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ARTICLE

Comparison of the performance properties of spunlaid non-woven fabrics used as face mask

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ABSTRACT

Face masks have an effect of preventing the spread of infectious diseases such as coronavirus disease 2019 (COVID-19). With these masks, it is primarily aimed to prevent the environment from being contaminated by the user. However, in the COVID-19 outbreak, many countries made it mandatory to use masks in areas with high human circulation such as marketplaces, shopping malls and hospitals, and then in all areas outside the home. Some tests such as filtration efficiency, microbial load, resistance to body fluids, flammability and breathability are performed to determine the protection potential and wearing comfort of face masks. In this study, we investigated the bacterial filtration efficiency (%), microbial load (cfu/g), breathability (Pa/cm^2) and air permeability values of five different face masks obtained by combining polypropylene (PP) nonwoven layers in different weights (accordance with EN 14683:2019 + AC:2019, EN ISO 11737-1:2018 and TS 391 EN ISO 9237 Standards). The surface morphologies of the nonwoven fabrics were characterized by scanning electron microscope (SEM). It was observed that the weight change in spunbond masks (1–4) was directly proportional to bacterial filtration efficiency and differential pressure, and inversely proportional to air permeability. In addition, SEM analysis showed that the average fiber diameter of the meltblown layer was at least 5.80 times smaller than the spunbond layers, and as a result, dramatic differences were also observed in the air permeability and differential pressure values of the Spunbond-Meltblown-Spunbond (SMS) mask (5) compared to spunbond masks.

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Mask; filtration efficiency; breathability; Covid-19; fabric weight; nonwoven

1. Introduction

The COVID-19 pandemic, in which the first case was seen in December 2019, reached approximately 298 million cases and 5 million deaths in almost 2 year (COVID-19 Dashboard, n.d). The three countries with the highest number of cases to date, accounting for about half of the total number of cases, are the U.S.A, India and Brazil, respectively (COVID-19 Situation by Country, Territory & Area, n.d). It has been reported that this disease is spread by respiratory particles such as droplets (>5–10 µm), droplet nuclei and aerosol (<5 µm) (WHO, 2014) or *via* fomites (Jayaweera et al., 2020). For this reason, hand hygiene, social distance and the use of face masks have been the most important weapons to prevent the spread of diseases such as COVID-19 (Kähler & Hain, 2020). A study conducted in China with the participation of 5981 people reported that 99% of the participants wore a mask during the COVID-19 pandemic (Tan et al., 2021). Although masks were first suggested to prevent contamination of the environment by the user, the use of masks has become mandatory in many countries in the COVID-19 pandemic. The use of masks has the potential to prevent the spread of the COVID-19 virus as well as other viral and bacterial pathogens transmitted through the respiratory passage (Chua et al., 2020). Some tests such as filtration efficiency, breathability and microbial load are applied to masks (Forouzandeh et al., 2021).The performance properties of masks are affected by many parameters such as fabric density, fabric composition and fabric weight (Lee et al., 2020).

In 1897, Carl Flügge and Emil Kocher discovered that infectious diseases spread through droplets (Gandhi et al., 2020). Dr. Jan Mikulicz-Radecki published the first study supporting the use of surgical masks in the same year (Chellamani et al., 2013). Dr. Alice Hamilton found *Streptococcus* bacteria in saliva droplets in 1905 and recommended that healthcare professionals close their mouths with a barrier during surgery (Chellamani et al., 2013). The Chicago Infectious Diseases Institute draws attention as the first institution to offer masks to protect healthcare professionals from respiratory infections (Chughtai et al., 2013). In addition to the use of cloth masks,disposable surgical masks began to be introduced in the 1960s (Chughtai et al.,

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2013). With the discovery of antibiotics in the 1940s, a dramatic decrease in bacterial infectious diseases (Aminov, 2017) led to a decrease in the interest in face masks (Gandhi et al., 2020). Some disease such as swine flu (H1N1), avian flu, ebola, severe acute respiratory syndrome (SARS), middle east respiratory syndrome (MERS) and finally COVID-19, which brought life to a standstill all over the world, caused an increase in interest in masks (Chu et al., 2020; Lau et al., 2008; Mohammed, 2015; Tang & Wong, 2004; Zhang et al., 2013).

Face masks can be made from woven, knitted or non-woven fabrics. Non-woven spunbond (S) and meltblown (M) fabrics are used for disposable masks. These masks are usually produced in three layers using meltblown in the middle and spunbond fabric in the inner and outer layers (SMS). Polystyrene, polycarbonate, polyethylene, polyester fibers are also used as raw materials, although polypropylene fibers are widely used (Chellamani et al., 2013). It has been reported that masks made of nonwoven fabrics provide protection for at least 4 h (Vincent & Edwards, 2016). These masks generally offer higher bacterial filtration efficiency (BFE) (Davies et al., 2013) and lower cost advantages compared to cloth fabrics.

In addition to disposable surgical masks and respirators such as N95, cloth masks are also frequently used, especially in countries with insufficient resources. Due to the cost of surgical masks at about 0.14 $ and respirators at 0.63 $ (Chughtai et al., 2013), people tend to use cloth masks in pandemic conditions where mask use is almost mandatory. However, the success of these masks in preventing the spread of respiratory infections is discussed. For this reason, many researchers recommend using cloth masks only in the absence of a surgical mask and respirator (Davies et al., 2013). Moreover, some studies reported that cloth masks produced from biodegradable raw materials such as cotton provide the necessary protection (Aydin et al., 2020) and that increasing environmental pollution can be prevented (Hartanto & Mayasari, 2021).

In disposable protective textile products, meltblown and spunbond nonwoven fabric structures provide advantages such as low cost and ease of production. The main differences in the meltblown and spunbond production stages are the drawing location and the temperature of the air used in the drawing. In the meltblown production technique, while the polymer is still molten, hot air is used at the exit of the spinneret. In this technique, while the hot air that converges with the filaments at the spinneret exit accelerates the fibers to form finer fibers, sufficient molecular orientation cannot be provided for good mechanical properties. However, in the spunbond technique, when the polymer comes out of the spinneret, it is solidified by cool air and the drawing is done at a certain distance from the spinneret. While this technique generally produces greater fiber diameters, it provides the necessary conditions for improving molecular orientation and mechanical properties. As a result, meltblown webs provide lower weight, lower strength, smaller filament diameter, smaller pore size, higher surface area and better filtration efficiency compared to spunbond webs. Meltblown webs are generally recommended to be used together with another structure such as spunbond (Hutten, 2007).

Table 1. Features of masks.

Sample code	Raw material	Ply and production process	GSM (g/m^2)
Mask 1	PP (%100)	2 ply-(SS)	Inner Layer-50 Outer Layer-50
Mask 2	PP (%100)	3 ply-(SSS)	Inner Layer-50 Middle Layer −30 Outer Layer −50
Mask 3	PP (%100)	3 ply-(SSS)	Inner Layer −30 Middle Layer −50 Outer Layer −50
Mask 4	PP (%100)	3 ply-(SSS)	Inner Layer −30 Middle Layer −30 Outer Layer −30
Mask 5	PP (%100)	3 ply-(SMS)	Inner Layer −20 Middle Layer −25 Outer Layer −30

Some parameters have effects on the filtration efficiency: size, velocity and shape of particles (Yassi & Bryce, 2004); structure and composition of fabric (Duran et al., 2013). However, the presence of moisture, mask design and distance travelled by droplets are other parameters that affect filtration efficiency. Increasing the moisture content of the mask (Spooner, 1967; WHO, 2014), decreasing the distance travelled by the droplets (Aydin et al., 2020; Weaver, 1919) and increasing the fiber thickness (Akduman & Akçakoca Kumbasar, 2018) decreases the filtration efficiency. As well as filtration efficiency, microbial load and breathability values are parameters that need to be examined. Breathability is measured by pressure differential, and high-pressure drops can cause breathing problems for users (Davies et al., 2013).

We measured bacterial filtration efficiency (BFE), breathability, microbial load and air permeability values of the masks obtained from PP nonwoven fabrics with different weights. The surface morphologies of the nonwoven mask fabrics were characterized by SEM. In the COVID-19 pandemic, where mask supply and costs are a current issue, we aimed to show that lower cost spunbond masks can have at least as much bacterial filtration efficiency as SMS masks, with better breathability when adequate conditions are met.

2. Materials and methods

2.1. Materials

Meltblown (M) and spunbond (S) nonwoven surfaces with different weights had been used on the mask layers. The process of combining the mask layers had been carried out by sewing. The weight analysis of fabrics was made in accordance with ISO 3801: 1977 standard. Raw material, layer quantities, product codes and weights of the masks used in the study are given in Table 1.

2.2. Method

2.2.1. Bacterial filtration analysis

BFE test was carried out in accordance with TS EN 14683 + AC: 2019 Annex B standard. Details on the BFE

Table 2. Application conditions of the BFE.

Test flow rate	28.3 L/min
Total test flow time	2 min
Number of Repetitions	5 pieces mask
test area	4.9 cm^2
Test condition	(21 ± 5) °C and (85 ± 5) % relative humidity, 4 h
Test microorganism	*Staphylococcus aureus* ATCC 6538
Bacteria concentration (cfu/ml)	5×10^5 cfu/ml
Incubation time and temperature	20–52 h, 37 ± 2 °C
Positive control sample average of number of bacteria (C)	3×10^3 cfu/ml
Mean particle size (MPS)	3.0 μm

test are given in Table 2. A specimen of the mask material is clamped between a six-stage cascade impactor and an aerosol chamber. An aerosol of *Staphylococcus aureus* is introduced into the aerosol chamber and drawn through the mask material and the impactor under vacuum. BFE of the mask is given by the number of colony forming units passing through the medical face mask material expressed as a percentage of the number of colony forming unit present in the challenge aerosol.

2.2.2. Breathability (differential pressure) analysis

Breathability test was carried out in accordance with TS EN 14683 + AC: 2019 Annex C standard. Information about the analysis made is given in Table 3.

2.2.3. Air permeability

Air Permeability test was carried out in air permeability test device (SDL ATLAS) at 100 Pa pressure in 38 cm^2 test area and in 3 repetitions according to TS 391 EN ISO 9237 standards. The data obtained as a result of the measurement are given in L/m^2/sec.

2.2.4. Microbial cleanliness (bioburden) analysis

Microbial Cleanliness test was conducted in accordance with EN ISO11737-1: 2018 and TS EN 14683 + AC: 2019 Annex D standards. The samples were weighted, put in the test solution and shaken well (250 rpm, 5 min). Later, they were inoculated on suitable agar. The plates are incubated for 3 days at 30 ± 1 °C and 7 days at 20–25 °C for Tryptic Soy Agar (TSA) and Sabouraud Dextrose Agar (SDA) plates, respectively. Total microorganism counts are calculated.

2.2.5. SEM analysis

SEM analysis were carried out with the Fei Quanta 250 Feg branded machine. Scanning electron microscope images were taken at 500× magnification to examine the surface morphology of specimens. Average fiber diameters were calculated by measuring 10 fiber diameters for each mask layer in SEM images.

3. Results and discussion

In the COVID-19 pandemic, where mask supply and cost are a current issue, we wanted to evaluate the performance of various masks made from spunbond-only layers against relatively higher-priced SMS masks. In this section, bacterial filtration efficiency (BFE), breathability, microbial load and air permeability values of the masks obtained from PP nonwoven fabrics with different weights were presented. The surface morphologies of the nonwoven mask fabrics were characterized by SEM.

Table 3. Information on breathability test application.

Test flow rate	8 L/min
Test condition	(21 ± 5)°C and (85 ± 5) % relative humidity, 4 h
Number of repetitions	5 pieces mask
Test area	25 mm

3.1. Bacterial filtration

BFE is one of the analysis methods needed to measure the effectiveness of medical masks against bacteria and similar sized microorganisms. As a result of the BFE analysis, the samples take a value between 1% and 99.9%. In order for the samples to be called medical masks, the BFE test result must be at least 95% and above (Type I). In addition, this value must be 98% and above (Type II and Type IIR) in order for the samples to have medium and high efficiency (EN 14683:2019 + AC:2019). According to these conditions, all masks except the mask 4 meet the required BFE criteria in the medical mask (%95,82–98,76). Mask 4 has a lower weight and fiber density per unit area than other masks, resulting in lower BFE (%87,72). Shokri et al. (2015) pointed in their studies that the number of fibers in unit area and a pore diameter are two of the parameters that affect the filtration efficiency of the fabric. Subsequently, they stated that high fiber density and low pore diameter increased the filtration efficiency. Although the weights of masks 2 and 3 are the same in the study, the arrangement of the spunbond surfaces used is different. This difference did not cause a significant change in the results. Masks number 2 and 3 meet the Type II requirements with BFE value of more than 98%. Also, mask 1 and mask 5 are seen to be in the Type I class. These results show that the fabric weight and the number of layers in the same structure change in direct proportion to the BFE value (Table 4). In addition, the BFE efficiency of the Mask 5 containing the meltblown layer is almost the same as the samples obtained from only spunbond, which has almost twice its weight. The reason why the meltblown layer increases the efficiency so much is related to the fact that it contains more fibers than other samples and has less air permeability, as can be understood from SEM analysis.

Table 4. BFE results of the masks.

Sample Code	Bacterial filtration efficiency (%)	Total weight (g/m^2)	Number of layers/structure
Mask 1	95,82 ± 0,18	100	2 (SS)
Mask 2	98,76 ± 0,15	130	3 (SSS)
Mask 3	98,50 ± 0,2	130	3 (SSS)
Mask 4	87,72 ± 0,58	90	3 (SSS)
Mask 5	96,14 ± 0,38	75	3 (SMS)

Note: S: Spunbond, M: Meltblown

Table 5. Differential pressure properties of masks.

Sample code	Differential pressure(Pa/cm^2)	Total weight (g/m^2)	Number of layers/structure
Mask 1	5.42 ± 0,33	100	2 (SS)
Mask 2	7.4 ± 0,70	130	3 (SSS)
Mask 3	6.98 ± 0,27	130	3 (SSS)
Mask 4	1.48 ± 0,30	90	3 (SSS)
Mask 5	34.68 ± 4,3	75	3 (SMS)

3.2. Breathability (differential pressure)

Differential pressure method determines how air passes from one side of the mask to the other (easy or hard). While the pressure value is required to be less than 40 Pa/cm^2 for Type I and Type II in the relevant standard, this value is determined as less than 60 Pa/cm^2 for Type III. According to the differential pressure results, it is seen that all of the mask samples (1–5) can be used as a medical mask. First, significant differences was not observed between Mask 2 and 3, whose weight and structure were the same but whose layer orders were different. In addition, the lower differential pressure value of the mask, the greater the breathability value (Hartanto & Mayasari, 2021). That is, breathability and differential pressure are inversely proportional. According to this information, the best result was obtained in Mask 4 and the worst result in Mask 5. The meltblown layer in Mask 5 leads to this result because of it has smaller pores than spunbond layers (Hutten, 2007). Furthermore, the BFE values of Masks 1–4, which are produced from fabrics with the same structure, change in direct proportion to the differential pressure, in accordance with the literature (Jung et al., 2010). As a result, the increase in weight in spunbond masks increases the differential pressure value. Differential pressure results are given in Table 5.

3.3. Microbial cleanliness

Microbial cleanliness is a method used to determine the amount of viable bacteria and fungi formed on the masks that are kept under suitable conditions for a certain period of time. In order for a mask to be used for medical purposes, it is stated in the relevant standard that the microbial cleaning value should be below 30 cfu/g. All masks appear to conform to the standard, with test results of 12–18 cfu/g. Although the results are close to each other, masks 1, 4, and 5 have best microbial cleanliness results. The reason why the analysis results give similar values to each other is that all samples are produced from the same raw material (PP). Teufel et al. (2010) stated that the type of raw material also affects the bacterial growth in their study about types and amounts of bacteria that grow after human contact on knitted fabrics produced from different raw materials. This study supports the justification we have presented above. Microbial cleanliness test results of the samples are shown in the Table 6.

In Table 6, the measurement results of the amount of colonies formed in 1 gram of mask fabric are given. When looking at the correlation between SEM images of fabrics and colony formation, it is seen that the gaps between the filaments in the 50 g/m^2 weight spunbond fabric structure are less than the 30 g/m^2 weight spunbond fabric. The number of colonies formed in this fabric structure was 18 cfu/g. However, in the same 3-layer spunbond fabric structure, when 30 gr/m^2 fabric structure remains in the inner layer, the number of colonies formed decreases to 13 cfu/g. It can be said that the permeability towards the interior is less. Colony amount observed after measurement in spunbond fabrics and SMS fabric structure with the same weight was the same (12 cfu/g).

3.4. Air permeability

Air permeability is an analysis made to understand how much of the air applied through the fabric passes. Basically, it depends on the weight, thickness and porosity of the fabric. The air permeability results show that the air permeability decreases with the increase in weight (except of the Mask 5). Epps and Leonas (2000) also stated that the increase in weight especially in nonwoven fabrics decrease air permeability, as in our study. The reason Mask 5 was excluded from this result is due to the metblown middle layer, which is structurally different from the other four samples. The difference created by the meltblown layer is also seen in the SEM images (Figure 1). In summary, the most air-permeable sample is number 4, while the least air-permeable sample is number 5. In addition, studies in the relevant literature have stated that low air permeability is a feature that increases mask performance (Babaahmadi et al., 2021). When the samples are evaluated in this respect, it can be said that the best sample is mask 5. As can be seen in the Table 7, the reason why the mask 5 is less breathable is again due to the middle layer (meltblown).

3.5. SEM analysis

SEM analysis was performed in order to see the pore structure of the mask layers having different weights and

Table 6. Microbial cleanliness of masks.

Sample code	Microbial cleanliness (cfu/g)	Total weight (g/m^2)	Number of layers/Structure
Mask 1	12	100	2 (SS)
Mask 2	18	130	3 (SSS)
Mask 3	13	130	3 (SSS)
Mask 4	12	90	3 (SSS)
Mask 5	12	75	3 (SMS)

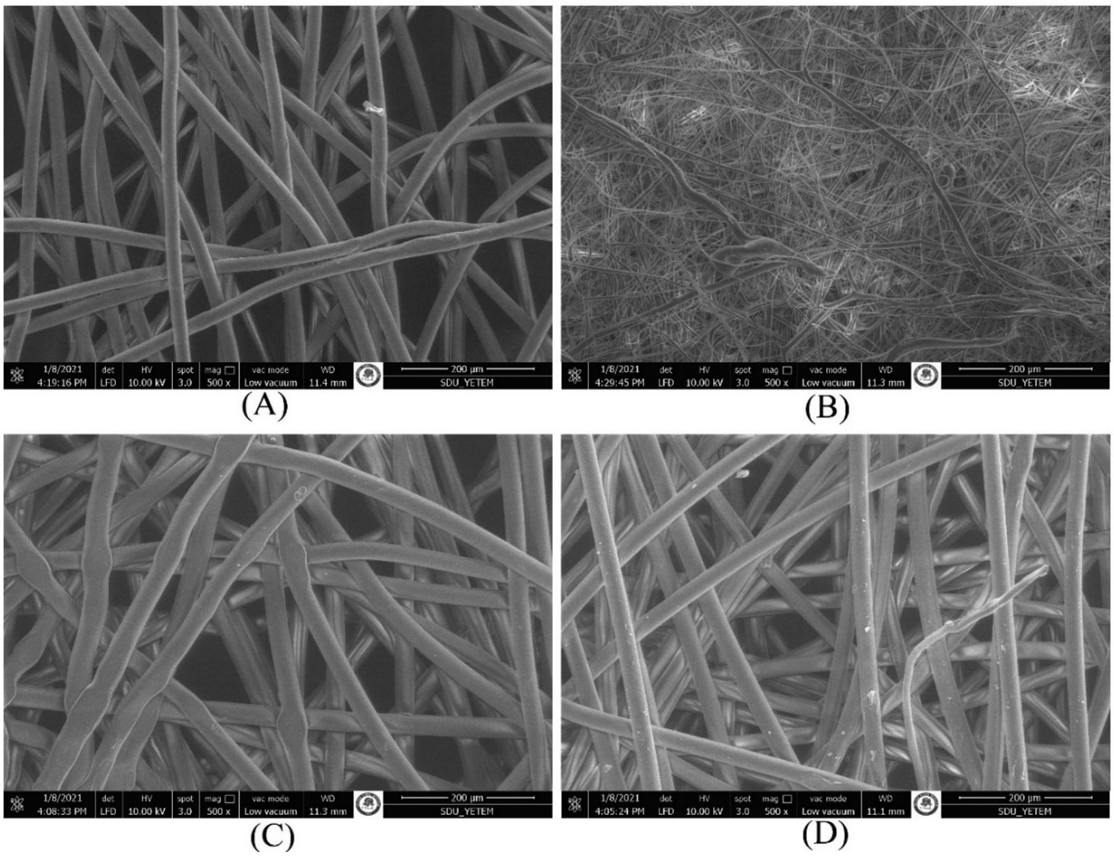

Figure 1. SEM images of nonwoven fabrics used in mask production under 500× zoom; (A) 20 g/m^2 spunbond (was used in mask 5), (B) 25 g/m^2 meltblown (was used in mask 5), (C) 30 g/m^2 spunbond (was used in mask 2, 3, 4 and 5), (D) 50 g/m^2 spunbond (was used in mask 1, 2 and 3).

Table 7. Air permeability properties of samples.

Sample Code	Total weight (g/m^2)	Inner layer (L/m^2/s)	Middle layer (L/m^2/s)	Outer layer (L/m^2/s)	All layers (L/m^2/s)
Mask 1	100	1920	–	1650	990
Mask 2	130	1740	3190	1660	773
Mask 3	130	3100	1780	1660	819
Mask 4	90	3720	3210	3480	1447
Mask 5	75	3410	156	2220	141

Table 8. Average fibre diameters of mask layers with different weights: (A) 20 g/m^2 spunbond (was used in mask 5), (B) 25 g/m^2 meltblown (was used in mask 5), (C) 30 g/m^2 spunbond (was used in mask 2, 3, 4 and 5), (D) 50 g/m^2 spunbond (was used in mask 1, 2 and 3).

Sample Code	Average Fibre Diameter(μm)
A	21,41 ± 1,63
B	3,69 ± 0,89
C	25,83 ± 3,50
D	28,06 ± 0,47

to calculate the fibre diameters. As a result of the analysis, it is seen that the pores on the spunbond nonwoven surfaces shrink with the increase in weight. This is due to the increased number of fibers per unit area and supports other results achieved. When the spunbond and the meltblown layers are compared, it is seen that the pores on the meltblown layer are much smaller than the spunbond. Also, as can be seen from the Table 8 and Figure 1, fibers in spunbond structure are almost 10 times larger than fibers in meltblown. This supports that there is more fiber per unit area in the meltblown layer.

4. Conclusions

In this study, the effect of weight and structure change on the performance properties of masks was investigated. Five different masks (Masks 1–5) obtained from polypropylene nonwovens were examined for bacterial filtration efficiency, breathability, microbial load and air permeability. Surface morphologies of fabrics were characterized by SEM images. Mask 1-4 consists of spunbond, mask 5 consists of meltblown in the middle and spunbond fabrics in the outer layers. Mask 1–5 have a total weight of 100, 130, 130, 90, and 75 g/m^2, respectively. The weight change in spunbond masks (1-4) is directly proportional to bacterial filtration efficiency and differential pressure, and inversely proportional to air permeability. There was no significant difference between the microbial load values of the masks (Except Mask 4). The SMS mask (5) has the lowest weight but higher BFE than Masks 1 and 4. However, it has 4.59 times higher differential pressure values and 5.48 times lower air permeability than the highest weight spunbond mask. It is seen that the 2-layer spunbond mask with 95.82% BFE and 5.42 Pa/cm^2 differential pressure value meets the same standards as the SMS mask that gives 96.14% BFE and 34.68 Pa/cm^2 differential pressure value (TS EN 14683 + AC: 2019 Annex B and C). Provided with sufficient weight, spunbond masks appear to be a good alternative to SMS masks, with lower prices and better breathability.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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