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Development of breathable and liquid/microbes barrier woven surgical gowns for hospital usage

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An attempt has been made to develop a breathable woven surgical gown with antimicrobial and liquid repellent properties by finishing with nanoparticles of silver and fluorocarbon using pad-dry-cure method. Box-Behnken design has been used to optimize the coating parameters, i.e. concentrations of nanosilver (NS), nanofluorocarbon (NFC) and binder. The selected coating parameters has decisive influence on the fabric properties, such as air permeability, moisture vapour permeability, antimicrobial and tensile behaviour. The optimum coating parameters such as concentrations of NS, NFC and binder result in improved air permeability and moisture vapour permeability of the fabric for 3 g/L of NS and 40 g/L of NFC. The antibacterial activity of fabric is found to be higher for increased NS concentration and lower for increased NFC. In case of tensile properties of coated fabrics, the increase in NS concentration increases the tensile strength and decreases the bending modulus of fabrics.

Keywords : Antimicrobial cotton fabrics, Dual finish, Liquid repellent fabrics, Nanosilver, Surgical gowns

1 Introduction

In recent years, attention towards functional finishing of medical textiles, such as blood repellent, antimicrobial and antistatic has increased due to the risk of dangerous microbes development on these fabrics when they come in contact with biological fluids such as blood, sweat, etc[1]. Of the various medical textiles, surgical gowns and surgical masks are important textile products which protect surgeons from hazardous viruses such as Hepatitis B, HIV, etc.[1-3]. These microbes, normally present in the patient's blood, are much smaller than the pore size of the fabric and thus can easily make contact with the skin of surgeons. In order to protect the surgeons from the penetration of these viruses, spunlaced, melt blown and spunbonded/melt blown/spunbonded (SMS) nonwoven fabrics are used as surgical gowns[3, 4]. However, these nonwoven fabrics are not widely used in Indian hospitals due to their limitations such as high cost, low blood barrier effect and not reusable. Mostly cotton and polyester/cotton blended woven fabrics are widely used for developing surgical gowns[2]. These woven fabrics has many benefits, such as low cost, stability against wash/reusability, reduced medical waste, good air permeability and good moisture transport, which are highly suitable for surgical gowns[5]. In order to get functional properties, surgical gowns are provided with liquid repellent and antimicrobial finishing (dual finish). Several studies have been carried out on developing the above-mentioned fabric by finishing the fabrics with liquid repellent and antimicrobial agents. Lee *et al*.[6] tried to develop the antimicrobial and liquid repellent cotton and nonwoven fabrics by treating with chitosan and fluoropolymers. They found that dual finished fabric has low antimicrobial and air permeability values. On the other hand, Bagherzadeh *et al*.[7] used cetyl trimethyl ammonium bromide (CTAB) and fluoroalkyl acrylic copolymer (AFF) for developing a dual finished fabric. The finished fabric showed better liquid repellency, however moisture vapour permeability of the finished fabric was affected. In another study, Thilagavathi and Kannian[8] applied neem extracts and fluorocarbon on the fabric surface and the finished fabric exhibited low antimicrobial activity due to presence of fluorocarbon on the surface of the fabric. In order to improve the antimicrobial property, Tomsic *et al*.[9] impart finish on cellulose fibre surface by applying nano silver and fluorocarbon. The finished fabric exhibited good antimicrobial and repellent properties; nevertheless air and water vapour permeability of the fabrics were affected. On the other hand, Montazer and Rangchi[3] applied fluorocarbon and CTAB on the surface of polypropylene and

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polyethylene nonwoven fabrics. The finished fabric showed good antimicrobial property, however the liquid repellent nature of the fabric was reduced due to cationic nature of CTAB. It has been observed from the reported literature that developing a dual finished fabric with good air and moisture vapour permeability is a challenging work. The protective surgical gowns should be given a dual finish without affecting the breathability and comfort of the fabrics. While developing a dual finished fabric, uniform dispersion of chemicals on fabric surface is an important requirement for developing a good quality antimicrobial and liquid barrier fabric. From the published literatures, it has been observed that the fabric finished with nano chemicals can provide an excellent functional performance, such as water and oil repellency, stain proof, antibacterial, antistatic, etc. without compromising the breathability of fabrics[10]. Therefore in the present study, nano liquid repellent and nano-antimicrobial agents have been applied on surgical fabrics which can provide good liquid repellent and antimicrobial characteristics to the fabric along with better breathability. In this research work, nanosilver and nanofluorocarbon have been taken along with a binder and applied on surgical fabric. The concentration of solutions has an influence on fabric properties, and hence solution concentrations of nanosilver, nanofluorocarbon and binder were taken as variables and then optimized using a statistical tool.

2 Materials and Methods

2.1 Materials

Vat dyed cotton fabric purchased from Madura Dyeing Ltd., Erode was used. The specifications of cotton fabric are given in Table 1. The purchased cotton fabric was washed with a soap solution in order to remove oils and dirt present in the fabric and conditioned according to the standard IS 6359:1971. Nanosilver and nanofluorocarbon supplied by Venous Dyes and Chemicals, Erode were used for developing an antimicrobial and liquid repellent fabric and their specifications are given in Table 2. The nanosilver having the size of 52 nm is used along with a binder to compatibilize its reactions with the cellulosic molecules of cotton fabric.

2.2 Nanosilver and Nanofluorocarbon Solution Preparation

Nanosilver was taken in the form of colloidal solution and diluted in water to prepare various concentrations of nanosilver (NS) solution. In the same way, nanofluorocarbon (NFC) was diluted in water for obtaining various concentrations of NFC solution. Both chemical solutions were then mixed with a binder solution and stirred well using a magnetic stirrer to get a homogeneous solution. The *p*H of the solution was maintained at around 4 - 5 by adding few drops of acetic acid.

2.3 Coating Process

The mixed chemical solution was taken as pad liquor and the fabric was padded with a squeezing pressure of 40 psi (70% wet pick-up). Finally, the coated fabric was dried at room temperature and cured at 150ºC for 3 min.

2.4 Experimental Design

Preliminary experiments were conducted to study the influence of nanosilver, nanofluorocarbon and binder concentrations on various functional properties of surgical gowns. The concentrations of nanosilver, nanoflurocarbon and binder solutions were varied within the range 1 - 10 g/L, 10 - 100 g/L and 10 - 50 g/L respectively and the fabric was finished using this solution. It has been observed that the optimal properties of the fabric lies in the range of 3, 40 and 15 g/L of nanosilver, nanofluorocarbon and binder respectively. Hence, to optimize these coating process variables, Box-Behnken design was chosen with the central points found in the

Table 1 — Specification of cotton fabric

Specification	Value
Thread count	
Warp	20^s Ne
Weft	20^s Ne
Ends per inch	60
Picks per inch	56
Cover factor	19.94
Weave	Plain
Dye used	Vat dye (surgical green)
Grams per square meter	143

Table 2 — Chemicals used for nanofinishing

Chemical	Commercial name	Functions
Nanofluorocarbon	Nanoprove FC	Liquid repellent finish
Acetic acid	Acetic acid	To control the acidity of the solution
Organic-inorganic binder	ISYS MTX	To bind the silver nanoparticles with the specimen.
Nanosilver	ISYS AG	Antimicrobial agent

preliminary studies. The process variables were nanosilver concentration (NS), nanofluorocarbon concentration (NFC) and binder concentration; they were chosen as critical variables and designed as X_1, X_2 and X_3 respectively. The low, middle and high levels of each variable were designed in coded form as -1, 0 and +1 respectively and experimental design of these variables is given in Table 3. The response surface equation was developed and the coefficients and constants used in response surface equation are given in Table 4. The nanofinished surgical gowns were tested on the functional properties of fabrics and the results are given in Table 5.

2.5 SEM Analysis

Surface morphology of the coated fabric samples was examined by SEM with a Joel JSM 820 Electron microscope. All the fabric samples were subjected for ion beam sputtering (JFC-1100, Japan) before the SEM analysis.

2.6 FTIR Analysis

Fourier transform infrared spectroscopy analysis was carried out for NS and NFC finished cotton fabrics to confirm the presence of NFC on cellulose molecules. FTIR spectrum of finished fabric was obtained using Shimadzu FTIR – 8400S, Kyoto Japan.

2.7 Assessment of Fabric Liquid Repellency

Liquid repellency of fabric was measured by surface contact angle test method according to ASTM D 5725-1999. Drops of standard test liquids were placed on the fabric surface and photograph of the water droplet was taken using Canon 40 D SLR camera. The captured image of water drop was analysed using digimizer image analysis software for wetting/repellency behaviour of fabric.

Table 3 — Experimental design for three variables

Sample No.	Levels of variables					
	X_1 levels		X_2 levels		X_3 levels	
	Coded	Actual	Coded	Actual	Coded	Actual
1	-1	1	-1	10	0	15
2	1	5	-1	10	0	15
3	-1	1	1	70	0	15
4	1	5	1	70	0	15
5	-1	1	0	40	-1	10
6	1	5	0	40	-1	10
7	-1	1	0	40	1	20
8	1	5	0	40	1	20
9	0	3	-1	10	-1	10
10	0	3	1	70	-1	10
11	0	3	-1	10	1	20
12	0	3	1	70	1	20
13	0	3	0	40	0	15
14	0	3	0	40	0	15
15	0	3	0	40	0	15

X_1 — Concentration of nanosilver in g/L; X_2—Concentration of nanofluorocarbon in g/L and X_3—Concentration of binder in g/L.

2.8 Assessment of Antimicrobial Property of Fabrics

Escherichia coli (*E. coli*) and *Staphylococcus aureus* (*S. aureus*) bacterial strains were tested in this study, which are common microorganisms present in hospital-acquired infections[11,12]. Antibacterial activity of unfinished and finished (NS and NFC) fabrics against these microbes were qualitatively analysed by agar diffusion method according to AATCC 147-2004. In this method, antimicrobial activity of fabric was observed by the presence/absence of bacterial growth in the contact zone between the agar and the samples as well as on the appearance of an inhibition zone[12].

2.9 Air Permeability and Moisture Vapour Permeability of Fabrics

Air permeability of unfinished and finished fabrics was evaluated using a Premier air permeability tester in accordance with ASTM standard D 737. Moisture vapour permeability of unfinished and finished fabrics was determined by moisture vapour permeability tester using open cup test method according to ASTM standard E 96-66. In this study, water method (at 23°C) was followed to assess the moisture vapour transfer of the fabric. The fabric to be tested was placed in environment chamber and constant test conditions were maintained throughout the test.

2.10 Assessment of Fabric Tensile Strength and Bending Modulus

Tensile strength of unfinished and finished (NS and NFC) cotton fabrics was tested by grab method using Instron 5567 according to ASTM D 5035-95. Bending modulus of unfinished and finished fabric was assessed using Shirley's stiffness tester according to the standard test method BS: 3356-1961.

3 Results and Discussion

3.1 SEM Analysis

SEM analysis was carried out to ensure the uniform distribution of finished chemicals on surface of fabric. Figure 1 shows SEM micrographs of unfinished and finished (NS and NFC) cotton fabric samples. It has been observed from Fig. 1(b) that the distribution of nanosilver and nanofluorocarbon on cotton fabric is

Table 4 — Coefficients and constants of response surface equation

Response	Response surface equation	R^2 value
Add-on% (R_0)	$R_0 = 0.77+0.02\times X_3+0.01\times X_1\times X_1-0.03\times X_2\times X_2+0.04\times X_1\times X_2+0.02\times X_2\times X_3+0.11\times X_1\times X_2\times X_3$.	0.895
Air permeability (R_1)	$R_1 = 97.94-2.27\times X_1-7.53\times X_2-4.62\times X_3-0.21\times X_1\times X_1+1.22\times X_2\times X_2-5.55\times X_3\times X_3-7.21\times X_1\times X_2-2.36\times X_2\times X_3-1.77\times X_1\times X_3+11.10\times X_1\times X_2\times X_3$	0.956
MVT (R_2)	$R_2 = 804.87-1.40\times X_1-6.68\times X_2-7.22\times X_3-13.33\times X_1\times X_1+10.52\times X_2\times X_2-14.87\times X_3\times X_3+4.25\times X_1\times X_2+2.13\times X_2\times X_3-0.03\times X_1\times X_3+111\times X_1\times X_2\times X_3$	0.965
Antibacterial efficiency against *E.coli* (R_3)	$R_3 = 0.88+0.46\times X_1-0.16\times X_2-0.02\times X_3-0.23\times X_1\times X_1-0.23\times X_2\times X_2-0.15\times X_3\times X_3-0.07\times X_1\times X_2+0.11\times X_1\times X_2\times X_3$	0.989
Antibacterial efficiency against *S.aureus* (R_4)	$R_4 = 0.82+0.40\times X_1-0.16\times X_2-0.20\times X_1\times X_1-0.24\times X_2\times X_2-0.19\times X_3\times X_3-0.07\times X_1\times X_2-0.03\times X_2\times X_3+0.02\times X_1\times X_3+0.11\times X_1\times X_2\times X_3$	0.989
Contact angle (R_5)	$R_5= 135+0.86\times X_1+47.83\times X_2+3.37\times X_3+0.14\times X_1\times X_1-50.16\times X_2\times X_2-6.11\times X_3\times X_3+0.18\times X_1\times X_2+2.74\times X_2\times X_3-3.60\times X_1\times X_3+11.1\times X_1\times X_2\times X_3$	0.965
Tensile strength (R_6)	$R_6= 43.80+0.06\times X_1+0.14\times X_2+0.48\times X_3+0.37\times X_1\times X_1-0.50\times X_2\times X_2-0.17\times X_3\times X_3+0.25\times X_1\times X_2-1.7\times X_2\times X_3-0.92\times X_1\times X_3+11.1\times X_1\times X_2\times X_3$	0.865
Bending modulus (R_7)	$R_7 = 0.17+0.01\times X_1-0.01\times X_2+0.01\times X_2\times X_3-0.01\times X_1\times X_3+0.01\times X_1\times X_2\times X_3$	0.925

Table 5 — Experimental values of nanofluorocarbon and nanosilver finished cotton fabrics

Add-on%	Contact angle deg	Zone of inhibition mm		Air permeability $cm^3/cm^2/s$	MVTR, $g/m^2/24h$	Tensile strength (Warp way) kgf	Bending modulus kg/cm^2
		E. coli	*S. aureus*				
0.812	40	0	0	103.416	813.654	43.915	0.179
0.765	35	1	0.9	107.916	807.151	43.872	0.198
0.651	134	0	0	105.194	788.458	42.999	0.135
0.776	130	0.7	0.6	79.791	798.961	43.917	0.165
0.800	119	0	0	98.861	792.377	42.746	0.138
0.765	134	1	0.8	103.583	784.839	44.421	0.195
0.799	131	0	0	84.610	768.551	45.431	0.165
0.801	132	1	0.9	81.944	760.868	43.390	0.179
0.698	29	0.8	0.6	99.318	810.167	40.416	0.195
0.711	120	0.3	0.2	87.451	795.861	44.761	0.165
0.744	32	0.7	0.6	104.237	800.906	44.876	0.151
0.821	134	0.2	0.1	82.564	795.137	42.456	0.179
0.767	135	0.9	0.9	97.687	799.614	44.420	0.179
0.756	134	0.8	0.9	97.885	806.545	41.781	0.179
0.792	135	0.9	0.9	98.231	808.444	45.158	0.165

uniform and nanoparticles are well deposited on the fibre surface.

3.2 FTIR Analysis

The presence of nanofluorocarbon on the fibre surface is chemically confirmed by analysing the FTIR spectra of NFC finished fabric sample. The wave numbers and their corresponding characteristic groups are given in Table 6. The strong and broad bands observed at 3313 cm^{-1} and 3444 cm^{-1} confirm the presence of OH stretching vibrations and the peak at 2907 cm^{-1} represents CH_2 and CH_3 stretching vibration of cotton fabric[13]. The presence of fluorocarbon in the finished fabric samples is confirmed by observing C-F vibration peaks[14] at 928 cm^{-1}.

3.3 Effect of Finishing Chemical Concentration on Fabric Add- on %

The finishing chemical concentration and their ratio in the padding solution have a great influence on fabric add-on % which is shown in Fig. 2(a). From Fig. 2(a) it is observed that the increase in NS concentration from 1 g/L to 3 g/L decreases the fabric add-on % from 0.79% to 0.76 %. Further increase in NS concentration from 3 g/L to 5 g/L decreases the add-on % to 0.74 %. This trend is observed only at a lower concentration of NFC and binder. However, at

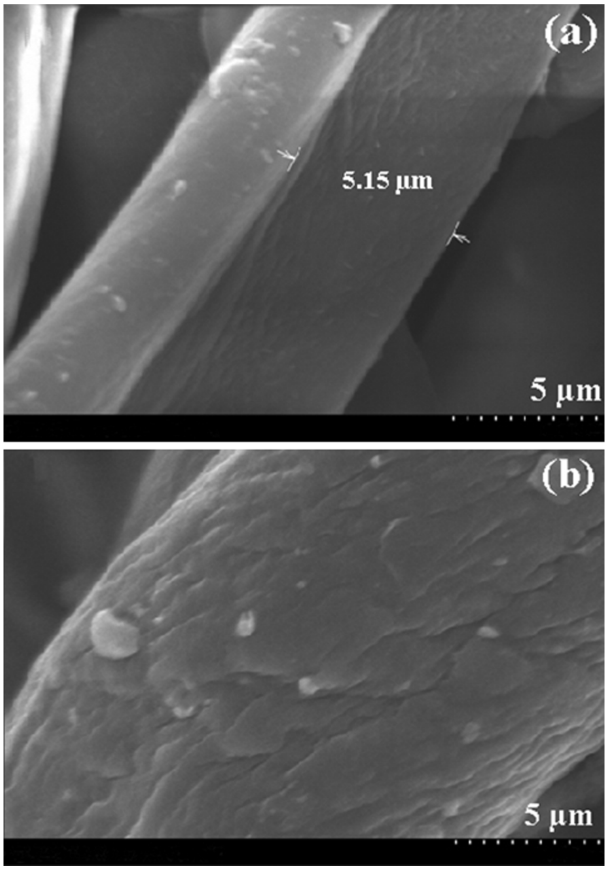

Fig. 1 — SEM images of unfinished (a), and finished (b), cotton fabrics

Table 6 — Infrared transmittance peaks (cm^{-1}) of untreated and treated cotton fabric

Wave numbers, cm^{-1}	Characteristic group
3313 and 3444.3	OH stretching
2907.6	CH_2 and CH_3 stretching
1653	Bending vibration (Absorbed water)
1438.8	CH and CH_2 bending
1148.2 and 928.1	FCF and CF_3,

a high level of NFC and binder, the increase in NS concentration increases the add-on %. This can be explained by the fact that while preparing the nano-solution by mixing of NS, NFC and binder, the distribution of NS could be uniform in the solution at its lower concentration of nanosilver. However, the increase in NS concentration (5 g/L) at the same level of NFC and binder, possibilities of agglomeration of NS could occur which might have reduced the deposition of NS on the fibre surface. In case of fabric finished with 70 g/L of NFC and 1 g/L of NS, the fabric add-on reaches 0.73 %. This could be explained by the fact that at higher concentration of NFC, the addition of NS might have increased the distance between the NS particles in the solution. As this solution is applied on fabric surface, nanosilver particles occupy only lesser area on the fabric surface, which, in turn, reduces the fabric add-on %. As the NS concentration increases from 1 g/L to 5 g/L, the distance between NS particles decreases, resulting in increased NS on fabric surface and the fabric add-on %. In addition, an increase in binder concentration increases the fabric add-on %. This can be attributed to the fact that the increase in binder concentration might have increased the affinity or adhesion of chemicals, which results in higher add-on %.

3.4 Effect of Finishing on Fabric Surface Contact Angle

In general, hydrophobic textile surface is developed by coating/depositing low surface energy materials on their surface. Figure 3 shows the typical images of water drops on unfinished fabric and finished fabrics (finished with NS and NFC). The water drop on unfinished cotton fabric [Fig. 3(a)] is almost absorbed, whereas finished cotton fabric [Fig. 3(b)] shows good liquid repellent behaviour and surface contact angle of 135.01°. Figure 2(b) shows the effect of finishing chemical concentration on fabric surface contact angle. From Fig. 2(b), it is observed that the increase in NS concentration from 1 g/L to 5 g/L has no significant change on surface contact angle of fabrics. The increase in NFC concentration from 10 g/L to 70 g/L increases the contact angle of fabric from 60° to 140°. This is attributed to the fact that increase in NFC concentration in the finishing solution reduces the surface energy of finished fabric which results in higher contact angle. On the other side, increase in binder concentration from 10 g/L to 20 g/L has no effect on contact angle of the fabric. From the contour graphs, it is observed that higher water repellency of fabric can be obtained for the finishing chemical having 40 - 70 g/L of NFC at any level of NS and binder.

3.5 Effect of Finishing Chemical Concentration on Fabric Air Permeability

Generally air permeability of fabric depends on number of pores present in the fabric and also the size of pores[2]. If a fabric has more number of pores, it shows good air permeability. Figure 4(a) shows the air permeability of NS, NFC and binder finished fabrics at various concentrations. From Fig. 4 (a) it is observed that the increase in NS concentration from 1 g/L to 5 g/L reduces the air permeability of fabrics. This may be attributed to the fact that more deposition of NS reduces the pore size of fabric, resulting in decreased air permeability of fabric. An increase in NFC concentration from 40 g/L to 70 g/L decreases the air permeability of fabric. This can be attributed to the fact that, while increasing the NS concentration at a higher level of NFC, the already deposited NS particles on fibre surface might be

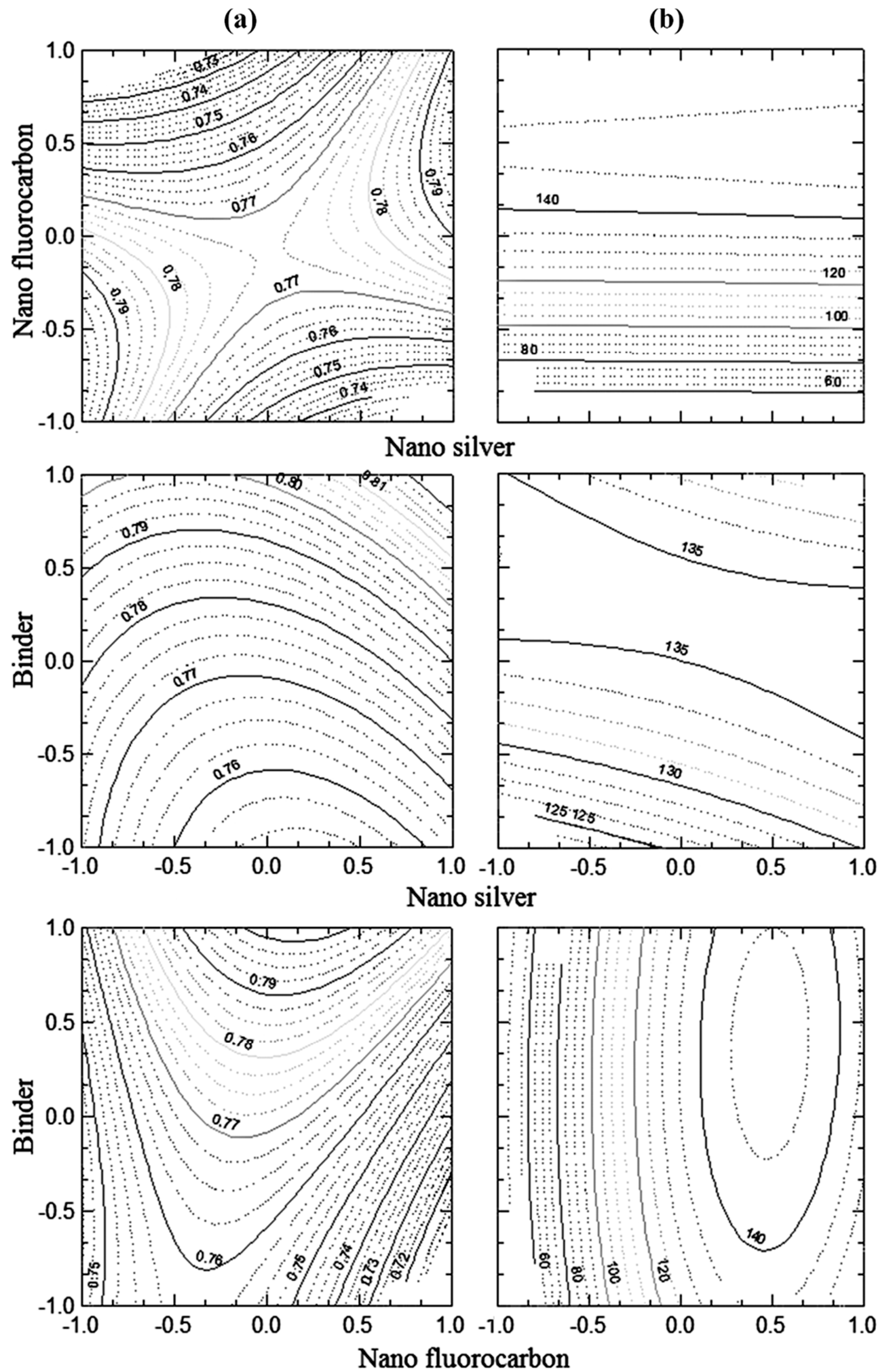

Fig. 2 — Contour diagrams depicting the influence of chemical concentration on add-on % (a), and surface contact angle (b), of fabrics

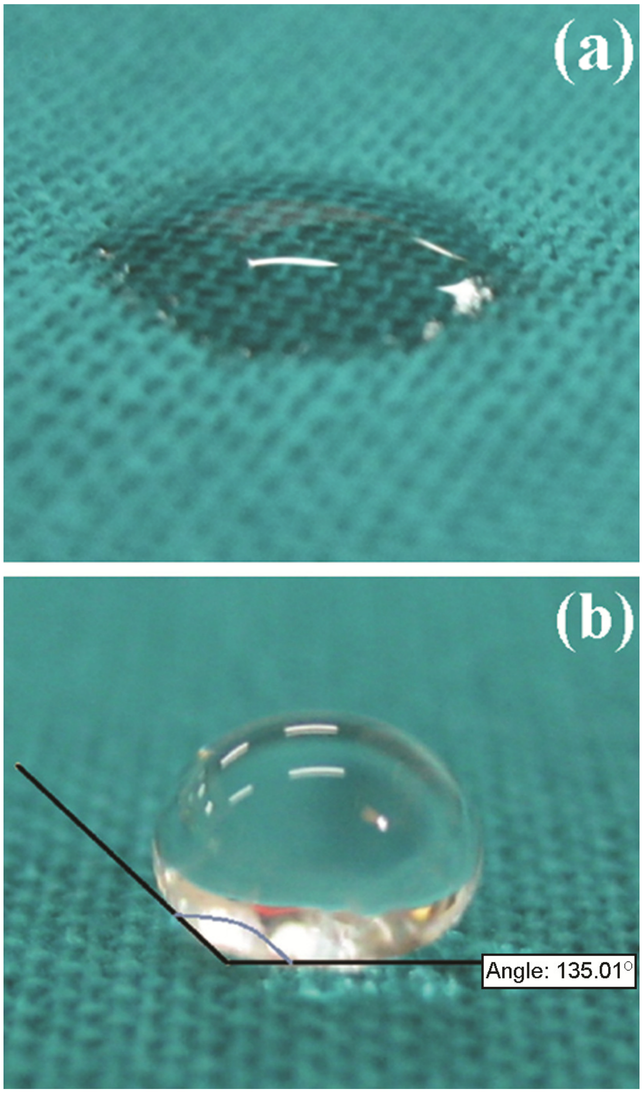

Fig. 3 — Images of distilled water droplet on unfinished (a), and finished (b) (NS and NFC), cotton fabrics

helping of deposition of NFC from the finishing solution[9]. This results in reduced fabric pores and hence low air permeability of fabrics. On the other hand, increase in binder concentration from 10 g/L to 15 g/L increases the fabric air permeability. However, at a high level of binder concentration (20 g/L), the air permeability of fabric is reduced. This is due to the fact that, while increasing the binder concentration from 10 g/L to 15 g/L, binding of more protruding fibres may occur. This helps in more opening of pores, which, in turn, improves air permeability of fabric. Further increase of binder concentration from 15 g/L to 20 g/L reduces the fabric pore size, resulting in decreased air permeability of fabric. Hence, it is inferred that the high air permeability of fabric has been obtained for 40 g/L of NFC and 15 g/L of binder with any level of NS.

3.6 Effect of Finishing on Fabric Moisture Vapour Transfer Rate

In general, moisture vapour transfer depends on the fabric diffusion coefficient and vapour pressure gradient[15]. A fabric having low surface energy materials such as fluorocarbon on its surface would not allow the transport of water particles/moisture vapour through the fabric. However, presence of nano-scale fluorocarbon on the fabric surface does not mask pores present in the fabric[13]. Hence, the transport of moisture vapour through the fabric pores is not disturbed in nano-finished fabrics. Figure 4(b) shows the influence of finishing chemical concentration on moisture vapour transfer rate of fabrics. From Fig. 4(b) it is observed that the increase in NS concentration from 1 g/L to 3 g/L increases the fabric moisture vapour transfer from 795 g/m^2/day to 805 g/m^2/day. However, at 5 g/L of NS, moisture vapour transfer is reduced from 805 g/m^2/day to 790 g/m^2/day. This can be attributed to the fact that at lower level of NS, vapour molecules may be retained by NS particles on fabric surface, which enhances the moisture vapour transfer rate. Further deposition of NS particles on fibre surface reduces the pore size of fabric, which, in turn, decreases moisture vapour transfer. The increase in binder concentration from 10 g/L to 15 g/L initially increases the fabric moisture vapour transfer from 790 g/m^2/day to 810 g/m^2/day and further increase in binder concentration (up to 20 g/L) decreases the moisture vapour transfer of fabric from 810 g/m^2/day to 785 g/m^2/day. This is attributed to the fact that the lower concentration of binder causes deposition of silver particles which may improve the moisture vapour transfer rate. However, at high binder concentration, it leads to bounding of entire protruding fibres on yarn surface andblocks the fabric pore which reduces the moisture transfer rate of the fabric. Hence, a high moisture vapour transfer of fabric can be observed by using low level of NS and low level of binder concentration.

3.7 Effect of Finishing on Antibacterial Efficiency of Fabric

3.7.1 Antibacterial Activity against Escherichia coli

Antibacterial activity of NS and NFC finished fabrics was qualitatively analysed by agar diffusion method. Figure 5 shows antimicrobial activity of unfinished and finished (NS and NFC) cotton fabric samples against the bacterial strain *E. coli*. The test results reveal that the bacterial growth on unfinished cotton fabric [Fig. 5(a)] is clearly observed and it confirms zero zone of inhibition as well as

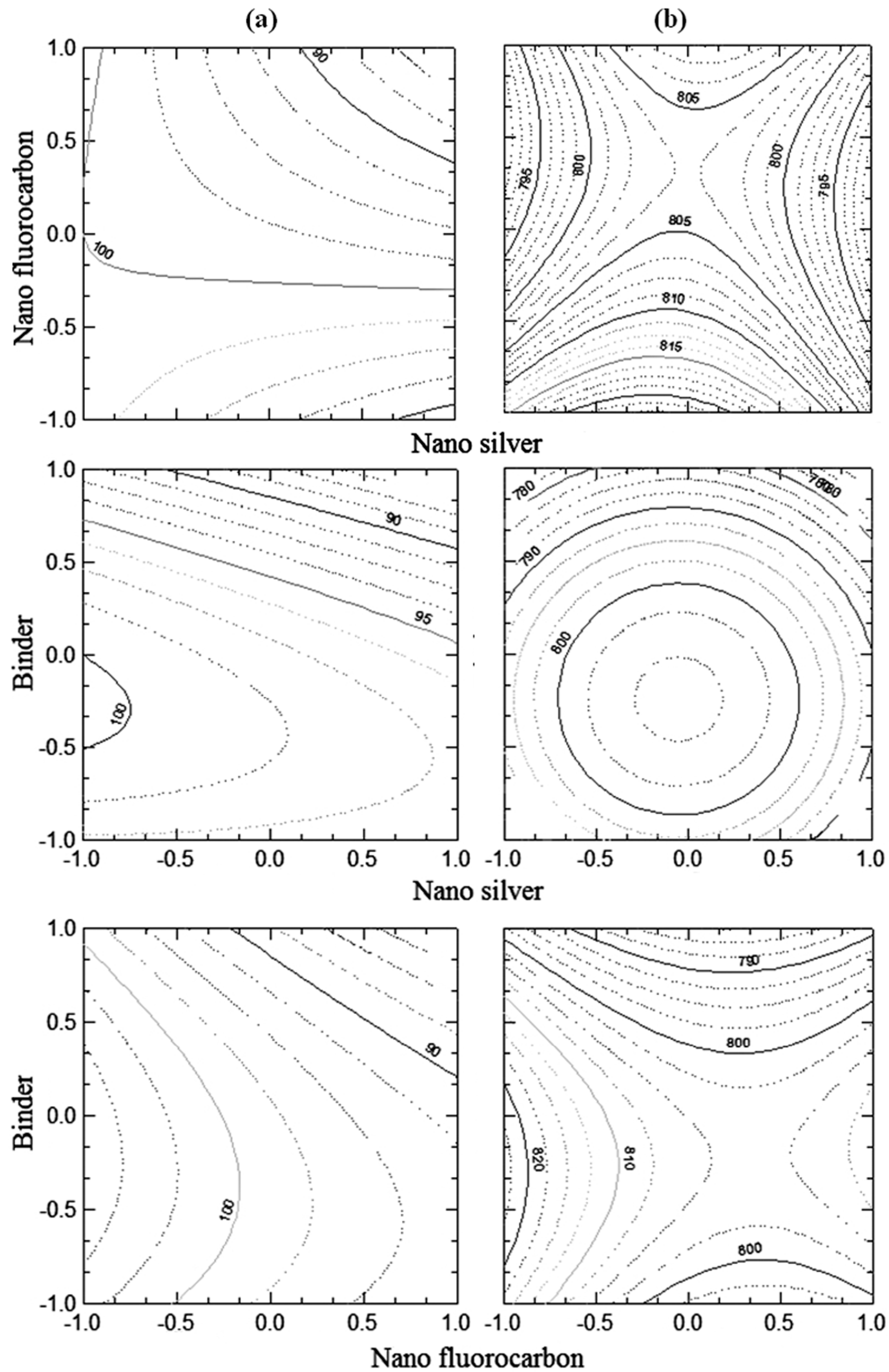

Fig. 4 — Contour diagrams depicting the influence of chemical concentration on air permeability (a), and moisture vapour transfer rate (b), of fabrics

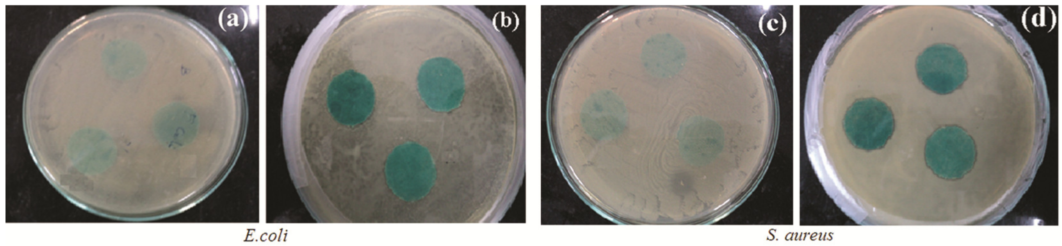

Fig. 5 — Photographic images of the zone of inhibition of unfinished (a), and finished cotton fabrics (b), against *E. coli* and *S. aureus*.

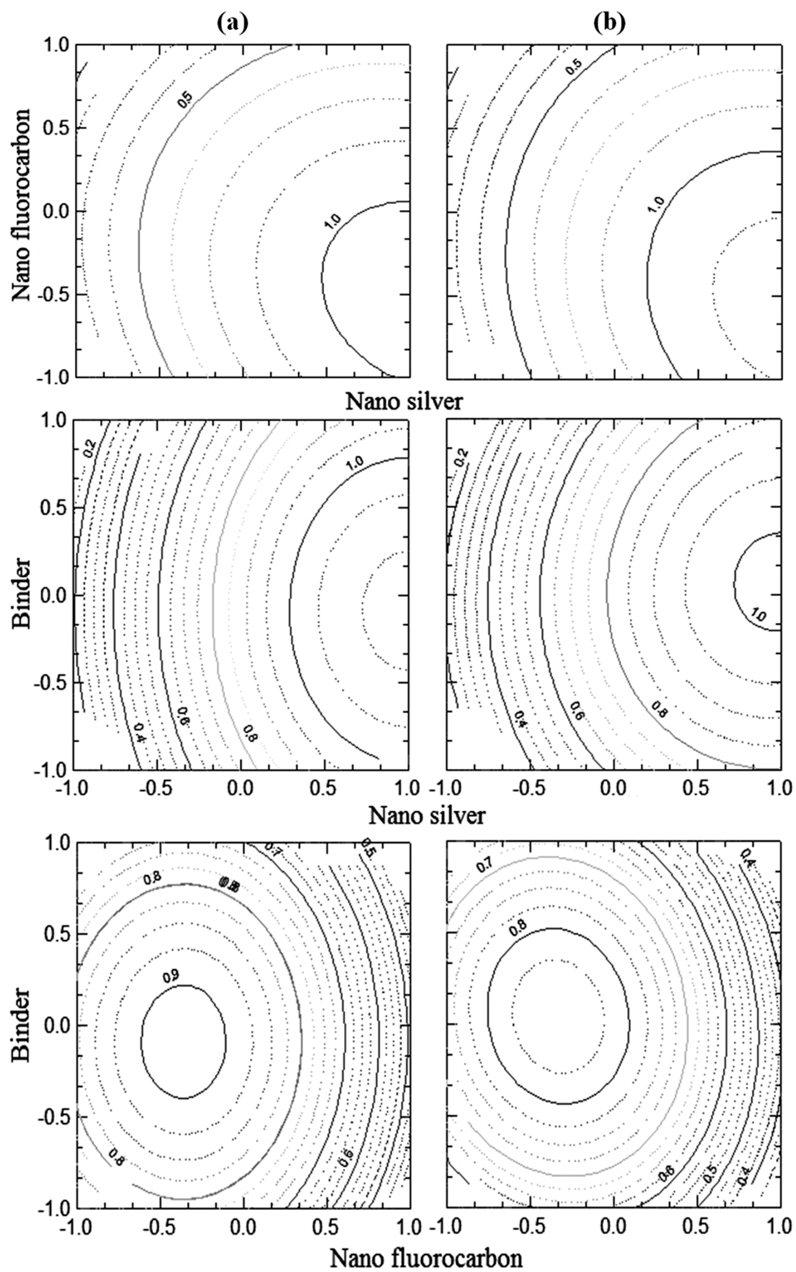

Fig. 6 — Contour diagrams depicting the influence of chemical concentration on bacterial inhibition zone for bacterial strain *E. coli* (a), and *S. aureus* (b)

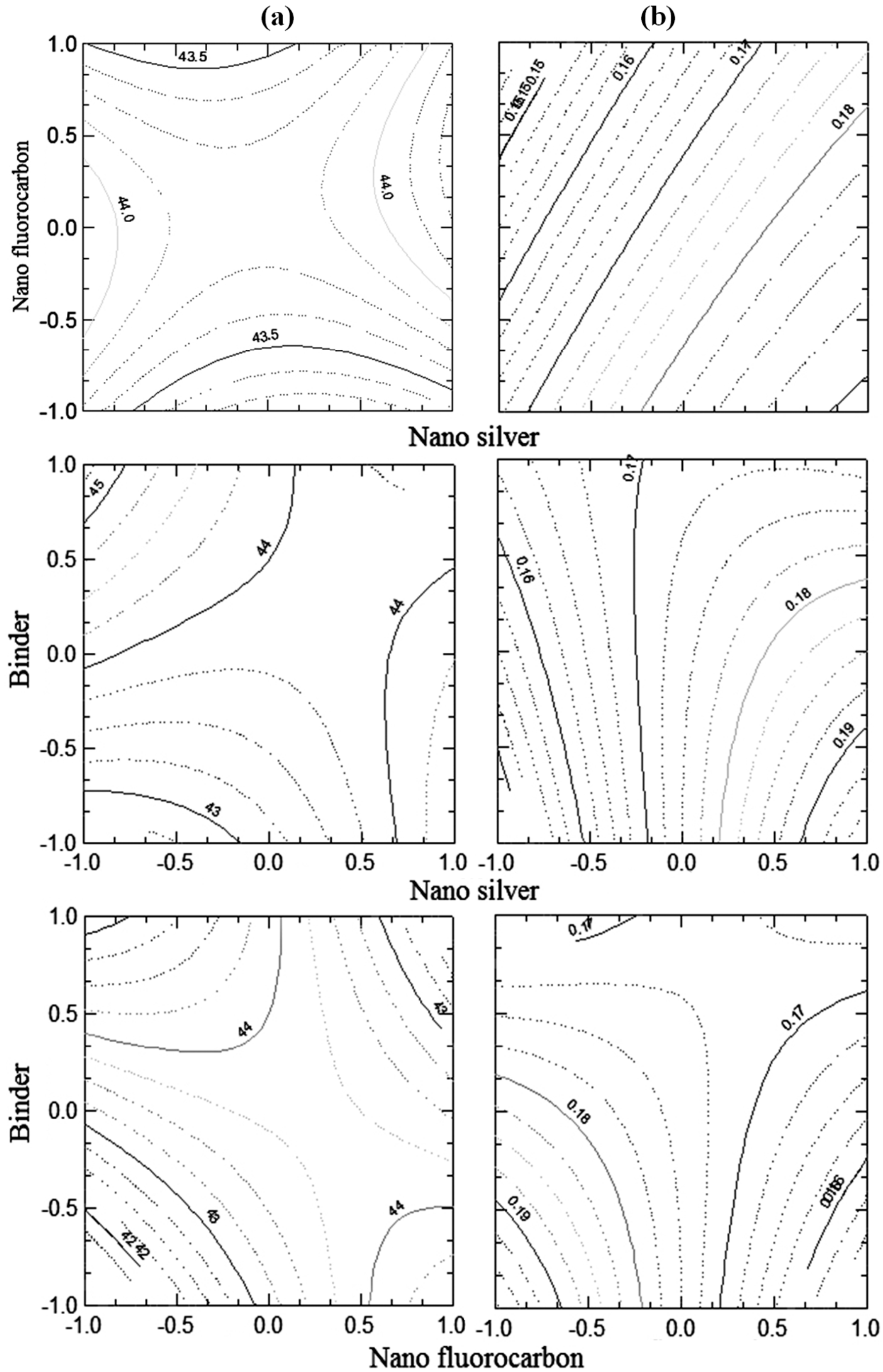

Fig. 7 — Contour diagrams depicting the effect chemical concentration on tensile strength (a), and bending modulus (b), of fabrics

no antibacterial activity. Nevertheless, the fabric finished with NS and NFC [Fig. 5(b)] shows clear bactericidal effect against *E. coli* i.e. complete killing of bacteria on the fabric surface with bactericidal inhibition zone of 1 - 2 mm. Essentially, antibacterial effect of fabric is decided by the amount of silver particles present on the fabric surface. Figure. 6(a) shows the antibacterial activity of NS and NFC finished fabric against *E. coli* bacteria and it is observed that an increase in NS concentration from 1 g/L to 5 g/L increases the bacterial inhibition zone from 0.4 mm to 1 mm. This is because of the presence of more silver particles on the fabric surface which increases the bacterial inhibition zone. An increase in binder concentration from 10 g/L to 20 g/L also increases the bacterial inhibition zone from 0.7 mm to 0.9 mm, which is insignificant. In order to confirm this, antibacterial test was conducted on binder alone treated fabric and results confirm the non-antibacterial activity of the fabric. An increase in NFC concentration from 10 g/L to 70 g/L decreases the bacterial inhibition zone from 0.8 mm to 0.5 mm. This is due to the fact that the increase in NFC concentration inhibits the antibacterial effect of silver particles. It is observed that the higher antimicrobial activity of fabric can be obtained when the fabric is finished with 3 - 5 g/L of NS and 15 g/L of binder for lower levels of NFC.

3.7.2 Antibacterial Activity against Staphylococcus aureus

The antibacterial activity of unfinished and finished (NS and NFC) cotton fabric was tested against the bacterial strain *S. aureus* and the results are shown in Fig. 5. The unfinished cotton fabric [Fig. 5(c)] clearly shows zero antibacterial activity. The fabric finished with NS and NFC [Fig. 5(d)] shows good bactericidal effect against *S. aureus* i.e. complete killing of bacteria on the fabric surface and also a clear bactericidal inhibition zone (1 - 2 mm), which is similar to the results of *E. coli* bacteria. Figure 6(b) shows the contour diagrams of antibacterial activity of NS and NFC finished fabric against *S. aureus* bacteria and it is observed that the increase in NS concentration from 1 g/L to 5 g/L, increases the bacterial inhibition zone from 0.3 mm to 1 mm. This may be due to presence of more silver particles on the fabric surface. However, an increase in NFC concentration from 10 g/L to 70 g/L decreases the antibacterial behaviour of the fabric. It is hence inferred that the nano-finished fabric has better antibacterial activity against the bacterial strain *S. aureus* as compared to unfinished fabric.

3.8 Effect of Finishing on Fabric Tensile Strength

The tensile behaviour of finished fabrics having various concentrations of finishing chemicals was tested and results are shown in Fig. 7(a). From Fig. 7(a) it is observed that the increase in NS concentration from 1 g/L to 5 g/L increases the tensile strength of fabrics. This is attributed to the fact that the higher concentration of NS might have increased the NS particles on the fibre surface. This results in more adhesion between the fibres and hence improvement in tensile strength of fabrics. Similarly, an increase in binder concentration from 10 g/L to 20 g/L increases the fabric tensile strength from 42 kgf to 45 kgf. This can be due to the fact that the increase in binder concentration increases the binding of threads, which results in higher tensile strength of the fabric. However, an increase in NFC concentration from 10 g/L to 70 g/L does not have any influence on fabric tensile strength.

3.9 Effect of Finishing on Fabric Bending Modulus

The bending modulus of fabric finished with various concentrations of chemicals was tested and the results are shown in Fig. 7(b). It is observed that an increase in NS concentration from 1 g/L to 5 g/L increases the bending modulus of fabric from 0.16 kg/cm^2 to 0.19 kg/cm^2. This is because of the deposition of nanosilver on the fibre surface, which increases the stiffness of fibre, thus resulting in higher bending modulus of fabric. The increase in NFC concentration from 10 g/L to 70 g/L reduces the bending modulus of fabric from 0.19 kg/cm^2 to 0.16 kg/cm^2. In addition, an increase in binder concentration from 10 g/L to 20 g/L at low level of NS (1 - 3 g/L) has no significant change in fabric bending modulus. Hence, the bending modulus of the fabric is positively influenced by the amount of NS particle and not by NFC particles.

4 Conclusion

In this study, surgical fabric with antimicrobial and liquid repellent (liquid barrier) characteristics has been developed by coating it with nanosilver and nanofluorocarbon without affecting its air and moisture vapour permeability.

4.1 The increase in NS concentration at high level of NFC and binder increases the add-on% of fabric.

4.2 In case of repellent property, the increase in NS concentration from 1 g/L to 5 g/L has no significant change in surface contact angle of fabric. However, the increase in NFC concentration from 10 g/L to 70 g/L increases the contact angle of fabric from 60° to 140º.

4.3 In case of air permeability of the fabric, the increase in NS concentration from 1 g/L to 5 g/L reduces the air permeability of fabrics. The increase in binder concentration from 10 g/L to 15 g/L increases the air permeability of fabrics. However at high level of binder concentration (20 g/L), air permeability of fabric is reduced.

4.4 In case of moisture vapour transfer rate of finished fabric, the increase in NS concentration from 1 g/L to 3 g/L increases the fabric moisture vapour transfer from 795 g/m^2/day to 805 g/m^2/day. However at 5g NS, the fabric moisture vapour transfer is reduced from 805 g/m^2/day to 790 g/m^2/day.

4.5 Antibacterial activity of NS and NFC finished fabric against *E.coli* reveals that the increase in NS concentration increases the bacterial inhibition zone whereas binder concentration has no effect on antibacterial activity. The same result is also obtained for the fabric tested against the bacterial strain *S. aureus*.

4.6 In case of tensile strength of finished fabric, the increase in NS and binder concentration increases the tensile strength of fabric.

4.7 In case of bending modulus of finished fabric, increase in NS concentration increases the bending modulus of fabric. The increase in NFC concentration reduces the bending modulus of fabric. In addition, the increase in binder concentration from 10 g/L to 20 g/L at low level of NS (1 - 3 g/L) has no significant change on fabric bending modulus. Therefore, bending modulus of fabric is positively influenced by NS particle and not by NFC particles.

4.8 From this study, it is concluded that the fabric treated with 3 g/L of nanosilver, 40 g/L nanofluorocarbon and 15g/L of binder imparts better antimicrobial and liquid repellent properties without affecting the breathability of fabrics.

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