Highly Protective Reusable Face Mask – Designing and Development

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Abstract

Wearing a face mask is a compulsory requirement for today's lifestyle due to Covid -19 pandemic. The non-woven based disposable protective face is available at a low cost; however, they have comfort issues while wearing (fibre formation) and disposal problems. The fabric-based mask available in the market does not guarantee protection. Roughly face masks are categorised into three categories as fabric mask, surgical mask and respirators. Fabric mask provides less protection on the other hand surgical mask and respirators gives good protection but are not recommended for common people. Hence, we at BTRA have designed and developed unique cotton-based 5layers highly protective face masks with improved comfort, breathability, and above 95% bacterial filtration efficiency. BTRA developed mask gives very good protection, is comfortable to use and is recommended to use by common people. The mask is tested as per the requirements of Surgical Face Mask IS 16289 class 3 and passed all test requirements. Further, the wash durability to normal home laundering is also studied.

Keywords

Face Mask, Covid-19, comfort, disposable, breathability, durability, bacterial filtration efficiency

1.0 Introduction:

As a consequence of the Covid-19 pandemic, it is mandatory for the wearer a protective face mask. The government of India has also imposed strict regulations for use of face masks in public areas to prevent the spread of covid-19. Therefore, everyone must buy it and hence the demand for face covering is boomed. Disposable protective masks (N95 and similar) are the most commonly used protective mask, however, suffocation due to the synthetic fibres and fibre formation inside the mask makes it very uncomfortable to use and disposal of such used masks is another big issue [1,2]. Therefore, some manufacture grabbed this opportunity to make reusable and washable face masks however their efficacy is unknown. Hence, it is important to develop a washable, reusable mask with reliable protection and comfort properties [3].

Reusable cotton face masks are preferred over disposable non-woven masks due to their comfort. However, the fabric used for the mask is normally open weave with large pores size. The porous nature of textiles means that viruses and bacteria can be trapped within the fabric structure, which possibly lowers the risk of the viruses being transferred. On the other hand, the size of bacteria, microbes and viruses are in the range of 0.012 to 0.5 microns. However, the pore size of the fabric is much larger than the pathogens and they can easily pass through the fabric pores. Reduction of the pore size without affecting the breathing comfort is necessary to improve the efficacy of the mask. The use of nanofibre membrane as a filter may help in solving the problem and improve filtration efficiency [4]. Hence, in this work, we have used the nano fibre-based membrane filter to reduce the pore size and improve the bacterial filtration efficiency. This work aimed to develop the washable, reusable, comfortable and highly protective face mask.

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2. Materials & Methods

2.1. Materials:

100% Cotton fabric with 95 GSM-having 96 ends per inches and 62 picks per inches with warp and weft count of 40Nes and 34Nes respectively was procured from India mart supplier. Polypropylene spun bond nonwoven with 30 GSM was used. Elastic, nose wire and elastic adjuster were procured for the local market.

2.2. Methods:

2.2.1. Electrospinning

The measured amount of acetic acid and formic acid in the required ratio was taken in a conical flask and stirred using a magnetic stirrer. The polymer was added slowly during stirring and kept for 2h. The needleless electrospinning machine from ELMARCO (NS IS500 U) with wire electrode was used for the nanofiber spinning. Electrospinning parameters such as concentration of polymer, positive electrode voltage, negative electrode voltage, the distance between the electrode and relative humidity were standardized. Morphology and diameter of Nylon 6 nanofibers were observed by Scanning Electron Microscope (SEM JEOL JSM 5400). Quanta chrome's 3G porometer operating under windows ® the 3G win software was used for the analysis of pore size. Nanofiber layer spun at optimised parameters was used to reduce the pore size of the designed mask.

2.2.2. Mask design:

The designing of the protective mask was the critical part. Considering the different patterns available and drawbacks of the theme, we have designed a uniquely comfortable and proper fitting mask in four different sizes as shown in table 1.

Table 1. Different sizes as per weight groups

Sr. No	Weight (kg)	Size	Dimensions	
			length	Width
1	10-20	XS	19	10
2	21-40	S	21	12
3	41-65	M	23	15
4	65+	L	25	16.5

Mask should be worn in such a way that the nose and mouth should be covered fully, there should be minimum leakages from the sides and it should stay at the proper place. Figure 1 shows the correct methods to take the measurements for the proper fitting mask. The upper edge of the mask should be a little below the eye to provide clear vision and 0.5 to 1inch under the chin. The horizontal length of the mask must cover the full mouth and be 1 inch away from the ear.

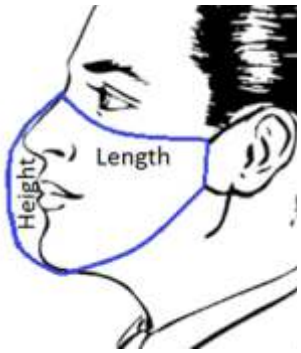

Figure 1. Measurement of proper fitting face mask.

One more important point to be noted is that the mask should not have a through cut at the centre to provide maximum protection. The mask having though out cut at the centre, stitching line may create pinholes at the centre through which the bacteria and viruses can penetrate though the mask directly near the nose and purpose of wearing a protective mask can diminish. Therefore, our mask does not have a throughout cut at the centre. The pattern design is shown in figure 2.

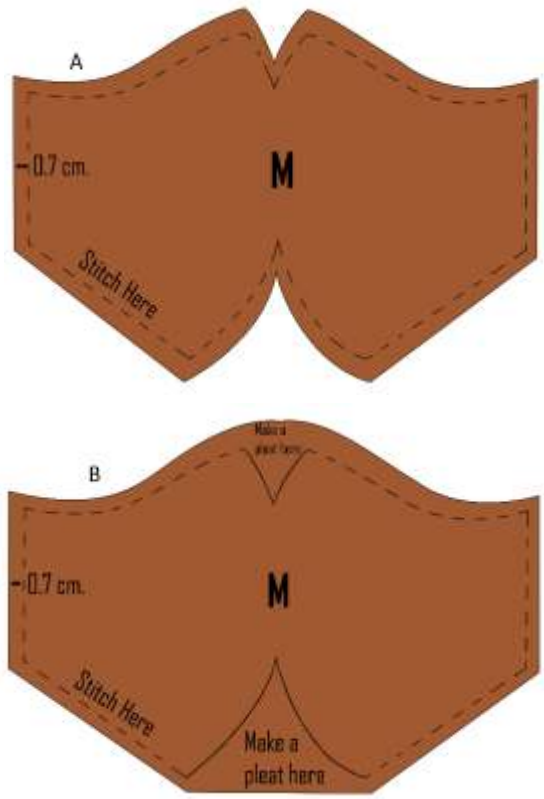

Figure 2 Master pattern of the mask – A-for fabric cutting, B- for nonwoven filter cutting

3. Characterisations:

Performance characterisation: Good performance of the protective face mask is one of the most important requirements. There are two Indian Standards (IS) wherein requirement criteria for the protective mask is given. Specification of the mask as per two different IS are listed in table 2.

It may be noticed from Table 2 that, bacterial filtration efficiency (BFE) and Breathability as differential pressure and breathing resistance are the most important parameters for surgical masks and respirators. Hence in our study, we have studied both the parameters for our developed mask.

Table 2. Specification of the mask as per IS 16289 and IS 9473

Parameters	Surgical Face Mask IS 16289			Respiratory protective devices IS 9473		
	Class 1	Class2	Class3	FFP 1	FFP 2	FFP 3
Bacterial filtration efficiency	95	98	98	--	--	--
Differential pressure @8L/min, pa	29.4 pa	29.4 pa	49.0pa			
Breathing Resistance @95l/min, mbar				2.1	2.4	3.0
Splash resistance	--	--	120	--	--	--
Sub-micron particulate filtration efficiency	--	--	98% @ 0.1µ	--	--	95% @ 0.3µ
Leakage	--	--	--	<25%	<11%	<5%
Penetration- Paraffin oil	--	--	--	NA	2%	1%
Flammability	--	--	--	Yes	Yes	Yes

3.1 Differential pressure:

Differential pressure test of the samples was performed according to IS 16289 as prescribed in annexe C at an airflow rate of 8 L/min. Five readings were taken from five different mask specimens and the average reading was recorded differential pressure value of the mask.

3.2 Bacterial filtration efficiency:

BFE of the BTRA developed face mask samples was performed as per the ASTM F-2101. The test samples were challenged to Staphylococcus aureus bacteria with a mean aerosol particle size of 3.0 ± 0.3 micron with a flow rate of 28.5 L/min. the bacterial aerosol passed through the mask was collected on the Tryptic soya agar and incubated for 24hr at 37°C. The growth of the bacteria was counted as several CFU and the percentage of the BFE was calculated. Similarly, the BFE of the washed samples was also studied after 5 and 10 items of washing.

3.3 Fabric characterisation:

All the cotton fabrics were subjected to colour fastness to washing, light and rubbing tests using respective IS standards.

4. Results and discussions:

4.1. Differential pressure:

Differential pressure (DP) essentially measures the difference in pressure between two given points. When considering the DP of any mask it measures the resistance created by the mask at constant airflow. Lowering the resistance better is the breathability and the mask will provide more comfort. We have measured the DP of our samples at an airflow rate of 8L/min as per IS 16289. We received the DP value of 55.5pa/cm2 which is a little higher than that of the standard requirement as shown in table 2 for the class 3 mask. However, we have also compared our face mask with various N95 masks available in the market and found that the DP values of the commercial N95 mask samples are very high than that of our developed samples.

Table 3 Differential pressure of the samples at 8L/min airflow

Sample Name	Differential pressure (pa/cm^2)
Fabric only single layers	6.12
Nonwoven filter	26.9
Mask	55.5

Table 3 shows the DP of various components of the mask. It may be noticed that the DP fabric is the result of its weaving pattern and cover factor by changing the weaving structure we can further reduce the DP of the mask and meet the requirement of 49 pa/cm2 for class 3 surgical masks.

4.2 Bacterial filtration efficiency:

BFE of the unwashed and washed samples is depicted in figure 3. It can be seen that initially before washing the BFE was 98%. This indicates that there is only 2% of bacterise can pass through the mask and the remaining 98% are filtered out. This high BFE can be attributed to the nano-membrane filter used as the middle layer of the mask. Nano membrane effectively works to reduce the pore size of the filter media without affecting breathability. This meets the requirement of IS 16289 class 3 masks. Further, after washing up to 10 washes the BFE is not reduced and can provide 98.5% bacterial protection.

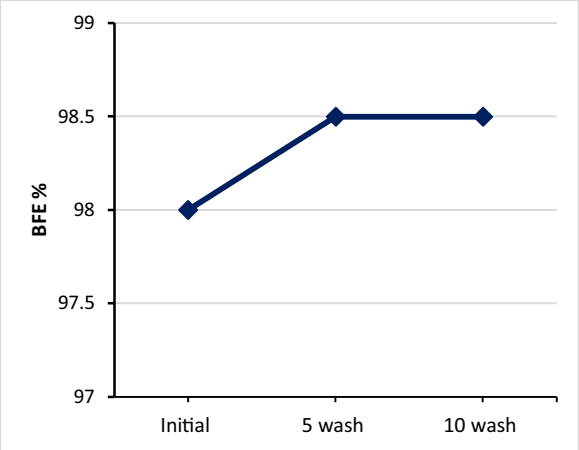

Figure 3 BFE of the mask samples up to 10 wash

4.3 Fabric characterisation:

The cotton fabrics used for the outer and inner layer of the mask was subjected to colour fastness to washing at 60°C for 30 min as per IS standard 105 C10 test method. The results and given in table 4. As can be seen from Table 4 that all the samples have goo colour fastness to washing. Similarly, colour fastness to natural sunlight was tested by accelerated test using IS 105 B02 standard method. It was found that all the samples have good colour fastness to light rating. Further, it can be seen from the table that only the black sample has poor colour fastness to wet rubbing.

Dimensional changes after washing were also analysed and reported in table 4 as % shrinkage.

Table 4 colour fastness properties of the mask samples

Fabric colour	Colour fastness				Shrinkage (%)	
	Washing	Light	Rubbing			
			Dry	Wet	warp	weft
White	NA	5	NA	NA	6.4	2.1
Black	4-5	5	4-5	2	5.4	2.6
Navy blue	4-5	5	4-5	3	5.1	6.8
Olive green	4-5	4	4-5	4	6.0	1.3
Mustered yellow	4-5	4	4-5	4	4.6	4.8
Purple	4-5	4	4-5	3	5.2	5.6

4.4 Design and comfort:

The design of the mask is made in such a way that it should meet the specifications of both the standards and provide comfort to the wearer. Cotton fabric, polypropylene nonwoven and nanofibre membrane are arranged in five different layers to make a protective mask. Adjustable nose chip provided at the top centre of the mask ensure the proper fitting and keep the mask at the proper position, eliminating the leakages and reducing the fogging effect. Further, elastic with little wider width (8mm) reduce the tress on the ear and an elastic adjuster makes it more comfortable to fit as per the choice of the individual.

The design and comfort of any face mask is the subject matter of an individual and hence cannot be tested quantitatively using any instrumental techniques. Therefore, the design and comfort of the mask were evaluated through the feedback of users. Total 50 reviews from different users of 25 to 55 age groups were analysed and found that more than 95% of the users are happy with the comfort that is the breathability of the mask and outer fabric feel. More than 70% are happy with the colours, print and look of the mask. It is well understood that the colour, print and design is the individual's choice and I defer from person to person. Further, a few people were unhappy with the size of the mask. This issue can be resolved by choosing the proper size as suggested in table 1. Overall, it was concluded from the feedback that, the BTRA developed mask provides comfort and also comply with the requirements of the standard.

5. Conclusions:

We at BREA have developed a highly protective face mask. Differential pressure of the mask was found to be 55.5 pa/cm2 which gives better breathing comfort. 98% BFE provides very good protection against bacterise. The mask passes the requirement of IS 16289 class 3 surgical masks. Front and back cotton fabric is skin-friendly and absorbed more sweat. The adjustable nose clip avoids the fogging on specs. The ear loop adjuster provides more comfort by reducing the stress on-ear.

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