Effectiveness of different facemask materials to combat transmission of airborne diseases

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MS received 8 September 2020; revised 20 February 2021; accepted 29 April 2021

Abstract. The pandemic COVID-19, caused by SARS-COV-2 virus has shaken the entire world with no such remedy till date. The only possible way to stop transmission of SARS-COV-2 is to take safety precautions including use of facemask. With the ever-increasing concern on the disease, it is necessary to choose facemask components to achieve the performance as good as commercially available N95 masks in a cost-effective way. This investigation compares the effectiveness of five different 3-layered masks with N95 mask in terms of pressure drop and aerosol filtration capabilities. Different combinations of cotton, polypropylene fabric, tissue and high-efficiency particulate air (HEPA) were used as mask materials. In comparison to N95 mask, the result shows that the 3-layered cotton mask has much lesser pressure drop but least droplet filtration efficiency, while polypropylene-HEPA-polypropylene mask is seen as the best cost-effective alternative to N95 in terms of droplets filtration efficiency and breathability. These findings are crucial to make the right non-medical facemask to combat COVID-19 and other airborne diseases.

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Published online: 16 June 2021

Graphic abstract

Keywords. Facemask; Fabric; Pore Size; Droplet; Breathability..

1. Introduction

To prevent spreading of the ongoing COVID 19 pandemic caused by SARS-COV-2 virus, substantial safety precautions are the preliminary steps to be considered. It has already been established that the SARS-COV-2 not only spreads via contact with an infected person, but also through aerosol transmission [1, 2]. In this regard, wearing of facemask is recommended to restrict aerosols generated while speaking, coughing, sneezing or even during breathing [3]. Such aerosols act as a transport medium to transmit the respiratory pathogens since the sizes of the pathogens are in the nanoscale (~ 150 nm for SARS-COV-2) [4]. Extensive studies reveal the fact that while larger sized aerosols get settled within a meter or so, fine aerosols remain suspended in air for several hours [5, 6]. Such fine

virus contaminated aerosols are able to get into deeper part of the respiratory track thereby causing infection [2]. A recent work on influenza virus reveals the presence of significant amounts of viral RNA in emitted aerosols during natural breathing, without coughing or sneezing [7]. These aerosols can travel for long distances with the air flow and can be inhaled by people surrounding the infected person. In order to stop such type of viral transmission, the demand for efficient face mask capable of restricting the flow of aerosol bearing pathogens has increased considerably. The critical requirement for a mask is that the filter components should be capable of preventing the penetration of hazardous particles within a range of sizes over a range of airflow (approximately 10 to 100 l/min). To curtail airborne transmission, different kinds of masks such as, surgical masks, protective masks with filtering face seal, respirators,

antibacterial masks for common people, traffic police, doctors and patients exist. In case of the very familiar N95/N99, the number after the N signifies the percentage of filtration capability of those masks. For the respirators, face seal leakage must be minimized.

Breathability, hydrophobic nature and flammability are important parameters that decide the standard of a mask. The breathability of masks purely depends on the fibrous material arrangement in the filter medium. The use of thick micro fibrous coating can increase the filtration efficiency at the expense of breathability. To ease breathability in high particle filtration mask, there should be an optimum resistance offered by the facemask during breathing. This necessitates the need for measuring the differential pressure across the mask. The analysis for the differential pressure must be carried out at the standard flow rate of 85 (l/min), i.e., 3 CFM (cubic feet per minute) - the condition under heavy exercise [8]. Konda *et al* (2020) [5] has done the analyses at 1.2 and 3.2 CFM for different fabrics with sample area of 59 cm². They found that the average differential pressure at 1.2 CFM across all the fabrics was 2.5 ± 0.4 Pa, which indicates low resistance and excellent breathability. The US Code of Federal Regulations also gives the standards for the differential pressure: 42 CFR Part 84.172 states that the maximum allowable resistance for non-powered N, R and P types mask should be 35 mm (343.2 Pa) of H₂O for inhalation and 25 mm (245.1 Pa) of H₂O for exhalation. Kim and his co-workers (2016) found 29.4 Pa, 58.8 Pa and 88.2 Pa pressure drop for different filters at 85 l/min air flow rate [9]. Another important parameter is the hydrophobic nature of the filter material in the innermost and the outermost layers to resist the aerosols generated during sneezing, coughing, and other human actions to enter the inner filter components.

Characterization of respiratory droplets produced by healthy and infected persons have been considered by different investigators [10–14]. The trajectory of the droplets highly depends on the diameter of droplet which ranges from 1 μ m to 500 μ m. While droplets lesser than 10 μ m becomes airborne, the larger ones (greater than 100 μ m) have inertia impact, with their trajectory determined by gravity and aerodynamic drag [12, 14]. Depending on the droplet size, ambient humidity and temperature, exhaled droplets from infected persons may dry out, leaving the desiccated pathogen nuclei suspended in the air or on surfaces [10–14]. Hence, the use of facemask has the potency to prevent airborne infection from suspended small droplets, desiccated pathogen nuclei and ballistic trajectories from larger droplets. Konda *et al* recently investigated the filtration performance of different textile materials in single and double layer. An aerosol generation and mixing chamber was used in their experiments. Their result shows that for particle sizes < 300 nm, the filtration efficiency was < 80% for the single fabric mask, while it exceeds 80% in hybrid double layered masks [5]. Our experimental set-up examines droplet from a human subject.

In the present work, five different combinations of filter components of facemasks, cotton, polypropylene fabric, tissue and high-efficiency particulate air (HEPA) filter were chosen. The pore sizes and pressure drop of the facemasks at a flow rate of 85 l/min (3 CFM) were examined. Also, the effectiveness of different combinations of facemask materials in reducing aerosol emission while speaking has been checked by processing exhaled droplets images acquired via an in-house developed set-up involving solid-state laser light illumination and DSLR camera. Frequency of exhaled droplets for various sizes has been performed to compare the effectiveness of various face mask materials. While the pore size of filter components plays an important role in restricting the aerosols to enter inside, the pressure drop must be examined to allow long time wearing ability of facemasks without much suffocation. Knowing the fact that the facemask as the protective equipment will act as the primary protection tool to combat such viral diseases, it is believed that the current study will provide the much-needed analyses in making of efficient facemask to deal with COVID-19 and other related diseases. The basic motivation here was to find a more cost-effective alternative to the N95 respirator by preparing a facemask for the common persons (not frontline health workers) with the most effective amongst the combination materials tried here.

2. Materials and methods

2.1 Materials

All the filter components and N95 respirators used in the present work are commercially available. Four different filter components: cotton fabric (100%), non-woven polypropylene (PP) fabric (80 Grams per Square Meter, GSM), tissue paper (Wentex Plus – 2Ply) and high-efficiency particulate air (HEPA) filter (made by SPY, Grade-H13) were used. The HEPA filter used in the tests was wetlaid glass nonwoven fibers of 99.97% efficiency at most penetrating particle size (MPPS) of 0.3 microns. Tissue paper, made of cellulose fibers of wood pulp, was chosen due to being soft, lightweight, highly absorbent and disposable in nature. Similarly, cotton is also a natural cellulosic fiber that developed in a ball or shielding pill and used as a soft, flexible, natural and breathable fabric material. The PP material used here is of 80 GSM areal density. All the tests were performed with five different combinations of the filter components described above in three layered masks and the commercially available N95 respirators has been used as a reference mask. Table 1 lists the different combinations of mask materials used in the current investigation.

2.2 Characterization and Instrumentation

2.2a Microstructure analysis: The microstructure of the sample fabrics and filters were characterized by field

Table 1. Description of six different combinations of mask materials.

Sl. no.	Sample code	Layer-1	Layer-2	Layer-3
1.	PPP	Polypropylene	Polypropylene	Polypropylene
2.	CCC	Cotton	Cotton	Cotton
3.	PCP	Polypropylene	Cotton Cloth	Polypropylene
4.	PTP	Polypropylene	Tissue	Polypropylene
5.	PHP	Polypropylene	HEPA	Polypropylene
6.	N95	As available in commercial facemasks		

emission scanning electron microscopy (FE-SEM, Carl Zeiss, Germany) at an accelerating potential of 5 kV. Prior to the FESEM, the samples were coated with platinum to make the surface conductive. The coating was made to be less than platinum nanoparticles of 5 nm diameter using sputtering technique, thereby preserving the fabrics spacing while enabling imaging of the samples avoiding any charging effect. Also, since all the samples were subjected to the same coating treatment, the impact of the coatings (if any) will be negligible on our experimental findings.

2.2b Frequency of Droplets Detection: Interferometric imaging procedure in which particles were illuminated by using a laser sheet was adapted for this study [15–17]. The evaluation of frequency and size distribution of exhaled droplets while speaking was performed through an in-house developed experimental set-up with a CW (continuous wave) diode pumped solid-state laser (Model: LSR-532F – 2W, Lasever Inc) and a DSLR camera (Model: D3300, Nikon, Thailand). The laser emitted 532 nm light (Green in colour) at 2W power and 3 mm beam diameter. A laser sheet is formed by using the laser illumination. The droplets emitted are illuminated while passing through that laser sheet. The illuminated droplets were captured by using the zoom lens (Nikon DX VR AF-P NIKKOR 18 - 55 mm 1:3.5 – 5.6 G) and images were processed in MATLAB to determine the droplet size distribution. The speech aerosol measurement compartment in the set-up, as shown in the Figure 1, made of nearly 5 mm thick cardboard had only a small opening to expose the mouth to the laser sheet mentioned at a safe distance (ensuring laser radiation intensity is within maximum permissible exposure (MPE) limit).

The lens attached inside had a dimension of 380 mm × 300 mm × 190 mm. The interior of the compartment was covered by a black paper sheet to avoid laser light ray reflection at the inner surfaces. The window was opened at the time of talking only. Centres of laser beam, talking window and hole for lens positioning were maintained at the same horizontal plane for all the experiments.

One subject (or speaker) spoke the phrase “Stay within threshold and stay healthy!” for all the experiments where the subject wore face mask (6 types and one fresh or new mask per experiment) for comparing their performance to resist exhaled droplets. The measurement of sound pressure level was performed in MATLAB by using the audio recorded at the time of the experiment. Videos (with 1920 × 1080 pixels resolution) for recording the exhaled droplets were acquired by using a DSLR camera equipped with a zoom lens at 50 fps with 55 mm focal length zoom position. The camera was positioned perpendicular to the laser sheet at 300 mm distance as shown in Figure 1(b). The region with 150 mm × 90 mm dimension was acquired. The camera was focused at the desired plane by imaging a thin wire positioned in the same plane. After each of the experiments, the particles in the measurement compartment were exhausted from the compartment by using an exhaust fan and a HEPA filter paper (attached at the roof of the compartment) for 10 minutes duration, before starting the next experiment. This step was performed to ensure that the measurement enclosure was free of droplets/particles before each experiment.

Number of droplets with various sizes are exhaled from the mouth at the time of talking. It is well-known that the exhaled droplets are the main contributor to spread various infectious diseases as directed by WHO [18]. Therefore, to investigate the performance of various masks, detection of droplet size distribution is necessary [5, 19]. Hence, evaluation of frequency or size distribution of exhaled droplets was performed through experimental investigations.

Image processing of exhaled droplets was performed to determine their size and number for obtaining the droplet size distribution. Before image processing, the frame was calibrated to know the size of one pixel and it estimated as 60 μm. The maximum sound pressure level of talking by wearing the masks was measured as 82 to 84 dB. The image

Figure 1. Schematic representation of droplet detection setup: (a) Side view, (b) Front view, (c) Cross-sectional view, all dimensions are in mm.

Figure 2. Image processing flow chart.

processing methodology adopted is represented as a flow chart shown in Figure 2.

Image frames of 1920×1080 pixels in jpg format were first extracted from the acquired video of 25 sec. From each of the videos, 1260 frames were extracted for analysis. Region of Interest was selected from each of the frames by cropping the image frames. Then the green channel matrices were extracted from the images, as green colour laser with 532.5 nm was used to illuminate the droplets. Each of the channel matrixes has a minimum and maximum value of 0 and 255. To segment the droplets from the background, image binarization was performed by selecting the threshold as 128 i.e. half of the maximum green channel matrix value [20]. Morphological closing operation was performed on the binary image to fill the non-connected portion of the droplets to avoid splitting of droplets in image due to the threshold operation. Disk structuring element with 8-connected neighbourhood was used to perform the morphological closing. Thereafter, connected component labelling with the 8-connected neighbourhood operation was performed to detect the shape or region of droplets [20]. The area of each droplets was extracted to eliminate single-pixel droplets from the count. Then, the minor diameters of the droplets, considered as droplet size, were determined from its geometric shape. As the droplets were mainly elliptical in shape due to their trajectory, considering the equivalent diameter would result in wrong estimation of droplet size. Thus, minor diameter of the droplet was considered as droplet size in this work. Number of droplets having $80 \mu\text{m}$ to $560 \mu\text{m}$ size with $80 \mu\text{m}$ step was estimated in this study.

2.2c Pressure drop measurement: An open-circuit subsonic wind tunnel, shown schematically in Figure 3, was used for measuring the pressure drop across the mask. It has a square honeycomb and three screens of different sizes in the settling chamber. The contraction ratio of the tunnel is 11. These help to minimise the atmospheric fluctuations inside the test section to less than 1% of the mean axial velocity [21, 22]. The wind tunnel has a test section with a cross-sectional area of $0.3 \times 0.3 \text{ m}^2$. The velocity inside the tunnel was varied using two variable frequency drives (VFD), each connected with a 7.5 HP AC motor. The temperature and humidity inside the laboratory were controlled at 25°C and 60% respectively by air conditioners and dehumidifier (Origin, Novita).

The ambient pressure and temperature were measured using analogue barometer combined with a digital thermometer (SATO, Japan). The cross-sectional area for air passage was reduced to an opening of 4600 mm^2 , cut on a 50 mm thick polystyrene, that matched and blocked the cross-sectional area at the test section of the wind tunnel. The choice of this opening area was based on the average frontal air-passage area for anti-pollution respirators. The mask was attached over the hole made in the polystyrene. The flow through the mask was induced by providing suction pressure using two VFD motors already mentioned. First, the velocity of air passing through the mask was measured using a DPM 4 in 1 Pitot static tube and a TSI 8715 micromanometer. The micromanometer has the measurement range from 0.12 m/s to 78 m/s with an accuracy of $\pm 0.04 \text{ m/s}$ ($\pm 0.025 \text{ Pa}$). Plastic pipes having 8 mm diameter was placed perpendicular to the flow direction, upon connected to the micromanometer to measure the pressure drop across the mask. The manometer provided pressure and velocity data averaging 20 samples, yet two sets of such data were obtained and averaged. The pressure across the test specimen was measured 80 mm away on either side. It is done to increase the accuracy as the flow may not be axial close to the mask.

3. Results and discussion

3.1 Size and distribution of constituent fibres in the facemask materials

The restriction of micro-droplets will depend not only on the fibrous arrangement of fabrics or filters but also the fiber diameter and the filter thickness. In order to choose the right fabric for the external mask layers, the fibrous arrangements of the fabrics were examined using FESEM (Figure 4).

In the current situation, in many places, homemade cotton-based facemasks are being used to restrict viral transmission. In a close view by FESEM, it has been found that cotton fabric is composed of thick fibers of diameter $10\text{--}15 \mu\text{m}$ with compact and regular arrangement. However,

Figure 3. Schematic representation of open circuit wind tunnel for pressure drop measurement.

Figure 4. FESEM images of filter components showing the distribution of fibers: (a, b) Cotton fabric before (a) and after (b) three times wash; (c) Polypropylene fabric; (d) Tissue paper; and (e-f) HEPA filter with a top view (e) and a cross-sectional view (f).

the cotton fabrics may not be recommended to be reused as the compact arrangement may not be stable upon uses or washing as tearing of fibers and widening of openings can be observed after third wash shown in Figure 4(b). Further, the cotton fabric is known to be good water-absorbing material and thereby microdroplets can be soaked fast allowing the contaminated droplet to pass through the fabric. Unlike cotton, non-woven polypropylene fabric is known to be a very effective filter component due to its hydrophobic nature. FESEM reveals that it has random arrangement of fibers with diameter 15–20 μm , and a press-melt area of 300 μm x 300 μm in a regular interval to hold the arrangement of fibers, making it reusable. With a thickness of 200 μm , the fabric has space openings in the range of 50–80 μm . Tissue paper has also been considered as a potential filter component in homemade mask as reported recently [23]. Similar to cotton, tissue also has the compact but random arrangement of fibers of diameter 8–12 μm . However, its hydrophilic nature and low strength remains worrisome when considering it as an effective filter

component. HEPA has been extensively used for air filtration technique restricting PM 2.5 or lesser particles and a very high filtration efficiency of 99.97% with 0.3 μm particle size. In FESEM image (Figure 4e), randomly distributed ultrafine glass microfibers having 1 μm or lesser diameter can be observed. Such a dense and compact arrangement offers the much-needed microdroplets interception efficiency. The cross-sectional view of the HEPA filter (as shown in Figure 4f) indicates a fiber thickness of 450 μm , which is high enough to restrict droplets diffusion and inertial impact. Further, the wetlaid glass microfibers have hydrophobic nature which makes it restrict droplet wetting at the surface. Table 2 summarizes the diameter, thickness and affinity for water of fibers in the examined facemask fabric.

Furthermore, the hydrophilic and hydrophobic nature of filter components were well-studied by contact angle measurement by dropping 8 μl water on to the filter surfaces and measuring the angle at the interface of liquid and solid platform. The change in contact angles with time for

Table 2. Facemask fabrics and their properties.

Material	Fiber dimension (μm)		Affinity for water	Reusability
	Diameter	Thickness		
Cotton	10–15	250	Hydrophilic	Medium
Polypropylene	15–20	200	Hydrophobic	High
Tissue	8–12	250	Hydrophilic	Low
HEPA	100–200 nm 1–2 μm	450	Hydrophobic	Medium

Figure 5. (a) Wettability test for polypropylene, HEPA, cotton and tissue as filter components, with the contact angle images of sample at start time and end time; (b) soaking rate of 8 μl water droplet on polypropylene (PP), HEPA, cotton and tissue.

all four mask materials, i.e., polypropylene, HEPA, cotton and tissue has been plotted in Figure 5(a). It can be seen

that while for tissue the water droplet soaked instantaneously within 0.3 sec, cotton takes little longer time, ~ 80

sec, to soak almost completely. It can be noted that though the contact angle on cotton at the starting was high $> 80^\circ$, but it started to deteriorate steadily just after 1 sec. Comparatively, though the contact angle of water droplet on polypropylene at the starting was comparable to cotton surface, the contact angle remains almost same up to ~ 200 sec, started to fall slowly and reached 30° after ~ 2100 sec, showing its hydrophobic nature. An extremely high hydrophobic nature has been observed for HEPA with the contact angle of 118° at the starting and remain constant till 250 sec after which little change in contact angle was observed. However, the contact angle value of 93° after 2100 sec indicates the least wettability of HEPA amongst others. The contact angle images for all samples at start time (0 sec) and end time have been represented in Figure 5(a). In other way, the soaking rates of $-152^\circ/\text{sec}$, $-0.84^\circ/\text{sec}$, $-0.02^\circ/\text{sec}$ and $-0.01^\circ/\text{sec}$ for the tissue, cotton, polypropylene and HEPA mask materials, respectively, as shown in Figure 5(b), clearly indicate highly hydrophobic nature for polypropylene and HEPA compared to cotton and tissue materials.

Based on these preliminary investigations, polypropylene was chosen as the mask component for the outermost and innermost layer of the masks due to its hydrophobic nature and stable fabric arrangement. However, to assess the performance of the common homemade cotton mask, a 3 layer cotton mask was also considered. The fabric material for each layer of the masks is as shown in Table 1.

3.2 Droplet detection

An image fragment of the original image frame and its green channel image are presented in Figures 6(a) and 6(b). The binarized and morphologically closed version of Figure 6(b) droplet enclosed in red is depicted in Figure 6(c). An example of the shape detected map of droplet (Figure 6(c)) is shown in Figure 6(d).

The droplet size distribution was plotted for the six different types of 3-layer masks (PPP, CCC, PCP, PTP, PHP and commercial N95) as shown in Figure 7. It can be depicted from the plot that the performance of CCC mask was the worst, i.e. the droplet filtration ability was the least as compared to other masks considered in this study. Importantly, it can be seen that the droplet count for PHP was the least and much comparable to the commercial N95 respirator. The favourable performance of PHP can be attributed to the random arrangement of fine fibers in HEPA and their compactness with fine pore size, thereby enabling restriction of droplets diffusion, and intercepting aerosols, while the encapsulating PP layers mitigate the inertial impact. Moreover, the hydrophobic nature of polypropylene as well as HEPA strongly inhibit the passing of droplets through the PHP combination. The use of cotton fabric in three layers or as the middle layer was found to be not so effective probably due to its hydrophilic nature,

hence allowing the droplets to pass through. Addition of PP layer as inner and outer layer restricted droplets to some extent as seen in Figure 7 in case of PPP. The use of tissue fabric as the middle layer along with PP fabrics as inner and outer (PTP) exhibited better performances compared to CCC, PCP or even PPP masks probably due to the compact arrangement of tissue fabrics.

3.3 Pressure drop measurement

The pressure drop has been analysed for the different combinations of mask materials, listed in Table 3, and compared with the commercially available N95 respirator. The pressure drop or the resistance to the flow of air through the mask is an essential parameter in developing a comfortable mask. Higher pressure drop may increase leakage (i.e. entry/exit of air avoiding face mask) in case of imperfect fitting or reduce exchange of air through respiration, in both cases jeopardizing the safety of the user. Pressure drop increases with a decrease in pore size and number of layers in the mask material. It needs to be maintained below a critical value (i.e., airflow resistance limits of 35 mm (343.2 Pa) and 25 mm (245.1 Pa) H_2O pressure, for inhalation and exhalation respectively) [9] for the comfort of the users. The inspiratory pressure for men decreased with volume from 97 to 39 cm H_2O (9512 Pa to 3824 Pa) below the ambient pressure [24]. The experiments performed using different masks for anti-yellow sand, quarantine, medical, general masks and handkerchiefs, suggested that the maximum pressure drop should be 150 Pa (42 CFR 84.180 –airflow resistance tests) as per the National Institute for Occupational Safety and Health (NIOSH) protocol. The maximum inhalation and exhalation resistances at 85 litres per minute flow rate (NIOSH standard) are 350 Pa and 250 Pa, respectively. Table 3 shows the pressure drop obtained from different combinations of mask materials.

The flow rate of 85 lpm was maintained through a standard mask area of 4600 mm^2 . Such flow rate, as the condition under heavy exercise, was chosen to distinguish various masks, as the differences in pressure drop among the in-house masks were even smaller at a lower flow rate. Further, the velocity inside a healthy person's trachea is in the order of few m/s [25].

It is seen from Table 3 that the average pressure drop for all the samples/fabrics is in the range of 10–11 Pa or $\sim 0.10 \text{ cm}$ of H_2O at the flow rate of 3 CFM i.e., 85 lpm. This indicates that all the masks are having low resistance and represents conditions for good breathability. It can be noted that, amongst all the combinations, though CCC showed the minimum pressure drop of 10.70 Pa as expected, the PHP indicated pressure drop of 10.85 Pa, even lower than N95 mask as reference. The masks having less than 29.4 Pa pressure drop for a given flow rate can be used comfortably by any age group [8].

Figure 6. (a) Image fragment of original image frame in RGB, (b) Corresponding Green channel image, (c) binarized and morphologically closed version of figure 6(b) droplet enclosed in red, (d) shape detection of figure 6(c) after connected component labelling.

Figure 7. Size distribution of exhaled droplets for six different 3-layer masks.

Thereby such breathability performances along with the droplet count experiment confirm PHP as the most acceptable combinations for face mask.

4. Conclusion

The present work investigated the effectiveness of different facemask components to provide the much-needed protection to combat airborne diseases like COVID-19 by testing five different fabrics. Knowing the fact that the

Table 3. Pressure drop for different combinations of mask materials.

Flow Rate: 3 CFM i.e., 85 lpm

Sample/ Fabric	Differential Pressure $\pm$ error $\Delta P < 29.4 \text{ Pa/cm}^2$	Differential Pressure $\pm$ error $\Delta P < 0.3 \text{ cm of H}_2\text{O}$
PPP	10.90 ± 0.43	0.111 ± 0.004
CCC	10.70 ± 0.74	0.10 ± 0.007
PCP	10.86 ± 0.54	0.110 ± 0.005
PTP	10.93 ± 0.65	0.111 ± 0.006
PHP	10.85 ± 0.21	0.110 ± 0.002
N95	10.96 ± 0.16	0.111 ± 0.001

spreading of SARS-COV-2 mostly occurs through aerosol transmission, the present work not only looked into their fibrous arrangements and breathability measurement, but also investigated the performance of aerosol transmission through the mask combinations. The detailed investigation reveals that the use of HEPA, which has a very compact arrangement of fibers and very fine pore size as the middle layer, along with the PP layers as outer and inner layer was the most effective in preventing aerosol transmission while speaking and its performance was comparable to the commercial N95 respirator. For non-medical purposes, facemask made with this combination of materials can be an economic choice as compared to

the N95 respirator. Despite the compactness of HEPA, breathability through the PHP mask indicated minimum pressure drop amongst all combinations other than CCC, may be due to the diffusion-controlled airflow through the HEPA. The present findings also suggest that the use of cotton fabrics as mask component may offer limited safety to combat such diseases probably because of its hydrophilic nature.

Acknowledgement

All the authors acknowledge Council of Scientific & Industrial Research (CSIR) for the funding. S.A.B appreciates CSIR-TWAS support through award FR No. 3240306320.

Contributions of authors The experiments were performed and the manuscript was prepared by M.P.K and S.A.B. The microscopic analyses were carried out by P.R., H.R. and N.M. The pressure drop part was performed by M.P.K., S.S.C. and M.T., and the droplet count experiments were performed by M.P.K., S.A.B. and S.D. The contact angle measurement experiments were carried out by S.A.B. and S.D. The results were interpreted and explained by P.R. The concept and the idea of the whole work have been represented with the guidance of H.H. All the authors contributed in editing the manuscript.

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