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Research Article

Improvement of Moisture Management Properties of Face Masks Using Electrospun Nanofiber Filter Insert

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Face coverings such as a face mask are one of the important preventive measures amidst the COVID-19 pandemic, by limiting exhaled particles and reducing expiratory droplet spread. Adding a filter to face masks may offer extra protection against the virus. Nevertheless, there remains a significant concern where thicker, tightly woven materials of masks may reduce the ability to breathe comfortably, due to inadequate moisture management properties of woven fabric in existing disposable surgical face masks. Therefore, the study on the properties of air permeability, water vapor permeability, and flexural rigidity of a face mask fabric is highly essential. This study is aimed at analyzing the potential application of electrospun nanofibers fabricated from electrospinning technique, as filter inserts in commercial surgical face masks. The function of electrospun nanofiber filter (NF) inserted in commercial surgical face masks was introduced in the study. The results indicated the significant reduction in air permeability and water vapor permeability along with the additional usage of electrospun NF within the surgical face masks, due to the smaller fiber size and interspaces in the filter layer as analyzed from FESEM analysis. The percentage of air permeability value was slightly decreased by 15.9%, from 339.5 to 285.5 mm/s, whereas the value of flexural rigidity of surgical face masks with and without electrospun NF insert is 0.1358 and 0.1207 mg/cm, respectively. Hence, the NF inserts are recommended as the potential core component in a face mask.

1. Introduction

Coronavirus disease 2019 (COVID-19) is described as an illness that originated from a novel coronavirus known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [1]. This coronavirus outbreak denoted as their first case of pneumonia of unknown cause was reported to the World Health Organization (WHO) China Country Office in December 2019 from Wuhan City, Hubei Province, China [2–3]. As of October 2020, there have been over 42 million cases of COVID-19 worldwide and more than 205 countries have been impacted by the disease [4]. As the society continues to adapt to life amidst the pandemic, there are few preventive measures against COVID-19 being suggested by the WHO and the United States Centres for Disease Control and Prevention as such the practice of self-quarantine, social distancing, and personal hygiene. Aside from the abovementioned preventive measures, the WHO has now advised the general public to wear a face covering such as face masks in public spaces, if necessary [5]. The outspread of respiratory illnesses are principally caused by droplets expelled from the nose and mouth. Therefore, by covering these body parts, face masks will significantly reduce the spreading of respiratory disease at its source [6].

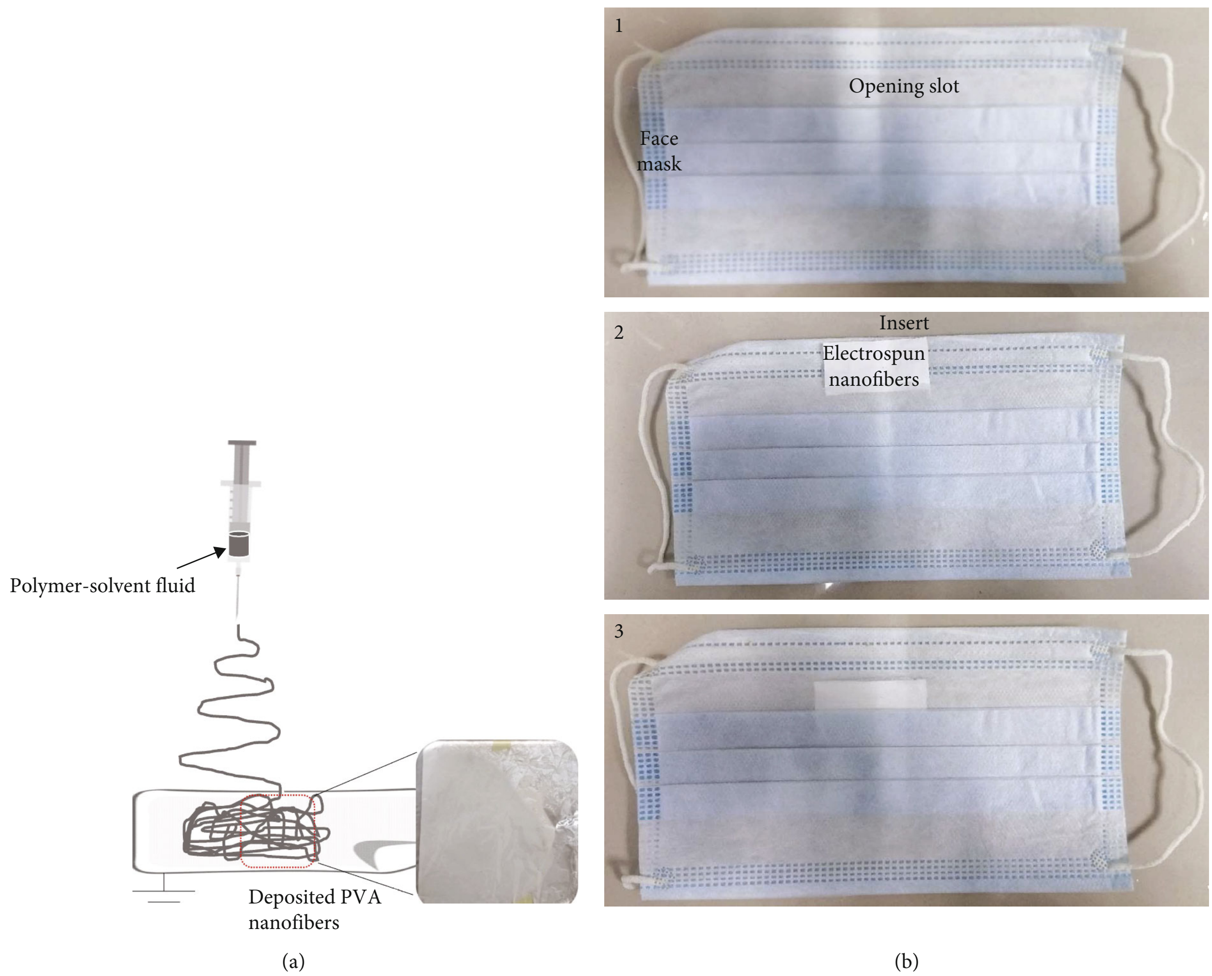

Figure 1: Preparation of electrospun nanofiber filter insert.

The common and widely used face masks by the citizens to minimize their exposure to crowds are commercial surgical face masks [7–9]. In general, these existing surgical face masks are made out of three-ply construction nonwoven polypropylene (PP) fabric created from a melt blowing process, with a fine inner mesh of submicron polymeric fibers that functions as a filter in the middle layer of a face mask structure [10, 11]. These fabric structures can affect the comfort properties of the face mask. Air permeability and water vapor permeability are two parameters associated with the comfort properties of textile materials. According to Yang et al. [12], wearing a face mask promotes heat stress, sweating, and discomfort in hot and humid weather. Therefore, identifying the air and water vapor permeability is essential for face mask materials. Aside from air and water vapor permeability, the flexural rigidity of the face mask also has an impact on the wearer's comfort. In textiles, materials with randomly oriented fibers have high rigidity, resulting in poor comfort properties to the wearer [13–14]. The face mask material is a nonwoven fabric constructed with randomly oriented fibers. Hence, research on the flexural rigidity of the face mask materials is required1. More recently, the interest in adding a filter to face masks has been expanded. Wang et al. [15] reported that developing a comfort mask with improved filtration requires a combination of different types of matrix material. By studying the bending behavior, the properties of fabrics such as comfort and handling can be understood. The use of electrospun nanofibers made by electrospinning has been investigated in the current study. Electrospinning is a technique to produce nanosize range of interconnected fibrous materials, which are potentially to be applied as mask fabric. On that basis, this study attempts to fabricate nanosized electrospun fibers generated from electrospinning that are able to control the air permeability throughout the mask's fabric. The incorporation of filter inserts made up of electrospun nanofibers hypothetically will provide superior properties over melt-blown fibers such as small pore diameter, large surface area per mass ratio, and good flexibility. The scope of this study relates to the performance of electrospun nanofibers as a mask filtration insert by examining the water vapor permeability, air permeability, and flexural rigidity of the face masks.

2. Materials and Methods

2.1. Procedure for Electrospinning. Polyvinyl acid (PVA), molecular weight (Mw) 125,000 g/mol, 99% hydrolyzed (Sigma-Aldrich) was selected as the material used to produce

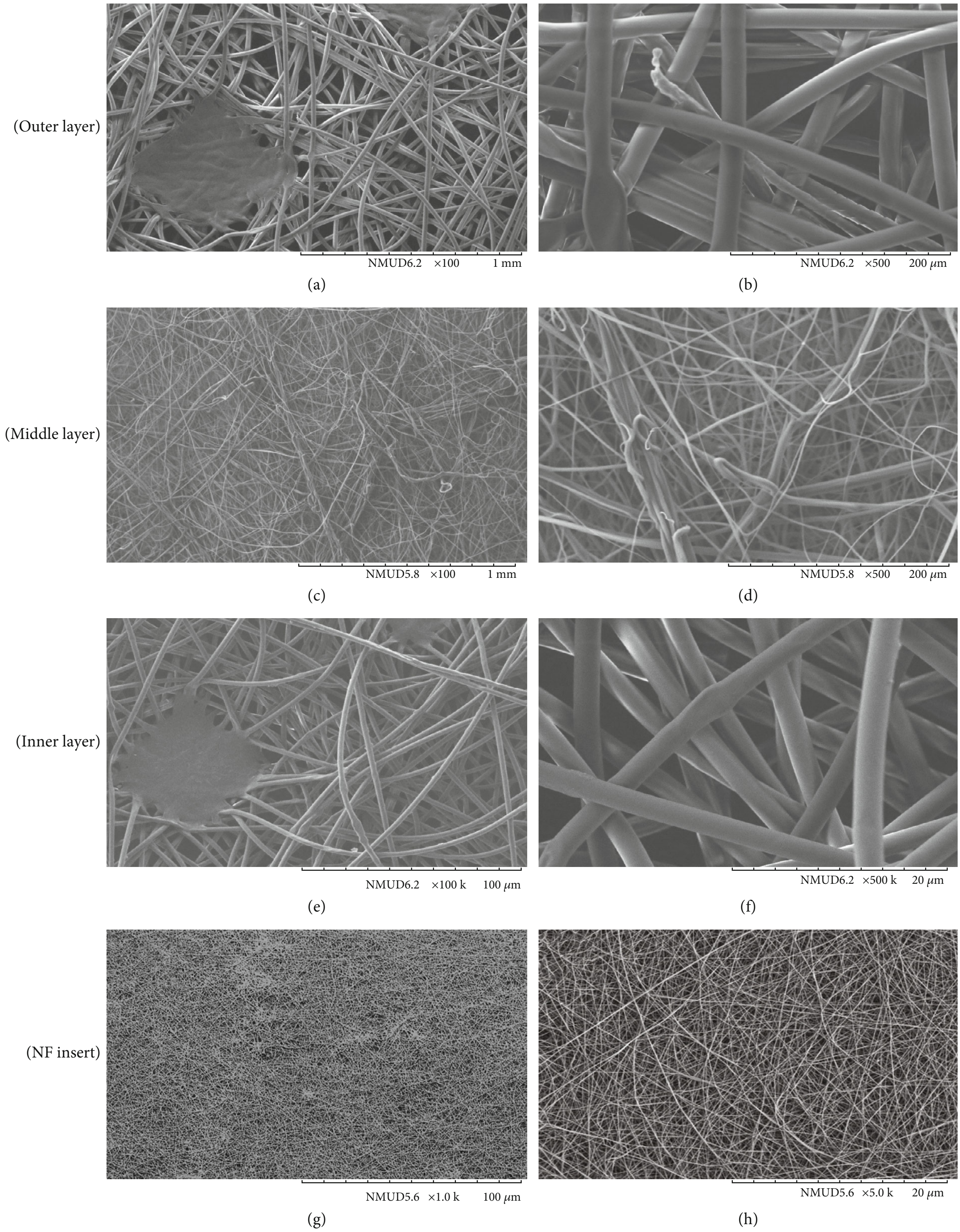

Figure 2: FESEM images showing the fiber structure of different layers in a surgical mask at different magnifications: (a, c, e) 100x, (b, d, f) 500x, (g) 1000x, and (h) 5000x.

electrospun nanofiber filter insert due to their excellent gas permeability, flexibility, and thermal characteristic [16–17]. The prepared 10 wt% PVA solution was then loaded into a plastic syringe equipped with a 0.4 mm internal diameter blunt needle, with a needle-collector distance of 10 cm, attached to a high voltage power supply and the ground

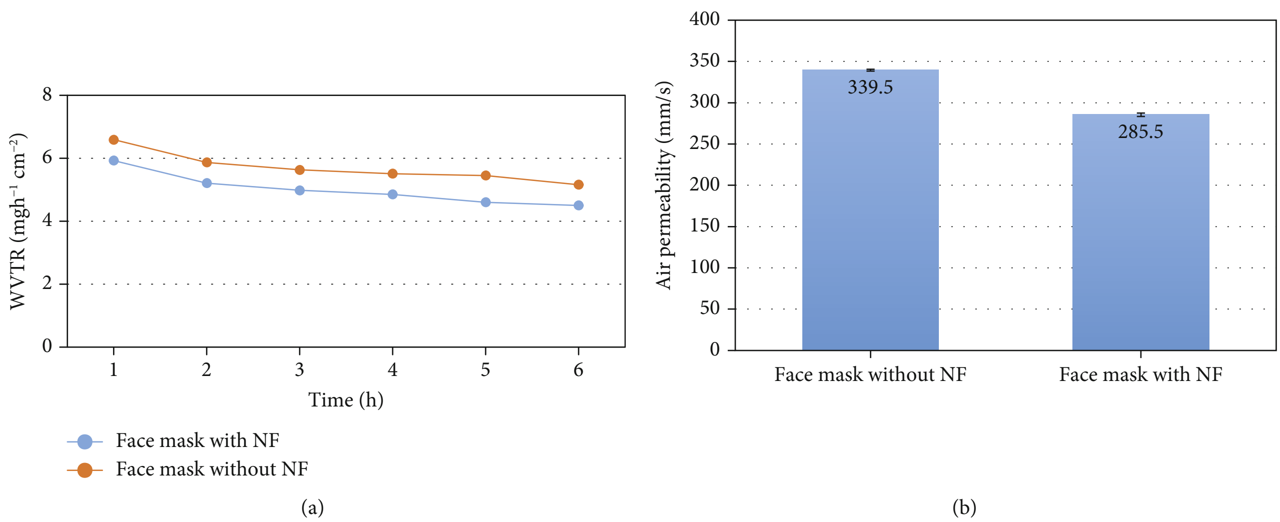

Figure 3: (a) Water vapor transmission rate (WVTR) and (b) air permeability of a surgical face mask with and without electrospun nanofiber (NF) inserts. The WVTR error bars were neglected due to a low value.

connected collector as in Figure 1. A high voltage value of 15 kV was applied to the tip of the needle to create voltage differences between the needle and a ground collector. A syringe pump was used to deliver the polymer solution from a syringe to the needle at a fixed rate of 0.5 ml/hr. The electrospinning setup was described elsewhere [18–20].

2.2. Morphology Observation. The surface morphology of the fabricated electrospun PVA nanofiber membrane was characterized using FESEM (Carl Zeiss, Supra 40vp) operated at an accelerating voltage of 10 kV. Nanofiber specimens were gold-coated using a sputter coater (Sputter Coater 108; Cressington Scientific Instruments) prior to FESEM analysis. A total of 50 fiber diameter measurements were taken randomly from FESEM images and measured using an image analysis software (Image J, National Institutes of Health, USA).

2.3. Preparation of Electrospun Nanofiber Filter Insert Face Mask. A simple and straightforward method to assemble an electrospun nanofiber (NF) filter insert into a surgical face mask was prepared according to Tebyetekerwa et al. [7]. Firstly, a small opening slot was created in the middle layer of the face mask., which can fit a NF filter. A rectangular membrane of NF filter of dimensions 2 cm × 5 cm and thickness 1.0 mm was inserted into an opening slot created on the commercial surgical face mask (INAFAS brand, three-ply disposable surgical face mask, Henso Medical (Hangzhou) Co., Ltd). Figure 1 shows the procedure to assemble an NF filter insert into a face mask.

2.4. Measurement of Flexural Rigidity, Air Permeability, and Water Vapour Permeability. The flexural rigidity test was conducted using the SDL Stiffness Tester. The flexural rigidity of both face mask fabric and electrospun nanofibers by applying the equation:

$$B = WC^3, \quad (1)$$

where B is the flexural rigidity, W is the weight of the fabric per area, and C is the bending length [11].

The study of air permeability analysis was determined using Air Tronic (3240, area 20 cm^2 at 125 Pa, Mesdan Lab, Italy) to measure airflow rates of face mask and electrospun nanofibers. An air flow of 10 l/min was selected for an air permeability test.

The determination of water vapor permeability of electrospun nanofibers was performed using the upright cup method principle using the SDL Atlas M21 Water Vapor Permeability Tester, as per instructed in the ASTM E96. The water vapor transmission rate (WVTR) or water vapor permeability was calculated as

$$\text{WVTR} = \frac{\Delta W}{\Delta t.A}\,\text{mgh}^{-1}\text{cm}^{-2}, \quad (2)$$

where $\Delta W/\Delta t$ is the amount of water loss (milligram) per unit time (hour) of moisture transfer and A is the evaporation exposure which are in cm^2 [21].

3. Results and Discussion

3.1. Morphological Analysis of Filtered Face Masks. Figure 2 depicts FESEM images of each layer in the surgical face mask structure, showing distinctive differences in the morphological fiber structure in terms of size and interspace porosity. According to the FESEM images, the first and third layers (outer and inner layer) of the surgical face mask were about 12-13 ?m in diameter with a random orientation network of fibers. The interspaces between the fibers are about 1-2 ?m. According to Liu et al. [22], the bigger airborne particle can get trapped by the interspace porosity of these layers through a static charge attraction or surface tension of droplets. The diameter of the second layer (middle layer) was in between 1 and 3 ?m with an uneven fiber size distribution. The interspace distance between the fibers is about 700-900 nm. Due to the smaller fiber size and interspaces in the filter layer, the efficiency of membrane filtration will be increased as any air impurities with a diameter smaller than 1 ?m will not be able to penetrate through the filter. On the other hand, FESEM images show that the electrospun nanofibers (NF insert) were about 150-300 nm with uniform fiber diameter distribution. Therefore, it is suggested that any air impurities larger than 400 nm will be effectively blocked by the NF filter insert. The NF insert provides an additional layer of membrane filtration as the incoming air need to pass through the fiber network providing numerous collision opportunities to trap air impurities. This finding has been supported by Tebyetekerwa et al. [7] which indicated that the high porosity and surface area of the electrospun nanofibers might have contributed to the improvement of the breathing and filterability properties of a face mask.

3.2. Permeability and Flexural Rigidity Properties of Filtered Face Masks. In this study, the flexural rigidity of surgical face masks with and without NF insert is 0.1358 and 0.1207 mg/cm, respectively. The greater value of the flexural rigidity of surgical face masks with NF insert indicates that the fabric stiffness is slightly increased. The increment in the fabric stiffness indicates that the surgical face mask with NF insert has less bending elasticity resulted in the increase of fabric density [11]. This statement is also supported by the study conducted by Yüksekkaya et al. [23]. The authors state that increasing flexural rigidity leads to the more rigid fabric material [23].

Results on the permeability properties showed that surgical face masks with NF insert have significantly lowered the value of water vapor transmission rate (WVTR) and air permeability (Figure 3). The WVTR of surgical face masks with NF insert was found to be at the highest in the first hour as the moisture permeated rapidly. As more moisture replaces the air in the pores, the moisture permeates more slowly and eventually reaches a steady state until slightly dropped in between 2 and 6 hours. The decrease in WVTR is attributed to high moisture content due to the filled interfacial gap. A similar trend was observed as in the surgical face mask without a NF insert. On the other hand, the results of air permeability were also complementing the existing data of water vapor transmission rate. In comparison to the surgical face mask with NF insert, the percentage of air permeability value was decreased by 15.9%, from 339.5 to 285.5 mm/s. The results suggested that the addition of NF inserts has increased the barrier to air permeability, increasing the performance of masks in controlling the air permeability of the face mask fabric.

4. Conclusions

Face masks are principally designed to aid reduce the wearer's respiratory exposure to airborne contaminants. The application of an inserted filter made up of the electrospun nanofibers, in between the layers of face masks, hypothetically aims to block the airborne particles passing through the fabric and improve the filtration capacity without reducing the wearer's comfort. In this work, we have studied the flexural rigidity, water vapor permeability and air permeability provided by electrospun nanofiber (NF) insert as an active filter layer in commercial surgical face masks. The outcome of this study showed that the barrier to both water vapor and air permeability of filtered face masks is increased with the use of NF insert, thus increasing its air filtration capacity. The permeability properties of the mask were improved as the size of the fibers decreased. The evaluation of fabric stiffness of surgical face mask fabric upon the addition of NF inserts suggested the slight increase of the flexural rigidity, approximately 0.0151 mg/cm. The additional NF filter inserts, however, do not drastically affect the comfort of the wearer. Nevertheless, this preliminary study still required further attention on other key factors in assessing mask comfort, such as determining the thermal conductivity, breathing resistance, and filtration efficiency of micron and submicron particles, accordingly. We believe the development in respiratory protective equipment will be rising to provide essential protection from airborne threats under the current pandemic.

Data Availability

All data are available within the manuscript. Raw data can be given with reasonable requests.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgments

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References

[1] M. A. Shereen, S. Khan, A. Kazmi, N. Bashir, and R. Siddique, "COVID-19 infection: origin, transmission, and characteristics of human coronaviruses," *Journal of Advanced Research*, vol. 24, pp. 81–89, 2020.

[2] J. Y. Kim, P. G. Choe, Y. Oh et al., "The first case of 2019 novel coronavirus pneumonia imported into Korea from Wuhan, China: implication for infection prevention and control measures," *Journal of Korean Medical Science*, vol. 35, pp. 1–4, 2020.

[3] I. Ali and O. M. Alharbi, "COVID-19: disease, management, treatment, and social impact," *Science of the total Environment*, vol. 138861, pp. 1–6, 2020.

[4] *Covid-19 outbreak live updates*, 2020, October 2020, https://www.outbreak.my/world/.

[5] S. Feng, C. Shen, N. Xia, W. Song, M. Fan, and B. J. Cowling, "Rational use of face masks in the COVID-19 pandemic," *The Lancet Respiratory Medicine*, vol. 8, no. 5, pp. 434–436, 2020.

[6] *It's time to face facts, America: masks work*, 2020, August 2020, https://www.wired.com/story/its-time-to-face-facts-america-masks-work/.

[7] M. Tebyetekerwa, Z. Xu, S. Yang, and S. Ramakrishna, "Electrospun nanofibers-based face masks," *Advanced Fiber Materials, Advanced Fiber Materials*, vol. 2, no. 3, pp. 161–166, 2020.

[8] *What types of face masks are available and where can I buy one?*, 2020, August 2020, https://www.canstar.com.au/health-insurance/p2-masks/.

[9] *Type and uses of face masks*, 2020, August 2020, https://www.safeworkaustralia.gov.au/doc/types-and-uses-face-masks/.

[10] *The best material for protective medical face masks*, 2020, August 2020, https://www.flexpackmag.com/articles/90449-the-best-material-for-protective-medical-face-masks/.

[11] W. C. Lau, *Analysis of Bending Rigidity of Nonwoven Fabrics*, Ph. D. Dissertation, Georgia Institute of Technology, Atlanta, 1976.

[12] A. Yang, L. Cai, R. Zhang et al., "Thermal management in nanofiber-based face mask," *Nano Letters*, vol. 17, pp. 3506–3510, 2017.

[13] M. Rajalakshmi and C. V. Koushik, "Comfort and textiles properties," *Journal of Interdisciplinary Cycle Research*, vol. 12, no. 6, pp. 1088–1090, 2020.

[14] K. Y. Wei, T. L. Vigo, and B. C. Goswami, "Structure–property relationships of thermally bonded poly-propylene nonwovens," *Journal of Applied Polymer Science*, vol. 30, no. 4, pp. 1523–1534, 1985.

[15] W. Han, Z. Wu, Y. Li, and Y. Wang, "Graphene family nanomaterials (GFNs)–promising materials for antimicrobial coating and film: A review," *Chemical Engineering Journal*, vol. 358, pp. 1022–1037, 2019.

[16] S. Ullah, A. Ullah, J. Lee et al., "Reusability comparison of melt-blown vs nanofiber face mask filters for use in the coronavirus pandemic," *ACS Applied Nano Materials*, vol. 3, pp. 7231–7241, 2020.

[17] J. C. Park, T. Ito, K. O. Kim et al., "Electrospun poly(vinyl alcohol) nanofibers: effects of degree of hydrolysis and enhanced water stability," *Polymer Journal*, vol. 42, no. 3, pp. 273–276, 2010.

[18] F. Fadil, N. D. N. Affandi, N. A. Ibrahim, M. I. Misnon, A. M. Harun, and M. K. Alam, "Advanced application of electrospun polycaprolactone fibers for seed germination activity," *Advances in Polymer Technology*, vol. 2021, Article ID 5912156, 10 pages, 2021.

[19] F. Fadil, N. D. N. Affandi, M. I. Misnon, N. N. Bonnia, A. M. Harun, and M. K. Alam, "Review on electrospun nanofiber-applied products," *Polymer*, vol. 13, no. 13, p. 2087, 2021.

[20] F. Fadil, N. D. N. Affandi, A. M. Harun, and M. K. Alam, "Dope-dyeing of polyvinyl alcohol (PVA) nanofibres with remazol yellow FG," *Polymer*, vol. 12, no. 12, p. 3043, 2020.

[21] M. Bajpai, S. K. Bajpai, and D. Gautam, "Investigation of regenerated cellulose/poly(acrylic acid) composite films for potential wound healing applications: a preliminary study," *Journal of Applied Chemistry*, vol. 2014, 9 pages, 2014.

[22] Z. Liu, D. Yu, Y. Ge et al., "Understanding the factors involved in determining the bioburdens of surgical masks," *Annals of translational medicine*, vol. 7, no. 23, pp. 754–757, 2019.

[23] M. E. Yüksekkaya, T. Howard, and S. Adanur, "Influence of the fabric properties on fabric stiffness for the industrial fabrics," *Textile and Apparel*, vol. 18, pp. 263–267, 2008.