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Home- and Laboratory-based Microscopy of Face Covering Materials

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Stay-at-home orders and social distancing regulations imposed during the COVID-19 pandemic have limited many scientists' access to instrumentation, thereby requiring the development of creative methods to conduct material analyses, including the use of makeshift home laboratories. Fortunately for those engaged in microscopy-related science, small footprint digital light microscopes are commercially available with spatial resolutions ranging from ≈ 20 µm, obtained from student-grade plastic optics, to ≈ 2 µm for higher quality/magnification glass lens systems. We have combined images collected using home-based microscopy together with those from more advanced systems, e.g. scanning electron microscopy (SEM) and X-ray computed tomography (XCT), to obtain insight into the microstructural properties of face covering materials. In this study the construction and textures of woven and non-woven fabrics [1], as well as face covering insert filter materials [2] were examined. Additionally, the microstructural impact of high relative humidity on a hydrophilic textile was documented along with the measurement of parameters required to model filtration behavior for selected materials [3].

>30 textiles were analyzed in this study and were obtained from various sources [1]. Home microscopy was performed using a low pixel density sensor (0.3 MP), in addition to two DinoLite microscopes (AM73915MZT and AM7515MT8A (5 MP)). Laboratory light microscopy was performed using a Hirox KH-8700 digital microscope. Backscattered electron images (BSE) of native surfaces of fabrics were collected with a Hitachi S3700N SEM using an accelerating voltage of 15 kV at a variable pressure of 100 Pa of ambient atmosphere. 3D imagery was obtained with a General Electric Phoenix XCT system equipped with a dual tube configuration and a Mo X-ray source operated at 60 kV. A home humidity experiment was conducted using a Humisys Model HF10-1-2-120 relative humidity generator where rayon was exposed to high relative humidity (RH), >95 % RH, for 4.25 hours before imaging. The environmental chamber for the experiment consisted of a Styrofoam beer cooler sealed with duct tape.

At-home imaging methods provide suitable field-of-view and resolution to visualize textural differences between the samples and measure yarn counts (0.1 mm scale) and fiber widths (10 µm scale) for most woven and non-woven textiles [1]. Overall, no statistically significant relationship was determined between a fabric's construction parameters and its filtration efficiency (FE). This is most likely because of the small sample size. It is estimated that > 150 independent samples would need to be measured to determine the relationship between yarn count and FE assuming a desired 5 % sampling precision and 95 % confidence interval.

Use of multiple layers is at the heart of the Center for Disease Control and Prevention's recent guidelines regarding double masking [4] and aligns with the rational design of face coverings comprised of two layers of woven fabric coupled with a 3rd layer of high FE, e.g. a polypropylene material, inserted between woven fabrics. Figure 1 shows the microstructure for the three materials recommended as inserts to the general public that were evaluated for the FE for various layered assemblages [2, 4] . The polypropylene materials (HEPA filter and sterilization wrap) are of value for this purpose given their overall chemical homogeneity. Melt-blown polypropylene produces a chaotic web of fibers of differing diameters in the filtration layers and comprise a portion of a HEPA filter (Figure 1A). While such a random network efficiently traps submicron particles of various sizes, issues regarding breathability and flow compatibility of fabric/insert pairs must be considered for these three layered assemblages as mismatches will promote leakage [2].

The World Health Organization updated guidance on face coverings calls for the innermost layer of a three layer face covering to be hydrophilic [5]. This provides a reservoir for water condensed from human breath that is ≈ 100 % RH [6]. Natural fiber derived textiles (e.g., cotton, wool, and rayon) take up more water than the synthetically based textiles [7]. A candidate for this hydrophilic layer is cotton flannel shown in Figure 2b; examples of hydrophobic N95 (2a) and polyester (2c) are shown for comparison. This effect was visualized using an in-home system on rayon where a fiber diameter increase of 14.7 % ± 11.5 % (1σ) was measured upon exposure to humidity [3]. Assuming a cylindrical geometry for the fibers, this results in a 32.8 % ± 27.1 % increase in fiber diameter [3], a finding that is in-line with a traditional understanding of water up-take by textile fibers [7]. The increase in natural fiber size due to water up-take can result in a tightening of the textile weave and, as a result, an increase in textile solidity. For textiles, solidity is calculated from the ratio of effective density of the material to its bulk density. However, due to the material and manufacturing variability, these calculated values can be inaccurate. While solidity can be estimated from 2D imaging the stereological leap to 3D will equally produce inaccurate results. Alternatively, a 3D imaging method, such as XCT, can provide a direct measure of a specimen's 3D framework. For proof-of-concept a cotton flannel measured in this study was analyzed by XCT and the solidity was calculated to be ≈ 27 %.

Results from these studies provide important insight into the effectiveness of the textiles which are often used as particle and droplet filtering face coverings [1, 4, 5][1], as well as face covering insert filter materials [2] were examined. Additionally, the microstructural impact of high relative humidity on a hydrophilic textile was documented along with the measurement of parameters required to model filtration behavior for selected materials [3].

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Results from these studies provide important insight into the effectiveness of the textiles which are often used as particle and droplet filtering face coverings [1, 4, 5]. According to particle filtration theory the efficiency of a fabric to filter is directly related to its solidity and thickness and inversely related to fiber diameter [1], all parameters measurable using microscopy.

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