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Research Article

Superhydrophobic Surface Modification for Enhanced Fabric Face Masks: The Impact of Varying HDTMS Concentrations

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Abstract – The widespread use of disposable surgical masks and N95 respirators has led to concerning environmental pollutions. As a result, there has been a growing demand for fabric face masks that are not only reusable and environmentally friendly, but also effective in preventing virus transmission. However, traditional fabric masks have a drawback: their hydrophilic nature increases the risk of virus transmission. To address this challenge, an innovative solution for achieving superhydrophobic surface on cotton, microfiber, and microfiber blend materials was investigated. The key focus of this investigation revolves around the impact of varying concentration of hexadecyltrimethoxysilane (HDTMS) on the hydrophobicity of different fabrics. Consequently, all cotton fabric samples treated with 5%, 10% and 20% HDTMS concentration exhibit water contact angles (WCA) surpassing 150º, effortlessly achieving a state of superhydrophobicity. The modified cotton and microfiber materials proudly display not only enhanced water repellency but also boast exceptional self-cleaning and stain resistant properties.

Keywords – Surface Modification, Superhydrophobic, Fabric Face Masks, Cotton, Microfiber, Surface Coating

I. INTRODUCTION

The surge in the usage of disposable surgical masks and N95 respirators, along with their improper disposal, has led to a concerning accumulation of solid waste. Studies have shown that in regions heavily affected by the COVID-19 pandemic, such as Wuhan, China, daily medical waste reached staggering amounts, reaching approximately 240 metric tonnes [1]. Similarly, in Malaysia, the estimated daily use of face masks exceeded seven million [2], worsening the environmental impact. The accumulation of discarded masks, particularly those made of polypropylene and other plastics, not only contributes to environmental pollution but also raises concerns about the release of potentially harmful substances as these masks degrade [3]. Moreover, the improper disposal of masks results in their transformation into microplastics, further polluting our oceans and posing a potential threat to marine life [4].

Wearing fabric face masks has emerged as a more sustainable alternative to address the environmental issues caused by disposable masks. However, fabric masks possess inherent hydrophilic properties that increase the risk of virus transmission. Fabrics like

cotton, microfiber, and their blends, commonly used for fabric masks, are naturally hydrophilic nature facilitates the absorption and retention of respiratory droplets containing viruses and contaminants, potentially compromising mask effectiveness and increasing the chances of contact between the wearer and pathogens [5]. Furthermore, the rewashing of fabric masks, although it allows for reuse, can lead to decrease mechanical strength and durability [6].

To overcome these challenges, researchers have explored the modification of fabric surfaces to create superhydrophobic coatings on fabric masks. The aim is to impart self-cleaning properties and enhance their hydrophobicity, thereby reducing the risk of wetting and viral transmission. Previous studies have demonstrated the effectiveness of superhydrophobic coatings in preventing liquid absorption and maintaining the cleanliness of surfaces [7]. However, existing methods for fabricating superhydrophobic coatings are often time-consuming, costly, and require complex equipment and processing conditions [8,9]. Therefore, it is essential to develop facile and cost-effective techniques for constructing superhydrophobic coatings on fabric masks to make them more practical for widespread use.

II. Materials and Method

This research involves the preparation of coating solution, coating techniques and evaluation. The chemicals used in these studies are analytical grades.

A. Screening of functional ingredients

Functional ingredients for coating solution were screened, including ethanol, HDTMS, and a combination of HDTMS and ethanol. 20 mL of ethanol solution and 20 mL of HDTMS solution were separately measured and transferred into 50 mL beakers. For the HDTMS-ethanol coating solution, 20% v/v concentration of HDTMS was dissolved in ethanol solution. The mixture was stirred continuously at room temperature for one hour to obtained homogeneous solution.

The cotton fabric was cut into six pieces (75 mm x 25 mm) and cleaned with ethanol. After drying, the samples were coated with three solutions using the dip coating method for five hours. The coated fabric was dried in an oven at 120^{o}C for six hours. Finally, the water contact angle of the samples was measured.

B. Preparation of superhydrophobic coating solution

The coating solutions used in the experiment were HDTMS-ethanol solutions. Three different concentrations of HDTMS (% v/v) were prepared by dissolving specific amounts in 100 ml of ethanol. The concentrations used were 5% v/v, 10% v/v, and 20% v/v. For instance, 5 mL of HDTMS was measured using a cylinder, and 95 mL of ethanol was measured and poured into a 200 mL beaker. The 5 mL of HDTMS was then dissolved in the ethanol, and the solution was continuously stirred was a magnetic stirrer to create a 5% v/v HDTMS coating solution. The mixture was stirred at room temperature for one hour.

C. Surface modification on various fabric face mask materials

Fabric materials (cotton, microfiber, and microfiber blend) were provided by a face mask manufacturer and cut into (75 mm x 25 mm) pieces. The fabric pieces were rinsed with distilled water, cleaned with ethanol using ultrasound for 30 minutes, and dried at 70^{o}C for one hour. They were then dip-coated with three different coating solutions (% v/v) for five hours. After drying in an oven at 120^{o}C for 24 hours, the samples were cooled to room temperature.

D. Water contact angle measurement

The water contact angle (WCA) was measured at room temperature using a contact angle goniometer (Model LSA 200 Surface Analyzer, LAUDA scientific). A droplet of deionized water was used (approximately 10 μL) was used with the sessile drop method. The droplet was placed at 10 positions on both the pristine and modified fabric, and the average contact angle value was determined.

E. Surface morphology analysis

The surface morphology of the pristine and modified fabric materials was observed using a field emission scanning electron microscope (SEM). Small fabric samples were placed on the SEM stand, and high-resolution images were captured using an electron beam. The images were viewed on a computer connected to the SEM at different magnifications (100x, 2000x, and 5000x).

III. Results and Discussion

The fabrics were coated with the coating solutions using dip coating method.

A. *Screening results*

The WCA of the modified cotton fabrics were measured and tabulated in Table 1.

Table 1. WCA of cotton fabric material coated with different coating formulation using dip coating method.

Formulation	WCA on pristine cotton fabric (°)	WCA on modified cotton fabric (°)
Ethanol	0	134.75 ± 1.4
HDTMS	0	146.05 ± 1.6
HDTMS-Ethanol	0	152.23 ± 1.8

Based on Table 1, the cotton fabric coated with HDTMS-ethanol solution had the highest water contact angle compared to other solutions. Cotton fabric coated with HDTMS-ethanol solution achieved superhydrophobicity with a WCA exceeding 150°. Similar results also obtained by other researchers [8, 10]. Ethanol solution alone improved the cotton fabric from superhydrophilic to hydrophobic. The addition of HDTMS, a hydrophobic agent, reduced the fabric's surface energy and increase the WCA. The combination of lowered surface energy and intrinsic surface roughness of cotton fabric resulted in increased WCA and hydrophobicity. As the cotton fabric modified with HDTMS-ethanol solution achieved superhydrophobic, this coating solution was selected in subsequent experiments.

B. *Effect of HDTMS (% v/v) on WCA of various Fabric face mask materials*

In the coating formulation, various HDTMS concentrations were examined to see how they affected the surface superhydrophobicity. 5% v/v, 10% v/v, and 20% v/v were the three different concentrations studied. The effect of HDTMS concentration on WCA of cotton, microfiber, and microfiber blend fabric materials is shown in Fig. 1. WCA measurements for pure cotton, microfiber, and microfiber blend fabric materials were all zero, 114.6 ± 0.7°, and 107.3 ± 0.9°, respectively. The WCA of pristine cotton fabric was shown to be superhydrophilic due to the presence of hydrophilic carbonyl and hydroxyl groups, which lead the surface to be extensively wetted by water droplets [9]. However, as the WCA points out, both pristine microfiber and microfiber blend material have a hydrophobic surface.

Based on Fig. 1, it can be observed that when a 5.0% v/v concentration HDTMS was used, the WCA on cotton fabric was measured at 151.3 ± 0.1°, on microfiber at 126.8 ± 0.5°, and a microfiber blend at 137.9 ± 0.5°. The modification of the cotton fabric resulted in a superhydrophobic surface, while the other two fabrics showed improved hydrophobicity. This superhydrophobic nature of the cotton fabric was attributed to the low surface energy of HDTMS [11].

Upon increasing the concentration to 10% v/v, the WCA on cotton fabric increased to 155.8 ± 0.5°, achieving a superhydrophobic surface. Both the microfiber and microfiber blend fabrics are still within the hydrophobic range. The highest WCA values were recorded for all three fabrics at a 20% v/v HDTMS concentration. The cotton and microfiber coated surface reached superhydrophobicity with WCAs of 158.1 ± 0.7° and 150.6 ± 0.7°, respectively. However, the microfiber blend fabric remained hydrophobic with WCA of 142.5 ± 0.6°, which is close to the superhydrophobic range.

These results indicate that increasing the HDTMS concentration in the coating led to a more hydrophobic surface modification. In addition to introducing the low surface energy material like HDTMS onto the fabric surfaces, the intrinsic surface roughness, resulting from micro-scale filament strands, contributes to its microscale roughness [12]. The higher the surface roughness of the fabrics, the higher the contact angle and the level of hydrophobicity. Therefore, the combination of the intrinsic microscale roughness naturally present in fabric surfaces and the role of HDTMS in lowering fabric surface energy resulted in higher WCAs. As a result, when the concentration of HDTMS in the formulation was increased, the WCA of the coated cotton, microfiber, and microfiber blend fabric materials also increased.

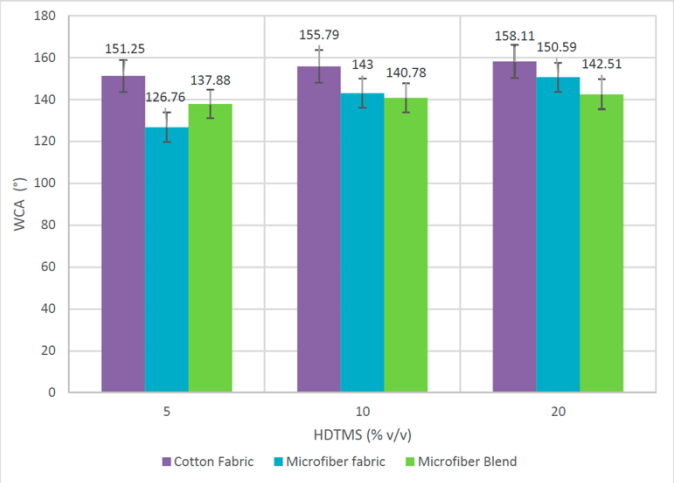

Fig. 1 WCA of coated cotton, microfiber, and microfiber blend fabric surfaces against concentration of HDTMS

C. *Surface morphology analysis*

SEM was employed to examine the surface morphology of pristine and modified cotton fabric, as well as microfiber. Due to their similar fabric structure, the surface morphology investigation focused on cotton fabric.

Fig. 2 displays SEM images illustrating the surface morphology. Fig. 2(a), (b), and (c) represent the pristine cotton fabric surface, while Figure 2(d), (e), and (f) depict the morphological surface of the modified cotton fabric. The modified cotton fabric was coated with a 20% v/v HDTMS solution. A comparison between the pristine and modified cotton fabric aimed to identify any variations resulting from the surface modification.

At a magnification of 100x, both the pristine cotton fabric (Fig 2(a)) and the modified cotton fabric (Fig 2(d)) exhibited longitudinal filament strand structures. The pristine cotton surfaces in Fig. 2(b) and (c) appeared clean and free from contaminations. Notably, significant differences were observed between the pristine and modified surfaces. The clear deposition of the HDTMS layer on the fiber structures can be observed in Fig. 2(f). This HDTMS layer imparts superhydrophobic properties to the cotton surface, in contrast to the pristine cotton fabric, which exhibited a complete wetting with a measured water angle (WCA) of 0°.

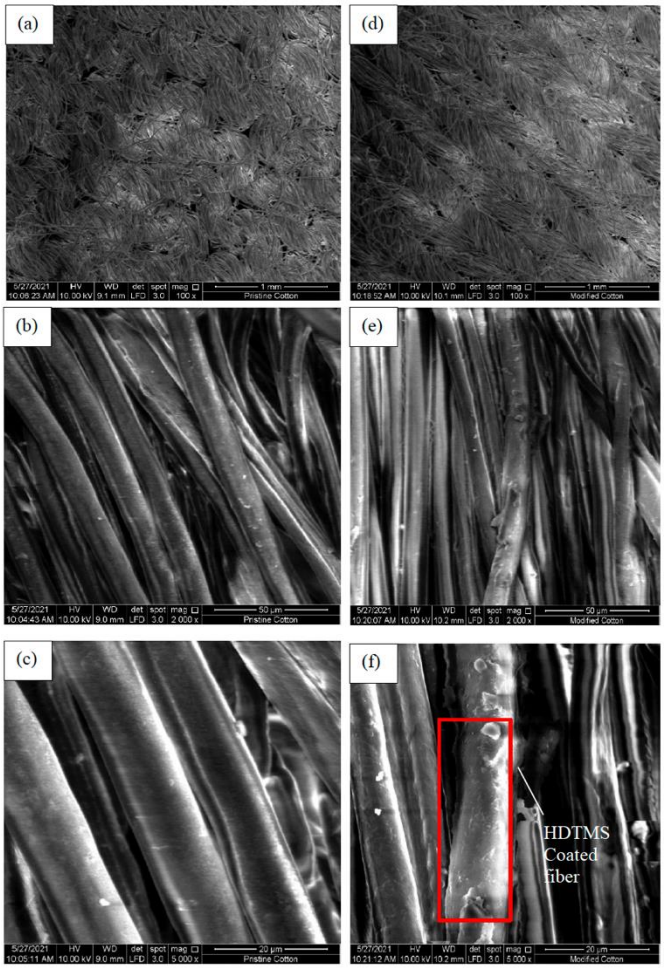

Fig. 2 SEM images of pristine cotton at a) 100x b) 2000x c)5000x and modified cotton at d) 100x e) 2000x f) 5000x magnification view

The SEM analysis revealed distinct changes in the surface morphology of the cotton fabric following HDTMS surface modification, leading to the development of a superhydrophobic surface.

IV. CONCLUSION

Superhydrophobic coatings were applied to the fabric surfaces using the dip coating technique using the silane precursor HDTMS in an ethanol solvent. The process involved making modification to the coating formulation by varying the percentage (v/v) HDTMS demonstrated water contact angles (WCA) exceeding 150°, indicating the formulation of superhydrophobic surfaces. Cotton and microfiber surface coated with 20% (v/v) HDTMS exhibited the WCA within the superhydrophobic range, while microfiber blend fabric tested was found to be hydrophobic. In essence, increasing the concentration of HDTMS resulted in higher WCAs and greater hydrophobicity of the coated surfaces.

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