Na and Al indicate local sources (emissions from households) and natural processes of rock weathering [6].

The analysis with the EDS system allowed us to determine the quantities of individual elements detected on the surface of mask layers under analysis. The analysis excluded the elements from internal coatings (Br, Te, Nb), copper (copper tape), and gold.

Due to the sample specificity, the chemical composition was dominated by carbon and oxygen. Aluminium, silicon, and calcium with sodium and potassium were identified as mineral admixtures (layer 4 and 5). The image of particles with a significant share of chromium was detected on the outer layer (1), while on the last one (5) a significant share of magnesium was found. The highest elemental diversity was observed in the analysis of layers 4 and 5, which proves that these layers feature much better adsorption properties.

## Discussion

Atmospheric dust, especially its finer fractions up to 2.5 µm, is generally considered harmful as a car-



**Figure 1.** PM<sub>2.5</sub> against the background of weather conditions (based on in-house data)

rier of not only natural minerals, but also of polycyclic aromatic hydrocarbons (PAHs) and many elements, including heavy metals [7, 8]. It has been proven that the smallest particles penetrate the lung space, from where they can be carried by blood to other organs, contributing to the development of many diseases and even death [9–11]. The main sources of anthropogenic dusts are production and fuel burning processes, especially the combustion of solid fuels [12]. Large amounts of dust are emitted by the power, mining, metallurgical, chemical, and construction industries (cement and lime production) [13, 14] and by the transport sector [15], as well as by the utilities and housing sector, which is the most important source in winter in Polish cities [16, 17]. During the heating season, in many cities in Central and Eastern Europe that use coal as the primary source of energy, permissible particulate matter levels are exceeded [18, 19]. In recent years, the problem of failure to meet the permissible levels of dust concentration in atmospheric air [20] has been affecting the countries in Central and Eastern Europe as well in the Balkans [21]. It is therefore a key issue for human health to reduce dust emissions and protect against pollution by wearing disposable dust masks. The comfort of wearing them and their effectiveness in intercepting pathogenic microorganisms was confirmed by many studies conducted during the SARS-CoV-2 pandemic [22–24]. The impact of elevated or exceeded pollution concentration, mainly in densely populated areas, on human health can be reduced by wearing disposable face masks [25–28]. The individual mask layers provided

the images of particles of various shapes and chemical compositions. Similar studies conducted in urban areas have confirmed the presence of soot, gypsum, or aluminosilicates on selected adsorption surfaces [29, 30]. The images of similar particles have been detected on the mask surface (Figures 3, 4), wherein their size, shape, and chemical composition indicate the formation of multimolecular conglomerates (halite, aluminosilicates, and concentric spherules).

## Conclusions

The experiment confirmed that protective masks made of 5-layer polypropylene (PP) non-woven fabric with slim design, intended for protection of the respiratory system against pathogenic microorganisms transmitted by droplets, retain particulate matter. The structural features of individual mask layers affect the diverse adsorption properties. The external mask layers (1 and 5) had much thicker fibres and larger free spaces between them as compared to the internal mask layers (especially 3 and 4). The internal mask layers under analysis showed much higher compaction level of finer fibres, thanks to which their adsorption properties were better. The microscopic imaging revealed diverse particles on the surface of individual face mask layers, including multi-element conglomerates – particles of soot, minerals, and concentric spherules with predominating shares of Fe, Cr, Al, and Mg. Further studies using the presented method will focus on the quantitative analysis of urban pollutants deposited on filters (masks).

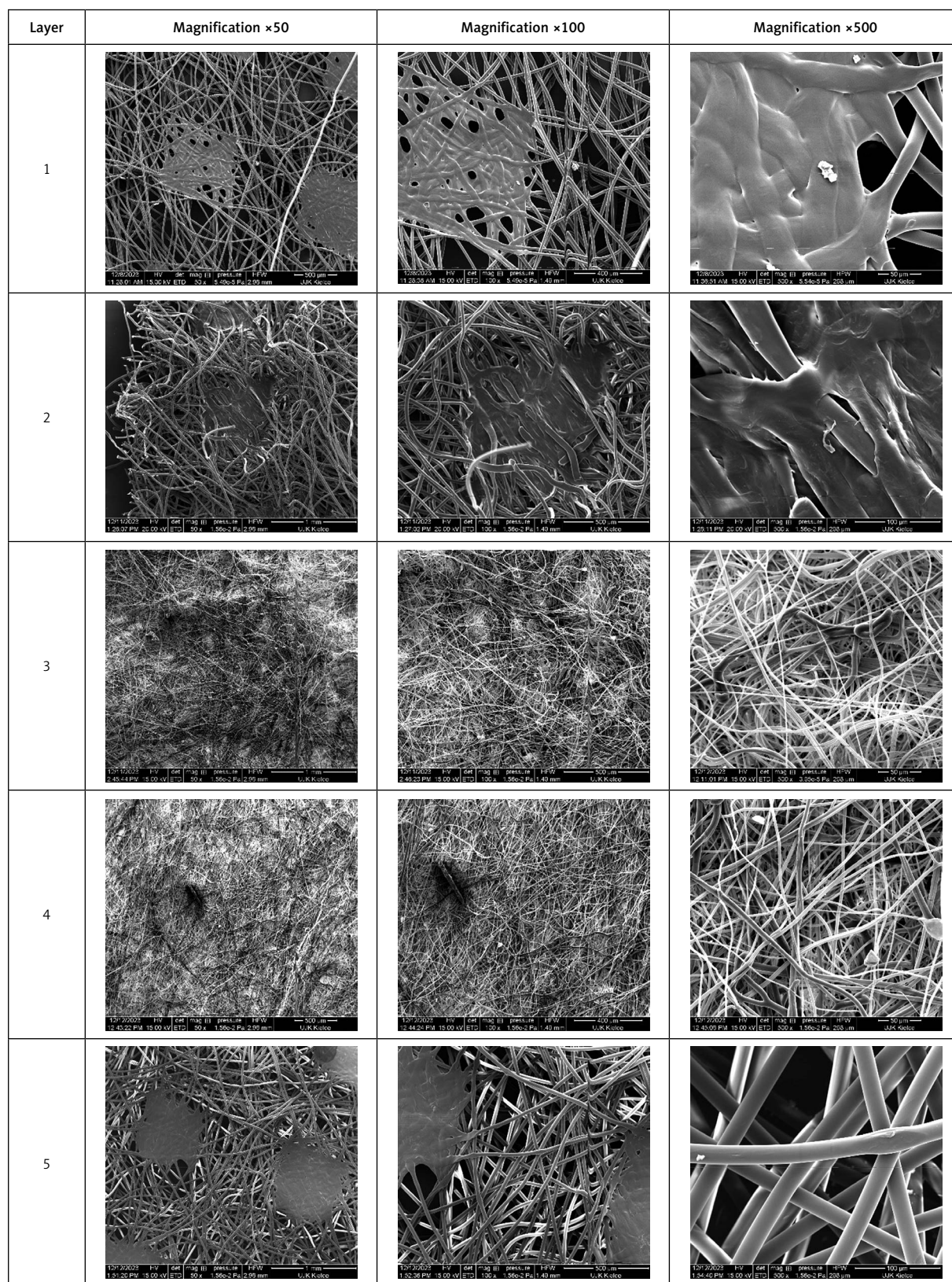


Figure 2. SEM images of individual layers of the FFP2 mask

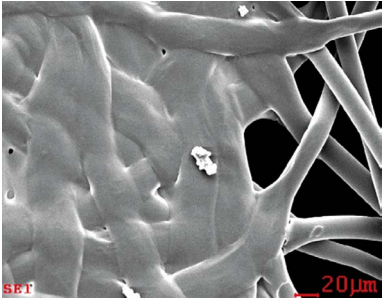
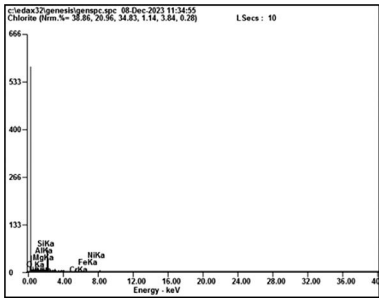
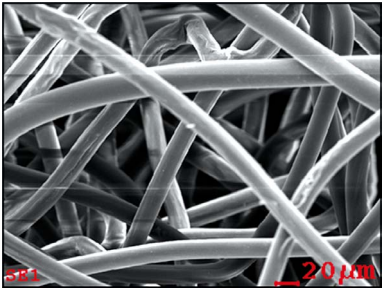
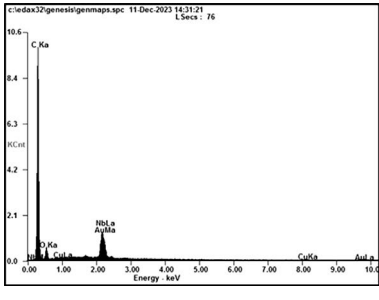
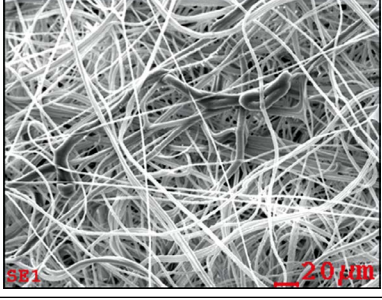
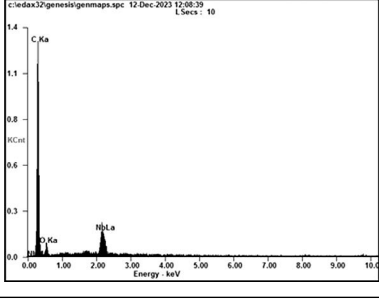
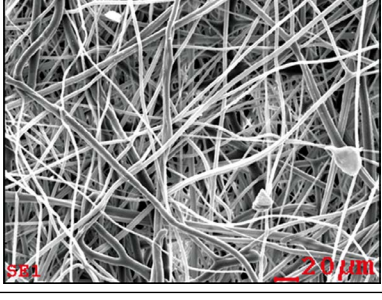
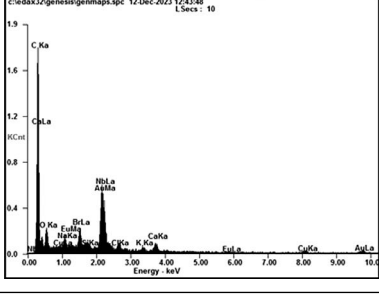
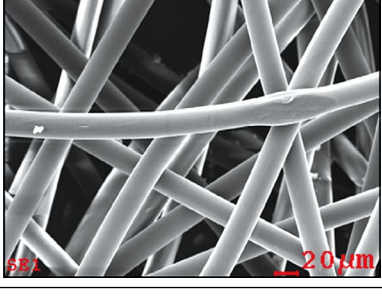
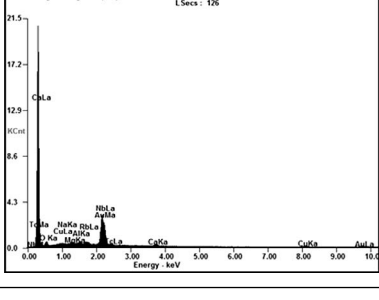
| Layer | SEM image                                                                           | X-ray analysis                                                                       | Element/Wt [%]                                                        |
|-------|-------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|-----------------------------------------------------------------------|
| 1     |    |    | C 88.73<br>O 5.9<br>Al 1.32<br>Si 2.75<br>Cr 1.3                      |
| 2     |    |    | C 73.54<br>O 7.12                                                     |
| 3     |   |   | C 79.63<br>O 6.7                                                      |
| 4     |  |  | C 98.95<br>O 0.4<br>Na 0.17<br>Si 0.2<br>Cl 0.07<br>K 0.05<br>Ca 0.16 |
| 5     |  |  | C 91.45<br>O 4.04<br>Na 0.91<br>Mg 1.12<br>Al 0.99<br>Ca 1.49         |

Figure 3. EDS chemical analysis of individual layers of a disposable mask

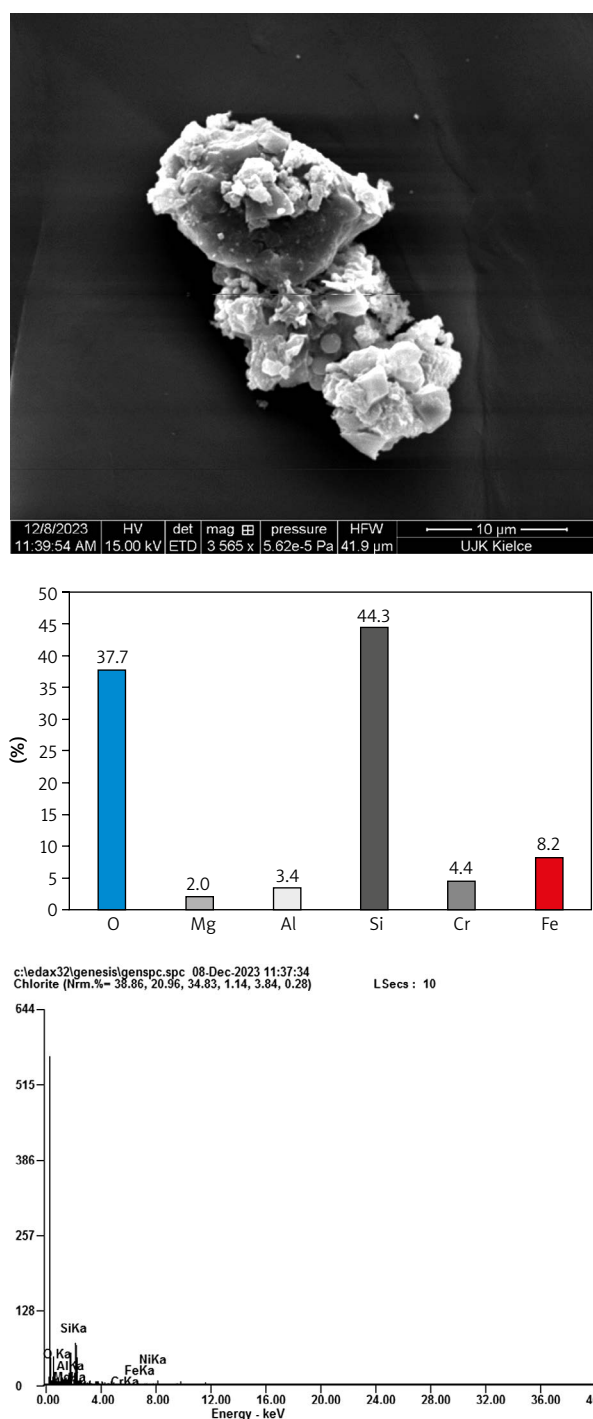


Figure 4. SEM and EDAX analysis

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## Ethical approval

Not applicable.

## Conflict of interest

The authors declare no conflict of interest.

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