Analysis of microstructure and protective performance of melt-blown materials for medical protective masks

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Abstract. Since the end of 2019, the Corona Virus Disease 2019 (COVID-19) pandemic has led to a surge in the use of all kinds of medical supplies, especially surgical masks. Based on the microstructure and anti-virus mechanism of melt-blown materials used for medical masks, this paper introduces the research status of nonwoven filter materials used for protective masks. At the same time, the surface interface structure of four disposable medical protective masks from different manufacturers was analyzed by scanning electron microscope, and the difference of melt-blown materials of these masks was studied. The results show that the fiber diameter of melt-blown mask with better protective effect is fine and compact, and the aperture formed between fibers is smaller. This research provides new ideas for further research and development of non-woven materials for medical masks.

1. Introduction
Since December 2019, the outbreak and continued spread of Corona Virus Disease 2019 (COVID-19) has had a severe impact on the health and lives of people around the world, drawing wide attention to the issue of public health[1]. Diseases such as COVID-19, severe acute respiratory syndrome (SARS) and highly pathogenic avian influenza are transmitted mainly through the respiratory tract. And until specific drugs and vaccines for such diseases are fully available, wearing protective masks is an effective means of preventing the invasion and transmission of the virus for health workers[2-3].

Medical protective masks can be divided into four categories: disposable medical masks, medical surgical masks, medical particulate matter protective masks and medical protective masks, and their protective grade increases in turn[4-5]. Medical masks can be divided into planar structures and three-dimensional structures according to their appearance. Medical surgical masks and disposable medical
masks are planar structures, and medical protective masks are three-dimensional arch structure. Medical masks take the form of multi-layer nonwoven fabric composite, including the outer layer, the filter layer and the inner layer, as shown in Figure 1. The outer layer is generally composed of spunbond or hot rolled nonwovens, which can not only work as the structural support but also intercept large particles and liquid droplets. The filter layer is the most crucial; it is usually made of charged melt-blown nonwovens, which can filter fine particulate matter[6-7]. The inner layer is composed of ordinary spunbonded, needled or spun nonwovens, which is designed to ensure moisture absorption and improve skin affinity and comfort. The protective mechanism of masks is analyzed from the level of air filtration technology. According to the interception and interaction modes of particles, the protective mechanism is generally based on the following filtering mechanisms: interception effect, inertia effect, diffusion effect, electrostatic effect and gravity effect. The interception effect, inertia effect and electrostatic effect play a major role in medical mask materials. Among them, it is quite important to make full use of the electrostatic deposition effect. The core layer filter material of the mask is treated with electrostatic electret to make itself charged, and then increases the electrostatic effect and enhances the adsorption and filtration effect[8].

The main raw materials of medical masks are melt-blown cloth and spunbonded cloth made of thermoplastic polymer[9]. However, there are many shortcomings on these masks, such as poor moisture absorption, inadequate comfort, and environmental pollution. During the COVID-19 pandemic, the bridge of the nose and face of medical workers suffered varying degrees of compression and damage from prolonged wear of masks. Meanwhile, a large number of disposable masks cannot be disposed of in a timely and effective manner, which also puts pressure on environmental protection and public health[10-11]. Polypropylene (PP) masterbatch is the basic raw material of medical masks, which has the advantages of low cost, good heat resistance and stable physical and chemical properties[12]. It has been widely used in medical nonwovens as a high-quality raw material. In order to further improve the properties of PP nonwovens, it is often modified by various methods. For example, SiO$_2$ aerogel and PP are fused and blended to prepare SiO$_2$ aerogel/PP melt-blown nonwoven material. Compared with pure PP melt-blown material, its filtering effect is enhanced by about 50% [13]. Some researchers used titanium dioxide (TiO$_2$), a photocatalytic antibacterial material with strong antibacterial performance, to modify TiO$_2$ first to make its antibacterial performance more stable. Then the modified TiO$_2$ was loaded onto PP melt-blown nonwoven fabric in the online composite mode, and onto PE/PET spunbonded nonwoven fabric in the offline composite mode. Finally, the two materials were combined to prepare the modified TiO$_2$/spunbonded melt-blown antibacterial composite filter material[14].

2. Materials and Methods

2.1. Materials
Disposable medical masks from four different manufacturers were selected for this test, which were represented by numerical numbers. Their basic information is shown in Table 1, and their appearance is shown in Figure 2.

| Serial number | Size/ (cm × cm) | Color     |
|---------------|----------------|-----------|
| 1#            | 17.6×9.60      | Sky blue  |
| 2#            | 17.7×9.05      | Grass green|
| 3#            | 17.5×9.25      | Sky blue  |
| 4#            | 14.2×9.15      | Sky blue  |
2.2. The experimental method
The field-emission scanning electron microscope (SEM, JEOL-7800F) was used to observe the outer layer and the cross-section of the filter layer of the mask. Each mask was cut to a certain size and fixed on the sample table with conductive adhesive. Platinum was sprayed on the surface of the mask to increase the conductivity of the material, and the acceleration voltage was tested at 8 kV.

3. Results and Discussion
In the production process of medical masks, the most critical material is the intermediate layer melt-blown cloth, mostly PP, which is made by melting, spinning, stretching, shaping and other steps. The PP fibers are ejected from the spinneret under high-speed and high-pressure hot gas flow, drawn into ultra-fine fibers with the diameter of 0.3~7.0 μm, evenly spread on the collection device. Then their own waste heat is used to bond into a network and reinforce into a cloth, finally the material got is electret treated to improve the filtration efficiency. Among them, the key process is electrostatic electret treatment, so that the filter material can increase the electrostatic adsorption of particles in the air, and greatly improve the filtering efficiency of the mask by using the electrostatic effect. The outer
and inner layers are composed of spunbonded nonwoven fabric. The filter material of them has a large aperture scale and can filter larger particles. The filter layer is made of melt-blown nonwoven fabric to filter particles of even smaller size.

Figure 3 shows the SEM morphologies of the outer layers of the four masks and the enlarged images of single fiber. It can be seen that the fiber diameter of the outer melt-blown material is roughly the same. The outer layer is a single PP spunbond layer with an average fiber diameter of about 20 μm. The point nodes of the inner and outer layers are formed by hot rolling process, mainly to improve the strength of the spunbond material. The outer layers of masks 1# and 2# are relatively loose, while the outer layers of masks 3# and 4# are relatively dense.

Figure 3. SEM images of four masks. (a). 1#, (b). 2#, (c). 3#, (d). 4# SEM images of melt-blown material of mask outer layer; (e). 1#, (f). 2#, (g). 3#, (h). 4# SEM images of melt-blown material fibers on the outer layer of masks.

The intermediate layer melt-blown material is the most important factor affecting the filtering efficiency of masks. Figure 4 shows the morphologies of melt-blown mask intermediate layers from four different manufacturers. It can be seen from the figure that the microfibers in the middle layer of all masks are randomly distributed and have a certain disorder. This structure enables them to have a larger specific surface area, so that melt-blown materials have better filtering and shielding properties. The smaller the fiber diameter of the middle layer of the mask is, the higher the porosity of the fiber mat formed by the accumulation of fibers, the smaller the pressure drop resistance and the better the protective effect[15]. The smaller the average diameter of the melt-blown fiber in the middle layer of the mask, the better its density. It can be seen from the figure that the middle layer of mask 1# has poor workmanship and the fiber thickness is about 40-50 μm. The average diameter of the melt-blown material fiber in the middle layer of mask 2# is less than 10 μm, and the average diameter of the melt-blown material fiber in the middle layer of mask 3# and mask 4# is about 2 μm, and the fiber of the melt-blown material in the middle layer of mask 3# and mask 4# is thin and dense, with few voids, which is more conducive to filtration. There are many tiny voids between the fibers in the middle layer of 2# mask. However, the fiber diameter of the melt-blown material in the middle layer of mask 1# is thick and loose, with a large gap, which is not conducive to filtration. As can be seen from the SEM section of the mask as shown in figure 4(e-h), the structure of the mask is divided into three layers: outer layer, middle layer and inner layer. The interlayer is a melt-blown layer, and its microfibers are interlaced and randomly distributed. The above research indicates that the smaller the average
diameter of the fibers of medical mask melt-blown material and the denser they are, the better their filtration performance will be.

![Figure 4. SEM images of four masks. (a). 1#, (b). 2#, (c). 3#, (d). 4# SEM images of melt-blown material in the middle layer of mask; (e). 1#, (f). 2#, (g). 3#, (h). 4# SEM images of cross sections of masks.](image)

4. Conclusion
With the rapid growth of national economic level, the continuous improvement of medical and health level, and the continuous enhancement of people's awareness of life and health, the performance of protective medical masks is also constantly improved. From the single filtration efficiency to the comfort, biodegradability and antibacterial, etc., the performance of masks is becoming more and more diversified. Scanning electron microscopy was used to characterize the melt-blown materials of four disposable medical masks from different manufacturers. It shows that the melt-blown materials of the middle layer have higher filtration efficiency, and the smaller pore diameter, the better protective effect. The above research has potential guiding significance for the development and improvement of medical protective masks.

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