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Evaluation of some physical and tensile properties of commercial surgical masks

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In this study, the performance characteristics of various surgical masks have been examined. Several physical properties, such as air permeability, tensile strength, and calculated surface porosity of 8 commercial 3-layer surgical masks, with all spunbonded layers and meltblown middle layer, have been determined and then compared. The production type of the nonwoven layer is effective on the air permeability values, and the values of the spunbonded masks are found higher than the masks containing a meltblown layer. The air permeability of the latter masks varies with the weight per unit area of the meltblown layer. Moreover, calculated porosities of the spunbonded masks are higher than those of the others. The influence of meltblown layers is found effective on the tensile strength values in machine direction.

Keywords: Air permeability, COVID- 19 pandemic, Nonwoven, Surgical masks, Tensile strength

1 Introduction

Masks, one of the most basic personal protective equipment, are disposable or reusable breathable textile-based structures that protect human beings against chemical, physical, and biological contaminations. U.S. Food & Drug Administration classified the personal protective equipment for infection control as N95 respirators, face masks, surgical masks and barrier face coverings. While academic studies on masks continue in a certain scope and progress, there has been an incredible increase in the number of studies after the declaration of the COVID-19 pandemic in March 2020. The results of the first studies about masks, conducted just after the declaration of the pandemic, revealed that they protected individuals against coronavirus infection[1-3]. Therefore, a new and hot academic topic was born in this field in order to determine the basic features of masks.

Human to human transmission of viral infections may happen in a variety of ways. These are inhalation of respiratory droplets, direct contact to infected person, indirect contact, sources, and vector borne transmission[4]. Early studies asserted the importance of wearing masks in indoor environment where the ventilation is poor to prevent transmission via respiratory droplets[5, 6]. Studies highlighted that wearing a mask in indoor public places and healthcare setting is mandatory in most of the countries. In some countries, these prohibition practices are still continued. It seems that these prohibitions will continue until the pandemic is completely over. In USA, regulations for use of masks are changing in state by state. It is possible to get information if use of mask is requirement or recommendation from states' health departments for local laws, rules or guidances. States[7], are following recommendations of Centers for Disease Control and Prevention (CDC), which is an officially federal, health protection agency[8,9] under U.S. Department of Health and Human Services[10] established in 1946 and headquartered in Atlanta, Georgia[11]. Their mission is to protect America from health, safety and security threats, both foreign and in the US[8]. In CDC's last Guide for Masks (January 2022), there are recommendations for each state in COVID-19 County Check Data Tracker according to transmission rate[12]. According to latest regulations (lastly reported by 15th February 2022), in most states including California, New York, Delaware, Hawaii, Illinois, New Mexico, Oregon and Washington; people should wear a mask in public, indoor settings. But it is also remarked that mask requirements might vary from place to place and citizens should follow local laws, rules, regulations or guidance[13].

In Europe, each European Governments' mandated wearing mask regulations are different[14]. Official guidance and regulations of local, state and national authorities can be checked in European Commission website for each government. By European Union COVID traffic light system, they show the overview of the epidemiological situation in individual member

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states (generally in their health ministry websites). European Centre for Disease Prevention and Control (ECDC) which is an EU agency aimed at strengthening Europe's defences against infectious diseases[15], publish recommendations for public health measures[16]. In its last report of EDCD (7 February 2022), the use of medical mask is classified in four groups of settings. For outdoor conditions, when physical distancing is not possible, wearing mask should be considered as they stated. In indoor conditions like in public spaces (public transport, supermarkets), wearing mask should be used either. As households, if someone has the symptoms of COVID-19, masks should be wear. As care settings, for protecting elderly or vulnerable people, face masks should also be considered[16]. When it is checked, regulations for Germany, mask wearing is mandatory in schools from the seventh grade and upwards. For public places (transport, public buildings), people above 6 years old must wear a face mask (surgical masks, KN95, or FFP2 masks) also in the places that social distances rules couldn't be kept[14].

Performance and mask design, which are the indicators of the protection of masks against viruses or other microorganisms, greatly affect consumer preferences. Although the basic features of the mask are less important for people who wear the mask only for short periods of time in social areas, this importance is much higher for people who need to work indoors and wear their masks for at least 8 hours.

Characteristics of mask filter, such as fibre packing density, thickness and chemical structure, along with the external factors affect the filtering efficiency of the masks[17]. N95 masks have higher filtration efficiency[18]. N95 masks block at least 95% of droplet-sized particles and aerosols[19]. Surgical masks as well as N95 masks are also effective in significantly reducing the risk of infection[20,21]. It is important that the masks should provide comfortable breathing to people besides the filtration efficiency. Lower values of pressure drop indicate that the mask is more breathable[22]. Although N95 masks have higher filtration efficiency, their breathability is lower than surgical masks. The higher air and water vapour permeability properties of surgical masks affect this situation[20]. The study comparing several physical properties of the surgical masks and N95 respirators stated that the pressure drop values at rest, light, moderate, and heavy conditions of N95 respirators were higher than the surgical masks[23]. Arumuru *et al*.[24] conducted a study on the comfort and pressure drops in inhalation and exhalation in case of wearing double masks. They observed that the pressure drop of surgical masks is lower than that of N95 masks.

The masks can be produced via weaving, knitting and nonwoven production techniques, and the production technique directly affects the mask performance[25]. The nonwoven fabrics outperform in terms of airborne droplet filtration and air permeability than woven and knitted fabrics[26]. In this context, the researches reveal that the surgical masks are the most preferred ones because they are easily accessible, disposable, and cheap[27-29]. Polypropylene (PP) is the most widely used polymer in the production of surgical masks. The non absorbent properties, mechanical integrity, printability, air permeable, low cost, and reusability of PP are outstanding features[30,31]. Moreover, it can be easily processed in meltblowing and it is very effective in filtration applications since it can be produced by addition of a nucleating agent for increasing filtration performances[32, 33]. Beside the PP, polyester, polyethylene and polystyrene are also used in surgical masks[25, 26, 29]. Generally, surgical masks consist of three layers. The outer and inner layers are generally produced with spunbonding technique and the outer layer can be colored and patterned. Since the inner layer touches the skin, it should be soft and should not irritate the skin. For this reason, no chemical treatment is applied to the inner layer[27]. The spunbond and meltblown fabrics can be used as the middle layer. This layer has the highest filtration efficiency.

In this study, it is aimed to determine some of the basic features of 8 different 3-layer masks that are found as commercial products in the market. For this purpose, several basic properties of masks and the fabrics that form masks are determined.

2 Materials and Methods

Eight different polypropylene (PP) nonwoven commercial disposable surgical masks and fabrics were investigated in this study. The surgical masks were of 3 layer and produced with spunbonding (S) and meltblowing (M) techniques. The characteristics of the masks are given in Table 1.

Weight per unit area values of the plies and masks were determined by an analytical balance with 0.1 mg sensitivity (Radwag, Poland) at standard atmosphere conditions (20±2°C temperature and 65±5% relative humidity). Thicknesses of the masks were determined

Table 1 — Characteristics of surgical masks

Sample code	Production process	Thickness, mm	Weight per unit area, g/m^2			Total weight of 3 layers, g/m^2
			Outer layer	Middle layer	Inner layer	
M1	SMS	0.29±0.02	21.24	29.48	22.00	72.72
M2	SMS	0.31±0.01	24.95	23.03	26.15	74.12
M3	SMS	0.33±0.01	30.24	28.25	21.67	80.12
M4	SMS	0.43±0.01	35.87	26.03	31.48	93.36
M5	SMS	0.18±0.01	14.40	11.03	16.93	42.48
M6	SSS	0.30±0.01	23.79	19.45	27.94	71.20
M7	SSS	0.31±0.02	25.01	36.16	29.91	91.04
M8	SSS	0.36±0.01	26.88	26.36	31.64	84.88

SMS–Spunbond-Meltblown-Spunbond, SSS–Spunbond- Spunbond –Spunbond.

by a micrometer (Mitutoyo, Japan). Moreover, optical microscopic images of all layers were taken by a stereo microscope (Olympus, Japan). Average fibre diameters of the masks were measured by taking approx. 12 fibres observed on the images into consideration via Image J software. In addition, the surface porosity values calculated from the 2D images of all layers were computed using Image J software by determination of area fraction (%) after adjustment of images as 8 bit and thresholding.

The air permeability values of the samples were measured by Prowhite Air Test II according to EN ISO 9237 standards at 100 Pa pressure in 20 cm^2 test area. The measurements were taken from both sides of the surgical masks. The tensile strength of the surgical masks was evaluated according to the ISO 9073-3:1989 standard in longitudinal (machine, MD) and transverse (cross, CD) directions by a homemade tensile tester. Elongation values were also recorded.

3 Results and Discussion

This study focuses on the determination of mechanical and physical properties of disposable PP 3-layer surgical masks that are commercially available. Table 1 summarizes the basic characteristics of the surgical masks. M1 to M5 were produced by SMS layers, on the other hand M6 to M8 were produced by the composition of SSS layers. The mask M4 shows the highest thickness and total weight values. The thinnest and the lightest mask is M5.

The air permeability values of surgical masks are given in Fig. 1. It is observed that the air permeabilities of the SMS masks are lower than that of the SSS masks. The air permeability of a surgical mask is important in terms of providing high filtering capacity[34] and breathing capability. Besides, it should block the entry of microorganisms during inhalation. Air permeability of nonwoven fabrics is affected by several parameters, such as porosity[35], weight, thickness, fibre diameter and fibre distribution in the nonwoven web[29, 36-38]. It is revealed that the meltblown layers are the efficient layers in blocking and they have lower porosities than the spunbonded layers. They have a compact structure compared to spunbonded ones[35]. Since the calculated surface porosity values of the SMS masks are lower than the SSS masks (Table 2) in accordance with the literature, higher air permeabilities of the SSS masks are expected. When the air permeability values of the SMS masks are considered within groups, it is observed that the M5 shows the highest air permeability value. When the unit weight and air permeability graph is drawn for these 5 masks (M1-M5), it is observed that the relationship between these parameters is based on an exponential and strong negative correlation (Fig. 2). The low thickness, low total weight and high porosity values of M5 are also responsible for the highest air permeability. The variation in the air permeability of SSS masks cannot be attributed to any measured physical property. Low air permeability means high filtration efficiency, as it traps the airborne particles more effectively[29,36]. Among all masks, the mask with the lowest air permeability and therefore the most efficient in terms

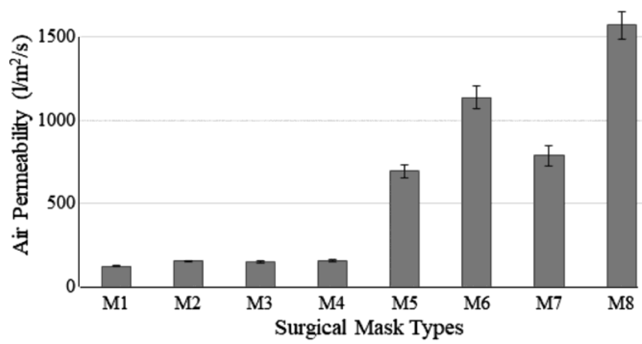


Fig. 1 — Air permeability values of surgical masks

Table 2 — Microscopic images of layers of surgical masks, average fibre diameters, and calculated surface porosity values

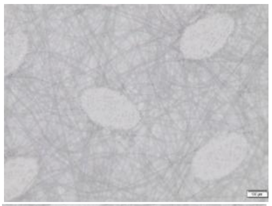
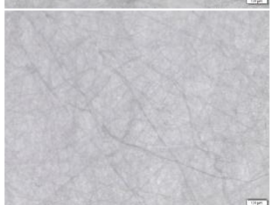
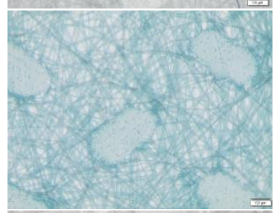
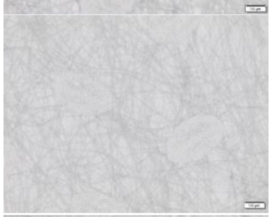
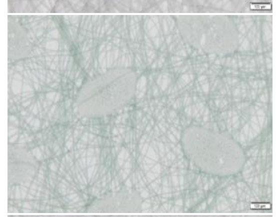
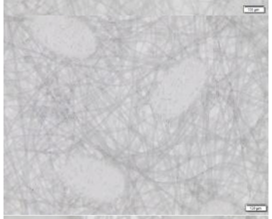
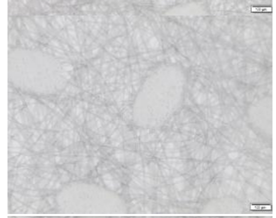
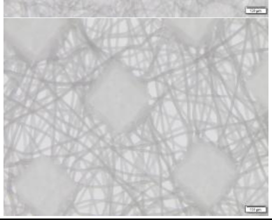
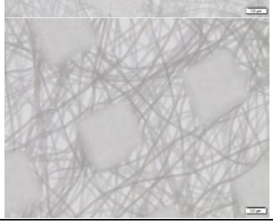
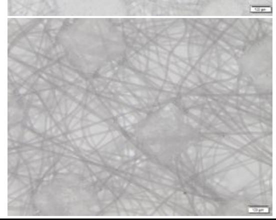
Mask	Inner surface	Middle surface	Outer surface	Average fibre diameter, µm	Calculated surface porosity, %
M1				6.80±0.02	7.08
M2				6.63±0.01	4.61
M3				6.78±0.02	10.56
M4				7.05±0.02	7.83
M5				6.78±0.01	11.39
M6				6.60±0.01	12.29
M7				6.87±0.02	11.41
M8				6.45±0.01	18.87

Table 3 — Tensile strength and elongation values of masks

Sample code	Tensile strength, GPa		Elongation, %		Breaking load of elastic band attachment, kN	Elongation in elastic band attachment, %
	MD	CD	MD	CD		
M1	0.30±0.04	0.70±0.04	5.90±0.17	3.83±0.42	1.07±0.27	7.93±1.10
M2	0.21±0.01	0.87±0.03	3.70±0.26	3.70±0.20	1.12±0.37	6.40±0.53
M3	0.38±0.03	0.70±0.02	5.00±0.86	3.53±0.32	0.89±0.15	6.97±0.68
M4	0.33±0.01	0.66±0.02	4.00±0.01	3.97±0.06	0.50±0.07	7.33±0.64
M5	0.44±0.03	1.10±0.14	4.27±0.15	4.30±0.10	0.73±0.13	6.40±0.81
M6	0.45±0.04	0.80±0.16	3.77±0.05	3.50±1.00	0.70±0.16	5.70±0.30
M7	0.45±0.09	0.58±0.11	3.70±0.45	3.73±0.38	0.82±0.16	7.10±1.08
M8	0.44±0.02	0.69±0.03	7.00±0.99	6.17±0.25	1.21±0.26	8.60±1.30

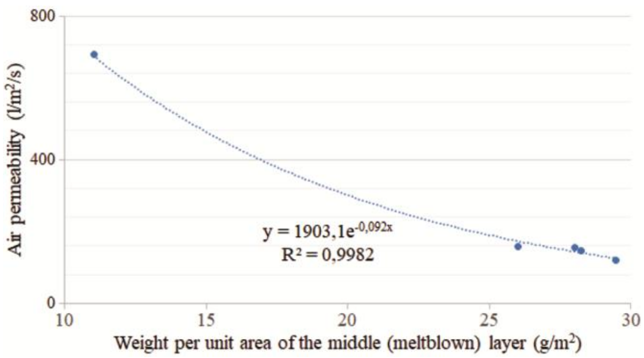


Fig. 2 — Variation in air permeability with weight per unit area of the meltblown layer

of filtration is M1. The most breathable mask is observed as M7. In order to choose the best mask for use; breathability, pressure drop, filtering capacity, and microorganism blocking should be evaluated together.

Although the strength of meltblown fabrics is generally lower than spunbonded fabrics[29,35], there is no tendency observed in the tensile strength values of the SMS masks in both MD and CD, as compared to the SSS masks (Table 3). Fibre diameter, fibre orientation, fabric weight, and thickness play crucial roles in tensile properties of nonwovens[35]. M5, which is the thinnest and lightest mask among meltblown masks, shows the maximum tensile strength values in both directions. Besides, it has the maximum air permeability and the calculated surface porosity values in the SMS masks group. M2 exhibits the minimum tensile strength in the MD, and for CD, M4 which has the highest total weight, shows the minimum tensile strength. The increase in the porosity values of the SSS masks results in a decrease in the MD tensile strength values.

In all tested surgical masks, the rubber bands in round cross sectional or strip formed are attached to the masks by ultrasonic welding or heat calendaring techniques. No effect of rubber band form and bonding techniques on the attachment point breaking load is observed.

4 Conclusion

In this study, some of the basic features of eight different commercial surgical masks have been investigated. The air permeability values of the masks formed by spunbonded layers are found higher than the masks containing meltblown middle layer. It can be concluded that the spunbonded layered masks are more breathable. The weight per unit area of the meltblown layer varies exponentially with the air permeability values of the SMS masks. Porosity, that is a significant factor affecting air permeability and filtering capability, is calculated from the 2D images of the mask layers. There is a tendency of an increase in air permeability with the increasing calculated surface porosity. According to the results of the tensile strength properties of masks, the presence of the meltblown layer in the masks is seen as an efficient factor.

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