Strojniški vestnik - Journal of Mechanical Engineering 68(2022)4, 281-289

DOI:10.5545/sv-jme.2022.38
Original Scientific Paper, Special Issue: SARS-CoV-2
Received for review: 2022-02-01
Received revised form: 2022-02-22
Accepted for publication: 2022-02-22

# Public Handling of Protective Masks from Use to Disposal and Recycling Options to New Products

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*A study was conducted on the waste of disposable surgical masks and their problematic impact on the environment. The studies examined have shown the negative effects on the environment that are likely to occur and those that have already occurred. In this article, society's relationship to the potential recycling of disposable surgical masks is considered and projected onto the possibilities of the cradle-to-cradle design approach. The development of a product from recycled surgical masks is driven by two different surveys. The first focuses on wear and disposal habits, and the second on the relationship to recycling. As a result, the flooring was developed with thermally treated recycled surgical masks replacing the filler layer. The goal of the product design was to improve the long-term life cycle analysis of a waste surgical mask.*
**Keywords: masks, medical waste, environment, recycling added-value product, life-cycle-analysis**

**Highlights**
- *Disposable surgical masks have been shown to have a high carbon footprint.*
- *Disposable surgical masks are the most commonly used protective masks in the Slovenian population.*
- *10 % or more of users incorrectly dispose of the protective masks they wear, regardless of the type of mask.*
- *Disposable masks are used longer than specified in the instructions for use in 84 % of cases, in contrast to respirators, which are disposed of correctly after 6 hours in 86 % of cases.*
- *92 % of survey participants would use products made from recycled face masks.*
- *A soil solution made from used surgical masks was developed.*

## 0 INTRODUCTION

The COVID-19 pandemic changed everyday life around the world. In response, many countries have enacted various regulations to prevent the spread [1] to [3]. The safety guidelines have brought many side effects, especially for the environment. The biggest positive side effect is the improvement in air quality [4], but the negative effects are alarming. Along with quarantines, online shopping and delivery has increased, leading to an increase in packaging waste. In addition, the amount of medical waste has increased dramatically [5] and [6], while the increased production of medical waste has increased $CO_2$ emissions [7] and [1].

While some safety guidelines differed from country to country, most countries required the use of face masks, which, along with gloves and surgical gowns, accounted for the majority of medical waste. Medical waste is often infectious and must be properly handled before disposal or recycling. However, due to the increasing volumes during the pandemic, where millions of disposable face masks and gloves were disposed of daily, many disposal centres are unable to process sufficient quantities [5] and [2]. At the height of the pandemic, Wuhan alone generated 240 tons of medical waste in a single month [8]. The UNEP report states that 400 million tons of plastic waste were produced daily worldwide during the pandemic [2]. As a result of the immense amounts of face masks and the waste generated, a new environmental crisis is emerging with many challenges [6].

Face masks are made of polymeric materials that degrade over time. Macroplastics break down into smaller fragments, first into microplastics and later into nanoplastics. Both microplastics and nanoplastics were one of the most problematic environmental pollutants even before the pandemic [5] and [6]. Studies [6] have shown that a disposable surgical mask can produce up to 147,000 micro- and nano-particles during three cycles of the ageing process. The fact that waste masks have already been found in the ocean is of concern [8], as marine life is already suffering from pollution. Studies [7] have also revealed several cases of animals getting caught in the rubber bands of the masks and suffocating. In addition, it has already been shown that many animals mistake the masks for food. Surgical masks have been shown to be ecotoxic, and improper handling can result in colossal amounts of micro- and nano-plastics after use ends [7].

The purpose of this article is to present a study on waste disposable surgical masks (WDSM) and their problematic effects on the environment. The most important consideration at the starting point is to understand society's relationship to potential recycling and the possibilities of the cradle-to-cradle design

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approach. Two different surveys were conducted. The first focused on the wearing and disposal habits of the Slovenian population in relation to protective masks, while the second focused on the relationship of Slovenians to face mask recycling and the acceptance of different product categories made from recycled face masks.

## 1 METHODS

The first part of the study consisted of a literature and paper search on the topic of face masks and environmental impacts of waste face masks. The research focused on categorising different types of face masks, understanding the life cycle analysis of a disposable surgical mask, including long-term impacts, and investigating available and potential disposal solutions. Based on the information gathered, two different questionnaires were created to define the disposal habits of the respondents, their attitudes toward recycling, and their attitudes toward products made from recycled face masks. The answers were then crucial for the design and development of a socially acceptable product made from used surgical masks.

## 2 FACE MASKS RESEARCH

### 2.1 Types of Facial Masks Used during the Pandemic of COVID-19

Textile face masks are the first category. They are made of variable textile material, are inexpensive and reusable. There are several types of textile masks, which differ in the number of layers and the material of the layers. Approval of such masks varies by country and is limited because they provide only basic protection, having been shown to be less effective against SARS-CoV-2 than, for example, N95. However, they provide adequate protection against air contaminants and were used in several Asian countries prior to the pandemics [9].

The second category is surgical or medical masks, also called disposable surgical masks (DSM), which are used to protect against droplets. Surgical masks usually consist of three, sometimes four, layers: the inner layer, which absorbs water and moisture; the middle layer, which serves as a filter and is made of melt-blown polypropylene; and the outer layer, which is hydrophobic. The inner and outer layers are made of non-woven fabric. Four-layer masks also have an activated carbon filter. An essential component of a surgical mask is also a flexible nasal strip made of plastic or metal [9].

Respirators are the third category of face masks. They include filtering facepiece (FFP) masks, full-length face shields and SCBA (self-contained breathing apparatus). FFP masks are filtered by a variety of complex polypropylene microfibers and electrostatic rates. There are three types of FFP masks: FFP1, FFP2 and FFP3, and they differ in the number of pleats of the filtering material. A full facepiece consists of a clear polycarbonate shield that runs across the face. It provides direct plastic containment and protects against droplets [9].

### 2.2 Life Cycle Analysis of Disposable Surgical Mask

The focus of current research [8] is to understand the long-term environmental impact of disposable surgical masks. To understand the impacts as comprehensively as possible, nine categories were considered: climate change, fossil fuel depletion, metal depletion, water depletion, freshwater ecotoxicity, freshwater eutrophication, marine ecotoxicity, marine eutrophication, and human toxicity. In each category, emissions were calculated for raw material procurement, production, transportation, use, and end-of-life. The disposable surgical mask was found to have high emissions for raw material procurement in all categories, but especially for carbon footprint, fossil fuel degradation, metal degradation, freshwater ecotoxicity, and marine ecotoxicity. The emission levels are also problematic for end-of-life condition in terms of carbon footprint, metal depletion, freshwater ecotoxicity, and marine ecotoxicity.

Some research [10] focused on two different scenarios for end-of-life masks: non-sanitary landfill and sanitary scenario. The following impact categories were considered and studied: non-carcinogenic toxicity to humans, carcinogenic toxicity to humans, marine ecotoxicity, freshwater ecotoxicity, mineral resource scarcity, stratospheric ozone layer depletion, land use, fossil resource scarcity, terrestrial acidification, global warming, terrestrial ecotoxicity. The first scenario showed that DSM has a lower environmental impact than FFP2 masks, especially because of the fossil resource scarcity factor, but a significantly higher environmental impact than washable masks. The most problematic impacts of DSM are stratospheric ozone depletion, soil acidification, and fossil resource scarcity. When considering the landfill disposal scenario, the results are similar, mainly because the production of a mask is the most problematic environmental impact. However, a difference can be seen in the factor for stratospheric ozone depletion, which is significantly lower. In both scenarios, the highest values are given for the terrestrial acidification category. This impact factor life cycle analyses (LCA) is described [11] as negatively affecting terrestrial ecosystems by lowering soil pH through atmospheric deposition of acidifying substances such as Sulphur oxides, nitrogen oxides, and ammonia. Decreased soil pH can lead to a deficiency of essential metal ions for plant growth and exposure of roots to toxic metal ions.

### 2.3 Disposable Surgical Masks (DSM)

Medical waste must be properly treated to eliminate all pathogens. The commonly used treatment technologies are thermal (autoclaving, incineration, plasma treatment, and microwave treatment) [5]. Prior to the pandemic, medical waste was excluded from medical personnel and facilities. During the pandemic, medical facilities were instructed to separate masks worn by an infected person from other masks used in a particular facility. The separated masks were then to be labelled. During the pandemics, the use of masks expanded to the entire population. With the wrong instructions on how to handle mask waste, the problem of inappropriate and unorganized mask collection or disposal began [7] and [12]. On the other hand, there is research [3] indicating that masks, as a layered composite material, can be a safe hotspot for antibiotic resistance gene colonization when disposed into the marine ecosystem. Decontamination of masks is challenging due to susceptibility to filtration [13]. However, studies [14] have shown that decontamination of previously used surgical masks is possible. The following categories were considered: optical integrity, air permeability, burst resistance, pressure differential, and particle filtration efficiency. Decontamination methods (oven, thermal drying, autoclave, hydrogen peroxide plasma vapor) were tested and evaluated for both performance and safety. The results showed that all tested methods successfully decontaminated a mask after only one cycle. In addition, the properties of a surgical mask were maintained for at least five cycles. Overall, the oven decontamination method (75 °C for 45 min) was found to be the simplest. The general guidelines [13] for reuse of facial masks state that the filtration efficiency of masks contaminated with fluids may be compromised and therefore they should not be reused, that each mask should be separated and labelled to avoid mixing the masks and avoiding direct contact with the metal surface or other masks, surgical masks should not be used when in contact with a potential COVID-19 positive person (coronavirus is much smaller than the pores in surgical masks).

Studies show that many different potential DSM recycling options can be considered, e.g. pyrolysis [15]. Crushed face masks were evaluated along with recycled concrete aggregate for civil engineering field, aggregate with mask showed good compressive strength (216 kPa) and resilient modulus (314.35 MPa). Similarly, the effect of surgical mask fibres (polypropylene) on the mechanical properties of concrete was evaluated. The mechanical properties improved. Polypropylene from surgical face masks was treated and converted into cathodes for supercapacitors.

Based on LCA [10], a disposable surgical mask could be improved by changing the position and attachment system of the nasal wire and rubber ear band to facilitate disassembly from the core of the mask. It would be even more efficient to manufacture the entire mask from a single polymer, which would allow for easier recycling. The most efficient solution would be to manufacture and use reusable masks with replaceable filters.

## 3 SURVEY RESEARCH

### 3.1 Survey on the Current Use of Protective Masks in Slovenia

A survey was conducted to collect data on the wearing habits of various protective masks and face coverings of Slovenians. It was conducted between March and June 2021. During this period, 670 correctly completed questionnaires were collected and analysed. 69 % of the participants were female and 31 % were male. All participants were 16 years of age or older, and 91% were between 16 years and 55 years of age. It was found that in the period from March 11, 2020 (declaration of the pandemic by WHO and introduction of measures requiring the wearing of protective masks) to March 8, 2021 (start of the survey), 98 % of Slovenians had used one of the following protective masks: DSM, FFP2 or FFP3 protective mask, or textile mask (TM). 81 % of respondents had used a DSM at least once during this period, and 63 % of respondents had used a TM at least once (Fig. 1). 3 % of respondents who answered otherwise referred primarily to other textiles such as a scarf, route, bandana, or buff, or they answered that they had not used protective masks or face coverings during the first year of the pandemic. When respondents were asked what type of mask they used most often, we obtained the results shown in Fig. 2.

From these results, it appears that Slovenians used DSM most often.

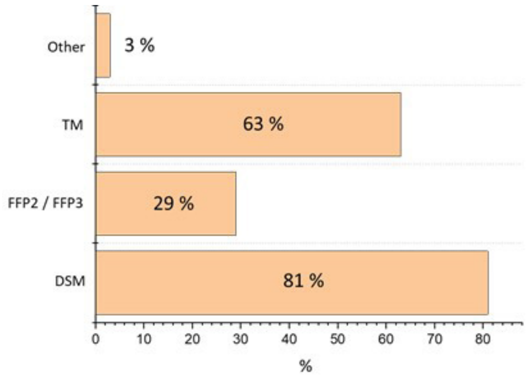


**Fig. 1.** *Survey answers to Question 1: Which face mask have you used since start of pandemic?*

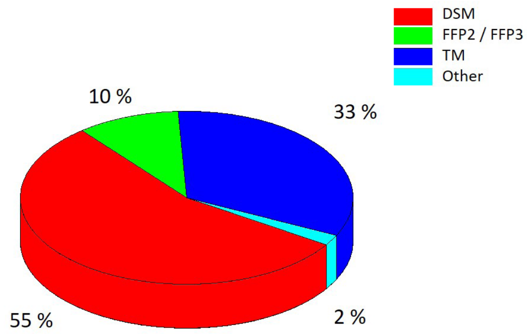


**Fig. 2.** *Survey answers to Question 2: Which face mask do you use most often?*

When asked how many masks you use per month, respondents answered an average of 16 masks, with a minimum of 0 mask and a maximum of 150 masks. When asked how much money they spend on buying masks for themselves, respondents answered an average of €51.6, with a minimum of €0 and a maximum of €500.

The population of Slovenia older than 16 years in the first half of 2021 was 1,791,246, so, using these data we can roughly estimate that in the first year of the pandemic in Slovenia, about 344 million protective masks were used, on which Slovenians spent €92.5 million of their personal money. In addition, companies and the government spent much more money to provide a sufficient amount of masks in schools, hospitals, industry etc.

An analysis of the handling of each type of mask was also performed. On this subject, we obtain the following results.

#### 3.1.1 Disposable Surgical Masks

Only 16 % of respondents use DSM correctly - they use each mask only once for a maximum of 2 hours. This means that 84 % of the population uses DSM more than once. When asked how often you use the same DSM, they responded as shown in Fig. 3.

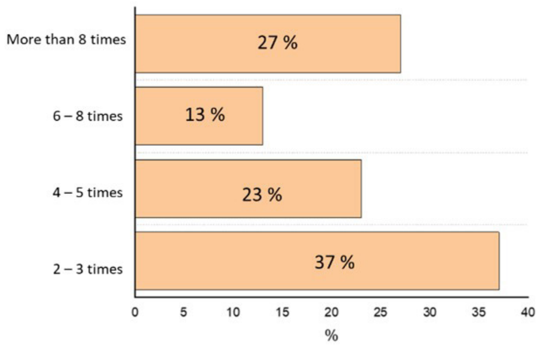


**Fig. 3.** *Survey answers to Question 3: How often do you use the same DSM?*

Since it has been determined that the DSM is the most commonly used type of protective mask, it is also extremely important how are they threated after use. As recommended by the Slovenian National Institute of Public Health, waste DSM should be placed in mixed municipal waste or, if possible, in infectious waste. Two-thirds of Slovenians adhere to this recommendation (Fig. 4), while 17 % have an even better solution at hand and dispose of waste DSM in infectious waste containers. 4 % of respondents who chose the other option indicated that they collect waste DSM in special bags or containers and do not throw it away yet. 12 % of respondents do not properly dispose of waste DSM according to current recommendations, as they dispose of it in plastic or paper waste.

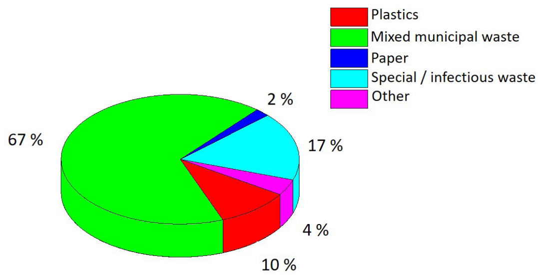


**Fig. 4.** *Survey answers to Question 4: Where do you dispose of waste DSM?*

### 3.1.2 Filtering Face-Piece Masks (FFP2/FFP3)

Users of FFP2 or FFP3 protective masks were asked the same questions as DSM users. It was found that most users of FFP2 or FFP3 masks use the masks correctly according to the instructions of the Slovenian National Institute of Public Health. 28 % of the respondents use the masks only once, and 86 % of the respondents do not use the same mask for more than 6 hours. The answers of those who wear the same mask more than once are shown in Fig. 5.

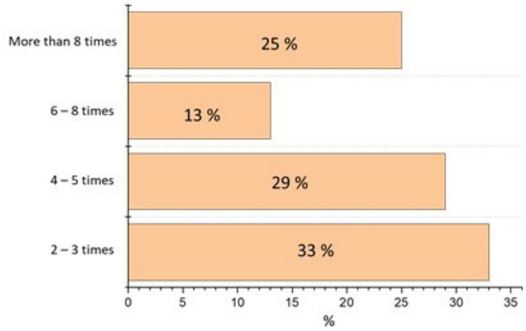


**Fig. 5.** *Survey answers to Question 5: How often do you use the same FFP2/FFP3 protective mask?*

A survey was also conducted on the disposal of waste FFP2/FFP3 mask. The recommendations of the Slovenian National Institute of Public Health for waste FFP2/FFP3 masks are the same as for waste DSM. 56 % of Slovenians follow this recommendation (Fig. 6), while 28 % have an even better solution ready and dispose of waste FFP2/FFP3 mask in containers for infectious waste. Better result compared to DSM users is to be expected, as 57 % of FFP2/FFP3 mask users are from the medical sector, while only 13 % of DSM users are from that sector. Only 5 % of respondents who selected the option other, indicated that they collect waste FFP2/FFP3 in special bags or containers and do not yet dispose of it. 11 % of respondents do not dispose of waste FFP2/FFP3 mask according to current recommendations.

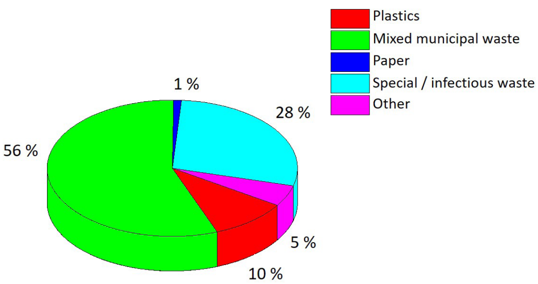


**Fig. 6.** *Survey answers to Question 6: Where do you dispose of waste FFP2/FFP3 masks?*

### 3.1.3 Textile Masks (TM)

A customized survey of TM users was also conducted. It was found that there was a wide variation in the duration of use of TMs before washing. The distribution of the duration of use is shown in Fig. 6.

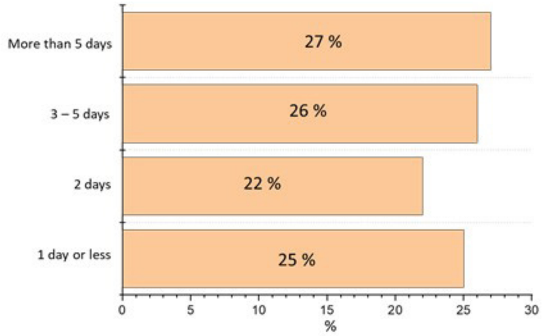


**Fig. 7.** *Survey answers to Question 7: How long do you use TM before you wash it?*

It was also studied how people deal with used TM. When asked how many times do you wash your TM before disposing of it, the most common response was that they did not dispose of any TM in the first year of the pandemic. 11 % responded that they disposed of TM after 6 to 10 washes and 13 % after more than 10 washes (Fig. 8). Those who already disposed of TMs were asked where they disposed of them. The responses are shown in Fig. 9. 80 % of respondents dispose of their TMs according to the current regulations for textile waste in Slovenia, which state that textile waste should be placed in mixed municipal waste or in special containers for textile waste. Those who answered with the option other still collect textile waste at home in special bags or containers and have not disposed of it yet.

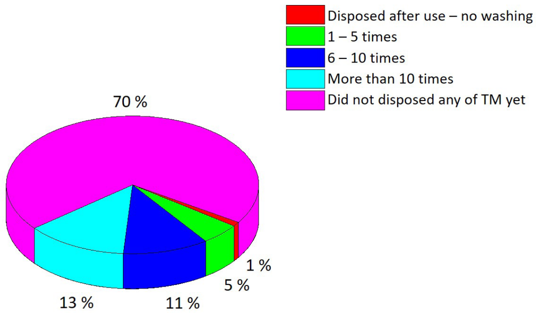


**Fig. 8.** *Survey answers to Question 8: How many times do you wash TM before disposal?*

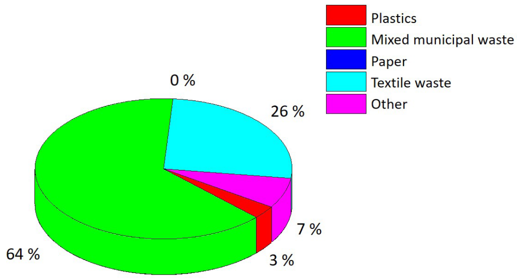


**Fig. 9.** *Survey answers to Question 9: Where do you dispose of used TMs?*

### 3.2 Survey on the Reuse of Used Face Masks

The second questionnaire contains 21 questions. Over a two-week period, 218 completed responses were collected (the response rate was 56 %). 71 % of the participants were female and 29 % were male. All participants were 16 years of age or older, and 99 % were between 16 years and 65 years of age.

The questionnaire was designed to obtain information on society's relationship to recycled products from DSM waste. From the introductory question and their answers, it appears that the majority of respondents separate their waste (97 %) and already consciously use products made from recycled materials (88 %). About 91 % of them would choose a reusable product if they had the choice between disposable and reusable. The main reasons for choosing reusable products are environmental awareness and convenience. The 9 % who would choose a disposable product cited price as the main influence on their decision, but also indicated that this decision varied from product to product.

#### 3.2.1 Recycling of DSM

The majority of respondents would be willing to collect DSM waste separately (96 %), while the remaining 4 % do not consider DSM waste problematic and would dispose of it in the residual waste garbage can or the plastic garbage can. Fewer respondents would be willing to pay more for the mask that can be 100 % recycled (66 %). 48 % of them would be willing to pay 10 % more, 45 % would be willing to pay 10 % to 30 % more and the remaining 7 % would be willing to pay more than 30 % more.

DSM waste can be disinfected and recycled into other products. 92 % of respondents would use products made from recycled face masks. They also stated that such a decision would be more environmentally friendly, as it would result in less waste entering the natural environment, and overall stated that they do not care about the origin of the product and only care about usability. The other 8 % stated that they have doubts about the safety and hygiene standards of such products, others are concerned that such products cost more and are not as high quality. As shown in Fig. 10, when asked which type of recycling they would prefer, 25 % of respondents answered that they would prefer products made from thermally recycled DSM, 8 % answered that they would prefer products made from mechanically recycled DSM, 62 % would prefer both equally, and 5 % would use neither.

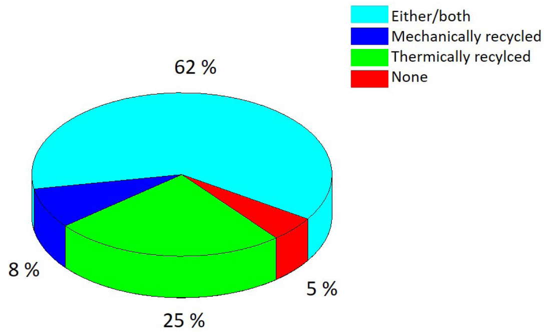


**Fig. 10.** *Survey answers to Question 10: Products from which mask recycling process would you prefer?*

#### 3.2.2 Products Made of Recycled DSM

Respondents were asked how likely they were to use a product from a particular product category that was made from DSM waste. Responses were ranked on a scale of 1 to 7, where 1 means I would never use it, while 7 means I would definitely use it. The product categories were: clothing, shoes, jewellery, bags, other fashion accessories, decor, lighting, furniture, bulkheads, flooring, packaging, and insulation (Fig. 11).

More than 50 % of respondents would definitely use bulkheads, flooring, packaging and isolation. They would be most likely to use Insulation made from DSM waste. 66 % of respondents chose 7, and 2 % chose 1. About 1 % chose 2, 4 % chose 3, 6 % chose 4, 7 % chose 5, and 13 % chose 6. Respondents would be least likely to use clothing, jewellery and other fashion accessories.

#### 3.2.3 Added-Value Product from DSM

For 79 % of respondents, products made from recycled material have added value. When asked if products made from recycled DSM had added value, 70 % answered yes, stating that their decision was based on the environmental impact of recycled products. They

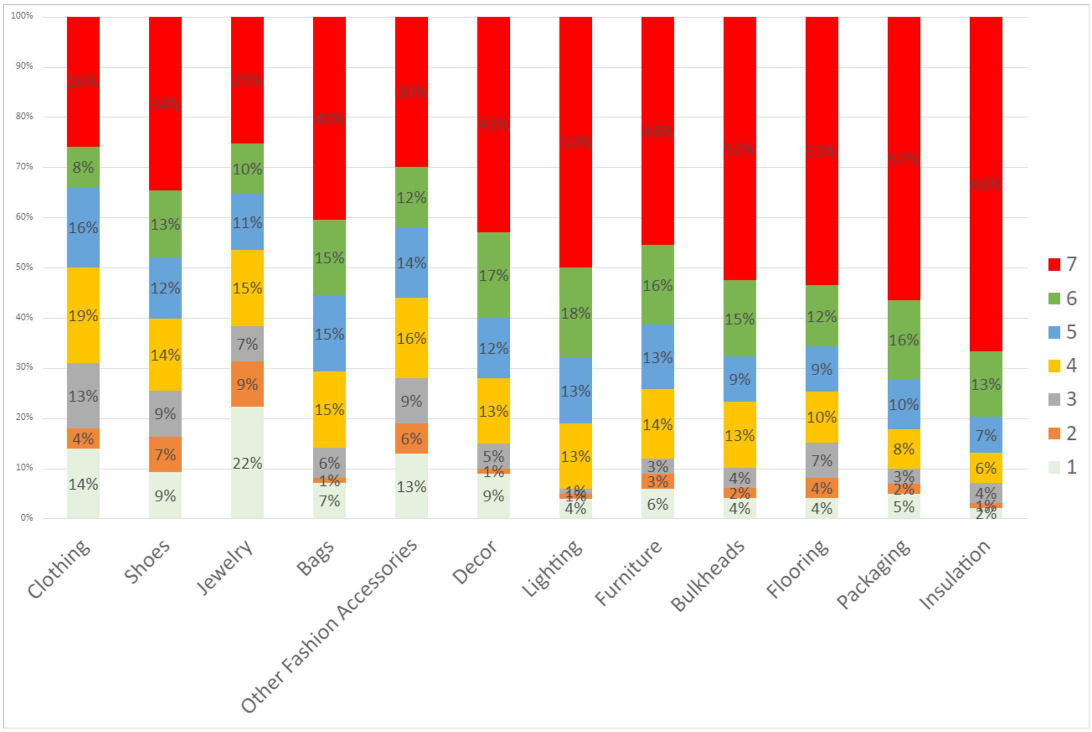


**Fig. 11.** *Survey answers to Question 11: Which products made from recycled face masks would you use, on a scale of 1 to 7?*

also pointed out that the feeling of doing something good for the environment plays a big role in decision making. 30 % of respondents answered in the negative, further explaining that they associate masks with unsanitary material or that they judge products only by quality and not by material.

The majority of respondents (65 %) believe that society is willing to accept products made from DSM waste.

## 4 RESULTS AND DISCUSSION

The designed product prototype is the result of research findings and surveys. The answers of the survey participants to the first questions were promising: 97 % already separate waste and 88 % consciously use products made of recycled material. The majority of respondents would be willing to collect used face masks separately, which is critical for product development because separating face masks in a landfill would not be efficient or even possible in some cases and could also be hazardous due to the characteristics of some wastes. The majority of responses also indicated that respondents would be willing to use products made from recycled DSM because they are aware of the environmental issues and see added value in a product made from recycled material. This kind of environmental awareness was an important confirmation for our design process.

In considering what types of masks we would use in the design process, we initially focused on a single type. The initial survey helped us understand what type of masks are most commonly used. It turned out that the majority of respondents use DSM the most and, on average, the frequency of discarding a mask is also highest for DSM. Since DSMs consist of different components and layers made of different materials, recycling is problematic because such a mask should be disassembled, and each group of materials should be recycled separately. Due to this construction of a face mask, our goal was to develop a product where the entire face mask can be used without any prior handling.

Particular attention was paid to respondents' answers about preferred product categories made from recycled face masks. We decided to focus on the flooring category since the only two categories that received a higher percentage of agreement were packaging and insulation. The goal was to create flooring similar to vinyl flooring.

Overall, it was critical to us and to respondents during the survey that proper sanitation be implemented. It also appeared that although the highest percentage of respondents would use both mechanically and thermally recycled products, a higher percentage would use thermally recycled products because they associate them with a higher level of disinfection. We studied the examples of already successful decontamination of such masks and considered how the procedures could be implemented when creating a prototype. It turned out that heating the masks to a certain temperature for a certain period of time is the most effective and simple procedure. In the research, which involved destroying pathogens but preserving the functions of a face mask, the waste masks were heated to 56 °C for 30 minutes. We set the temperature of 56 °C as the minimum temperature for our further work. Our waste mask bottom plate should consist of several layers, and we decided that the middle layer should be waste masks. The middle layer in floor plates usually represents the filling and provides additional thickness. Our surgical masks were therefore poured into a mould, which was then pressed in a high-pressure press at a temperature of 180 °C for 20 minutes. As the masks were melted, the mould was pressed for several hours to allow it to cool and harden into a plastic-like sheet. Between the melted polypropylene layer, we could see the ear band and the nose wires, which are now "glued" into the whole (Fig. 12).

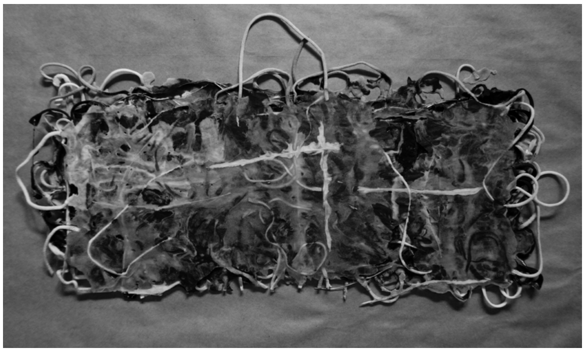

**Fig. 12.** *Testing the melting and cooling process of WDSM*

The entire plate was cold pressed together in a high-pressure press. The bottom part was the "backing layer" which is IXPE foam (radiation cross-linked polyethylene), the outer part is a decorative layer, a clear backing layer (which provides compressive strength and wear resistance) and the top layer is ultraviolet (UV) protection. Fig. 13 shows a sectional view of the designed WDSM flooring, and Fig. 14 shows a sample of the composite layers.

Considering the LCA, we wanted to ensure that as little energy as possible was used in the production of the middle layer, while completely avoiding the pollution of fresh water. The only possible disadvantage of such a flooring production would be the transport of the collected waste of surgical masks from the assembly centre to the factory/production line.

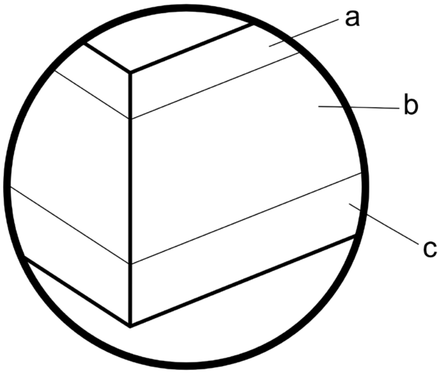


**Fig. 13.** *Graphical representation of the layers in a WDSM flooring; a UV protection, backing and decorative layer, b filling/WDSM layer, and c bottom backing layer*

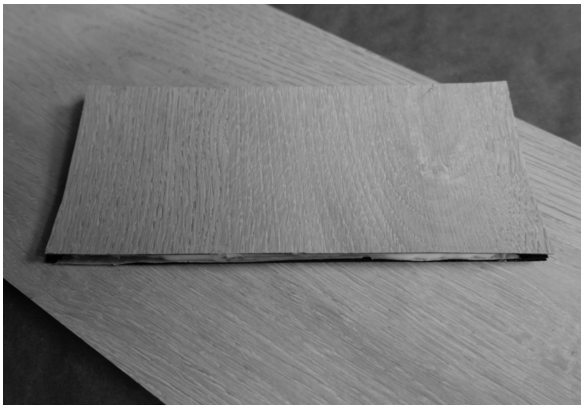

**Fig. 14.** *Sample of pressed layers of WDSM flooring*

## 5 CONCLUSIONS

Since the COVID-19 pandemic, the use and disposal of DSM has increased dramatically, resulting in DSM waste being thrown into landfills and the natural environment. Of particular concern is the breakdown of DSM into microplastics, which are already among the most damaging to the environment. The need to reuse and recycle facial masks has arisen even though the composition of DSM does not support a traditional recycling process.

The main objective of this research was to understand the environmental impact of DSM and to develop a product from used surgical masks. The research results combined with two different surveys helped us to design a prototype for a floor plate.

We changed the middle layer of a typical floor slab and replaced it with pressed and melted surgical masks. This layer provides enough stiffness and flexural strength to be used as flooring.

## 6 ACKNOWLEDGEMENTS

This work was partially supported by Slovenian Research Agency under the research programme P2-0118 Textile Chemistry.

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