Studies on combined flame-retardant and water-repellent treatments on cotton drill fabric

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Bleached cotton drill fabric was treated with phosphorus-based flame retardant followed by water and oil repellents to achieve flame-retardant, water-repellent and oil-repellent properties for critical applications such as nuclear biological chemical (NBC) protective suits. The results indicate that by an effective combination of above finishing agents, satisfactory performance could be achieved, although it is very difficult to understand the nature of reaction that takes place between a phosphorus-based flame retardant and the fluorocarbon-based water repellent. The treated fabrics were evaluated for flammability, water repellency and oil repellency. The effect of different add-on levels on important physical properties was also studied. The flame-retardant behaviour was pursued through thermal studies. The flame retardant and water-repellent treated fabric with a total add-on level of 17.7% gave satisfactory results in terms of functional and physical properties.

Keywords: Char length, Cotton fabric, Flame retardant, Fluorocarbon, Oil repellent, Water repellent

1 Introduction

The complexity of rendering the light weight fabrics flame retardant by chemical application or by dope treatment for apparel, industrial, military and critical areas like nuclear biological chemical (NBC) protective suits has generated a lot of interest among the various research organizations throughout the world. The flammability behaviour of textiles is influenced by a number of factors such as weight/unit area, cloth cover, thickness, surface properties and finishing effects such as napped or lofty constructions\textsuperscript{1,2}.

Generally, the heavy and tightly woven fabric constructions are less flammable than the light or open weave constructions although the above conclusions for both natural and synthetic fabrics are not acceptable worldwide. This stems from the fact that the above generalisations are based on only a very limited number of studies as scanty literature is available on the effect of fabric structure on finishing treatments such as flame retardancy, water repellency, etc and it does not carry the details of fabric composition and geometry. Moreover, the high claims made by different organizations lack one or the other basic requirements, namely (i) carcinogenic and mutagenic nature of flame-retardant chemicals, (ii) very high add-on requirements to accomplish functional properties which impair the physical and comfort properties, (iii) poor launderability, and (iv) lack of sophisticated instruments which measure flammability to simulate the practical conditions.

In the recent past, due to the significant advancement in the field of combat technology, the present day soldier is exposed to very serious hazards of atomic, thermomuclear fragmentation, biological and chemical warfare as well as those of multisensor system of reconnaissance, intelligence and surveillance. The augmented prerequisites of its designing have naturally expanded the prospects of research in military clothing. However, each of these designing prerequisites is contrary to one or the other and this makes the task of fabric engineer a complex one. Take the instance of achieving water-repellent nylon fabric for apparel purpose which almost requires jammed construction (maximum weavable) for optimum level of repellency and at the same time has a air permeability of 30 cc/cm\textsuperscript{2}/s, or a light-weight flame-retardant cotton fabric wherein it is nearly impossible to get satisfactory flame-retardant properties along with the satisfactory comfort properties like stiffness, wicking, air permeability, etc.

This paper reports the results of experimental investigations designed to study and develop outer cotton fabric for NBC protective clothing, wherein the
fabric is required to exhibit flame-retardant, water-repellent and oil-repellent properties along with satisfactory physical properties. The implication of water-repellent treatment on FR properties is also briefly discussed.

2 Materials and Methods

2.1 Materials

Bleached cotton drill fabric having the following specifications was used:
weight, 195 g/m²; ends/cm, 28; picks/cm, 28; cloth cover, 25.8; porosity, 70%; breaking strength (warp), 98 kg; and breaking strength (weft), 48 kg.

Glogard-DNP (solid contents 35%), a fibre reactive organic phosphorus compound with metallic oxide, was used as a flame-retardant along with melamine resin from L&N Chemicals. FC-270, a fluorochemical emulsion (solids contents 17%) from 3M Birla, was used as water and oil repellent.

2.2 Methods

2.2.1 Fabric Preparation

The fabric was initially scoured so as to remove the residual finishing agents before padding. It was then conditioned at 65% RH for 2 h before flame-retardant treatment.

2.2.2 Flame-Retardant Treatment

Conditioned fabric samples were padded with an aqueous solution of a mixture of Glogard-DNP and melamine resin by 2 dips and 2 nips through squeeze rollers and the wet pick up was maintained at 70-75% (pneumatic pressure of 3.5 kg/cm² on rollers). The padded samples were dried at 80-100°C and cured at 150-155°C for 3-3.5 min. After curing, the samples were washed with 2 gpl Sandozin non-ionic detergent liquid and 2 gpl soda ash for 5 min and then washed with water and dried. The add-on obtained was calculated based on the initial weight of the fabric.

The FR pad bath concentration was varied from 30% to 50% to get the add-on levels of 12-20%. Melamine resin concentration was 10% of the FR concentration. The pH in different treatments was as follows:

pH of two-step treatment, FR bath, 5-6
pH of single-bath (step) treatment, 5-6
pH of FC bath, 4.5-5.5

Samples S₁, S₂ and S₃ were treated with FR and FC in two-step process, whereas the sample SB₄ was subjected to single-step process wherein FR and FC were combined in the same bath.

In the second step, the FR-treated fabric was impregnated with FC-270 by 2 dips and 2 nips and the conditions employed were identical to that of flame-retardant treatment, except that curing temperature was maintained at 170-175°C.

In an analogous treatment, the fabric was subjected to single bath treatment in which FR and FC were combined. In all the experiments, FC concentration was kept constant at 45 gpl.

2.2.3 Tests

Breaking strength, spray rating, stiffness and wing tear (single rip) tests were performed according to IS : 1969, IS : 390, BS : 3356 and BS : 4303 respectively.

2.2.3.1 Measurement of Contact Angle

The contact angle was measured using the contact angle meter (model II) of Kerneco Instruments Inc, Germany, as follows:

The specimen is set on the curette and a droplet is settled by using a microburette. The shadow of each drop is seen as arc of the circle in the field of goniometer. The contact angle is measured directly by adjusting the movable scale to the target at the point of contact. The contact angle is the angle between the tangent line at the contact point and the horizontal line of the solid surface. In this case of adhesion wetting, the contact angle (θ) was measured using the protractor scale of the meter.

2.2.3.2 Oil Repellency Test

A test specimen (2.5 cm wide and 25 cm long) with the major axis parallel to the machine direction was placed over a Whatman filter paper No.1 covering a 3.8 cm diam. cylindrical mandrel and a load of 50±1 g was attached to each end of the specimen. A drop (4±1 mg) of diethylphthalate coloured with CI disperse red 11 was allowed to fall through 5 mm on the upper surface of the specimen. At the end of 6 h, the specimen was carefully removed and the filter paper examined for penetration of the dyed liquid. The sample was considered to pass the test when minimum 7 out of 10 specimens showed no penetration.

2.2.3.3 Determination of Phosphorus and Nitrogen Contents

The phosphorus content was determined by gravimetric method based on precipitation of ammonium phosphomolybdate and the nitrogen content by the Kjeldahl method.
2.4 Thermal Behaviour Studies

The thermal studies were carried out on Dupont thermal system as detailed below:
- DSC: Dupont 2100; Rate, 10°C/min; Flow, 20 ml/min; and Atmosphere, nitrogen.
- TGA: Dupont 2100; Rate, 50°C/min; Flow, 60 ml/min; and Atmosphere, nitrogen.

2.5 Surface Studies

The surfaces of the treated fibre and yarn were studied with the help of scanning electron microscope SEM: Jeol 35 CF with Polaron DC sputtering unit.

3 Results and Discussion

3.1 FR Properties

The results obtained on cotton drill fabric treated with Glogard-DNP for flame retardancy and with fluorocarbon (FC-270) for water and oil repellency by single process and two-bath process using pad-dry-cure technique are shown in Table 1. A comparison of the results of samples treated in two-bath process suggests that at comparable add-on levels, the sample S2FR with add-on of 16.7% shows the minimum char length of 7.8 cm and 7.6 cm when both warp and weft are compared. Although a clear trend is seen for the char length in warp direction, the results in weft direction are not clear. All the samples treated for flame retardancy and those treated for both flame retardancy and water repellency (FR+FC) did not show after flame and after glow, suggesting that an add-on level of 12% is sufficient enough to give a char length of about 8-9 cm on medium weight fabrics. The difference is noticed basically in terms of yield in char length. The char length values observed for sample S2FR at 1.2% phosphorus content and 3.4% nitrogen content are much less compared to those for sample S4FR (19.6% add-on) at somewhat higher phosphorus content (1.4%) and 3.2% nitrogen content. This shows that phosphorus compounds, which contribute to flame retardancy, do not necessarily show a linear relationship with the amount of phosphorus added to the cotton fabric with its char length. It is clear that the degree of flame retardancy is related to the amount of char and hence the general conception that to increase the degree of flame retardancy, the amount of flame retardant needed in the fabric to produce a given increment of flame retardancy is not valid. Tesoro reported that the amount of phosphorus compound needed to contribute a certain degree of flame retardancy can be greatly reduced by incorporation of compounds containing chlorine, bromine and nitrogen. Bajaj reported the efficiency of phosphorus-based compounds in enhancing the flame-retardant properties by incorporating N-methyl crosslinking agents through N-P synergism. The data reveal the synergistic effect of nitrogen as well as fluorocarbon.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Add-on %</th>
<th>N %</th>
<th>P on fabric %</th>
<th>P in Char %</th>
<th>Char length cm</th>
<th>Contact angle deg</th>
<th>Water repellency rating</th>
<th>Oil repellency rating</th>
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<td>S1FR</td>
<td>11.4</td>
<td>2.3</td>
<td>1.0</td>
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<td>8.8</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>3.4</td>
<td>1.2</td>
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<td>7.8</td>
<td>7.6</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>10/10</td>
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<td>19.6</td>
<td>3.2</td>
<td>1.4</td>
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<td>7.9</td>
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<td>S3FR+FC</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>10/10</td>
<td></td>
</tr>
<tr>
<td>S4FR+FC</td>
<td>16.4</td>
<td>2.2</td>
<td>0.8</td>
<td>0.70</td>
<td>7.5</td>
<td>8.8</td>
<td>98</td>
<td>50</td>
</tr>
</tbody>
</table>

S1FR, S2FR & S3FR: Samples treated with flame retardant
S1FR+FC, S2FR+FC & S3FR+FC: Samples treated with flame retardant + water repellent (FC)
S4FR+FC: Sample treated with flame retardant and water repellent in single bath
N—Nitrogen; and P—Phosphorus
(FC-270) in enhancing the flame-retardant properties imparted to cotton fabric by Glogard-DNP and suggests that somewhat higher nitrogen content is required to reach a char length in the range of 7.5-8.3 cm in the case of two-step treatment.

It is also interesting to note that the water-repellent treatment given after the FR treatment has not affected the FR properties significantly, except in samples S1,FR+FC (12.2% add-on) and S2,FR+FC (20.4% add-on). This is because of the non-compatibility of flame-retardant Glogard-DNP and FC, and treating the FR-treated fabric with a water-repellent compound which can also contribute to FR properties in antagonistic effect. This is reflected in the results of samples S1,FR+FC and S2,FR+FC but not in sample S3,FR+FC (17.7% add-on), indicating that there may be an optimum combination of FR and FC at which the mutual influence of FR and FC is limited.

The efficiency of FR+FC as a flame-retardant and water-repellent system was examined by a single-bath treatment apart from a two-step sequential treatment (Table 1). A comparison of the results of single-bath process [SB,FR+FC (add-on, 16.4%) and S3,FR+FC (add-on, 17.7%)] shows the same char length of 7.5 cm in warp direction, but considerably high char length in weft direction. However, during testing, it was observed that burning behaviour was erratic and did not show consistent results. This may be attributed to the heterogeneous mixture of padding solution comprising aqueous-based FR-resin and emulsion-based FC. The irregular burning of the fabric (SB,FR+FC) observed during testing is attributed to the physical presence of FC on the surface, which is expected to retard the catalytic action of FR on the cellulose fabric. Kuryla and Papa have expressed the complexity of the situation when the flame retardants used are stable up to the point of polymer degradation. In the present work also, FC has a higher decomposition temperature than the cellulose, making the reaction very complex to understand. A comparison of results obtained in the single-step and two-step applications suggests that at comparable nitrogen content, a somewhat lower phosphorus content is required to achieve the char length of 7.5 cm (warp), as observed when samples S1,FR and SB,FR+FC are compared. This may be attributed to the high degree of phosphorylation which occurs at high curing temperature after FR treatment, as the curing temperature was 170-175°C in single-bath process compared to 150-155°C in two-step process.

However, the situation is less well-defined when the samples are compared in the weft direction to come to a logical conclusion.

### 3.2 Water Repellency and Oil Repellency

The use of fluorochemicals to alter the surface properties of textiles so as to achieve low surface energies is well known. On such surfaces, liquids with relatively low surface tensions are held as drops with characteristic contact angles. The non-uniform surfaces of the textiles necessitate the need to consider both advancing and receding contact angles. However, in the capillary systems of textiles, it is the advancing contact angle on the fibres that controls spreading and wicking. In the present investigation, all the samples treated with fluorocarbon emulsion measured contact angles in the range of 95-100°, with sample S1 measuring the highest contact angle. This is expected because the concentration of fluorocarbon emulsion was kept constant (45 gpl) in all the treatments. It is also observed that all the samples treated in two-step process passed the spray rating (rating 90). It is also interesting to note that out of all the samples treated with flame-retardant and water-repellent agents, only single-bath treated sample S1 failed in the water repellency test. Even though no penetration of water through the sample was observed, a distinct surface wetting was observed. The spray rating test being basically a measure of surface wetting rather than a measure of resistance to penetration, the penetration aspect was not taken into consideration. This resulted in the rating of 50, which is far from the satisfactory level. Even though the contact angle of 98° was observed in single-step application, which is more than 95° observed in sample S1, the spray rating observed in single-bath treated sample was 50, giving ample indication of the non-uniform distribution of fluorocarbon emulsion when combined with flame retardant. This is expected because the extent of surface coverage of fluorocarbon emulsion decides the values of contact angle. In the spray rating test, the area of the fabric subjected to water is very high compared to the area subjected in the contact angle. Surprisingly, the flame retardant treated samples with a rating of 50 in spray rating test measured 0° contact angle. The repellency effect observed in the FR-treated samples may be due to the presence of melamine resin, high cloth cover and the high swellability of cotton yarns. The melamine resin used along with FR also contributes for water repellency and our conclusion is based on the views expressed by Sunshine.
The contact angle observations seem to correlate closely with oil-repellency ratings than the spray ratings, as all the samples treated with fluorocarbon emulsion by two-step and single-step processes passed the oil-repellency test with contact angles ranging in between 95-100°. The earlier work by Grajeck and Peterson shows the dependence of oil repellency of fabrics on the amount of fluorocarbon applied to the fabric.

Table 1 also shows that all the samples (S2FR+FC, S3FR+FC, S4FR+FC and S5FR+FC) after FC treatment passed the oil-repellency test, irrespective of the FR add-on. This is likely because the oil repellency is basically influenced by the perfluoroalkyl group with optimal chain length (10-C) under controlled conditions at which water and oil repellency is achieved. In the present work, it was observed that even after 48 h under a tension of 50 g, the sample did not show any penetration even though the standard time was 6 h only. This gives an indication of the superior oil-repellent effect offered by fluorochemicals which is not achieved by conventional water-repellent agents such as waxes, silicones, etc.

3.3 Differential Scanning Calorimetry

The DSC curves for the FR and FR+FC treated samples are shown in Fig. 1 and the peak temperatures of endotherms and exotherms of these fabrics are given in Table 2.

The DSC thermogram of sample S2FR (Fig. 1a) shows a single endotherm. The endotherm begins at 105°C and has a shallow peak at 152°C and finally finishes at 200°C, followed by a large exotherm with a well-defined peak at 304°C. The DSC curve of sample S2FR+FC (Fig. 1c) shows a similar endotherm as that of S2FR at 150°C and a large exotherm which reaches a maximum at 322°C. The endotherm and exotherm...
3.4 Thermogravimetric Analysis

TGA curves of fabrics treated with flame retardant and water repellent are shown in Fig. 2 and the data in Table 3. The degradation pattern of the virgin cotton fabric was studied first and then those of the treated fabrics to understand the interactions between the cotton fabric and flame retardant and water repellent. In the case of control fabric (Fig. 2e), the first stage of degradation may be attributed to the thermo-oxidative degradation of cotton fabric, which is transformed into carbonaceous residues which may undergo further decomposition in the later stages. The degradation curves obtained for the treated fabrics show two significant changes in the slopes, indicating two-stage degradation and weight loss. It may be seen from the curves that the onset of thermal breakdown starts at lower temperatures as compared to that in the untreated fabric. The shift in the thermal decomposition of cellulose (control fabric) from 337°C to 312°C (S1FR, Fig. 2c) and 301°C (S2FR, Fig. 2a) suggests that the thermal decomposition of FR-treated fabric starts at a lower temperature.

The first weight loss in S2 FR began near 300°C and this degradation corresponds to the thermal degradation of cellulose. Samples S1FR and S2FR show less weight loss compared to untreated fabric in the temperature range of 300-350°C and the rate of weight loss is also significantly reduced in the above temperature range. It is observed that the weight loss is more in the first stage compared to that in the second stage. The weight loss in samples S2 and S1 was consistent and same (47%) in the first step and around 38% in the second step after FR treatment. This gives an indication that the presence of flame retardant only alters the onset of thermal breakdown of cellulose and rate of weight loss, rather than the actual weight loss. However, the above samples showed varying level of weight loss after water-repellent treatment, sample S2 showing more weight loss (57%) compared to S1 (48%) in the first stage of degradation. Weight loss remained consistent in the above samples after FR and FC treatments in the 2nd stage of degradation, irrespective of the add-on levels. The weight loss of the material during degradation was found to give an indication of an increase in the thermal stability of the treated fabric compared with control. The high residue left at the end of degradation reaction in treated samples in the temperature range of 300-350°C is attributed to the pyrolysis of phosphorylated cotton.

The characteristics shape of the thermograms of the treated samples at the second stage which is absent in the control sample may be due to a sudden exothermic isomerisation because of the presence of FR and the
rapid reaction between the product and the cellulose. Phosphorus from vertical burning shows that phosphorylated cotton fabric retained about 80-90% phosphorus in char. The presence of high levels of phosphorus in char gives an indication that the flame retardant used in the present study functions by the condensed phase mechanism. This is in agreement with the views expressed by Holme and Patel.

TG analysis shows that the FR has acted by catalytic dehydration of cellulose, as is evidenced by the alteration of decomposition path of cellulose in all the FR-treated samples, and the percentage residue obtained at the end of analysis reveals that the fabrics treated with FR formulation and FR+FC formulation have higher percentage residue compared to the control fabric.

3.5 Physical Properties

3.5.1 Breaking Strength

The breaking strength values of control and treated fabrics are shown in Table 4. The loss in breaking strength varied from 22% to 31% in the warp direction and 1% to 19% in the weft direction after the flame-retardant treatment. The loss in strength was more in warp direction compared to weft direction in all the treated samples after the flame-retardant treatment. When compared with the control.
the flame-retardant and water-repellent treated fabrics incurred a loss in strength in the range of 20-25% in warp direction and 6-21% in weft direction.

Sample S₁ (12.2% add-on) showed lowest retention of strength after FR+FC treatment in both warp and weft directions compared to samples S₂ (17.7% add-on) and S₃ (20.4% add-on). This is surprising as we anticipated more loss in strength in those samples with higher add-on, because the increased crosslink density would reduce the strength linearly. Curing the flame retardant impregnated fabric treated under acidic conditions (pH 5-6) causes tendering which results in strength loss. This is seen from the results of FR and FC treated fabric (Table 4). The change in strength is controlled by the FR add-on %, crosslink density, curing time and temperature, pH of the padding bath solution, etc.

Raising the curing temperature will favour the decomposition of FR, phosphorylation of cellulose, and more crosslinking and diffusion of reactants. The increase in the curing time and temperature results in more degradation of the fabric in the presence of latent acid catalyst and causes loss in breaking strength. Low and medium weight fabrics are more prone to curing parameters than the heavy fabrics. It is also observed that samples S₁ and S₃ exhibited more or less same strength retention in both warp and weft directions after flame-retardant and water-repellent treatments. An increase in breaking strength is observed for all the samples (S₁, S₂, and S₃) in warp direction after FC treatment, whereas loss in strength is observed in weft direction. The loss in strength was less in weft direction compared to warp direction in both FR and FR+FC treated fabrics. Sample S₁ showed lowest retention of strength in both the directions after FR and FR+FC treatments. The loss in strength observed after FC treatment is difficult to elucidate as to whether the differences observed are due to the chemical nature of FC in the treated samples or because of the high curing temperature (170-175°C) employed after padding with FC formulation. The breaking strength retention in single-bath treatment is compatible with two-step process and no pronounced difference is observed.

3.5.2 Stiffness and Tear Strength

The stiffness and tear strength results of control and treated fabrics are shown in Table 4. It is observed that the use of melamine resin with flame retardant imparts a stiffer hand to the treated fabrics, in addition to the influence of FR add-on, curing time and curing temperature. Here, the function of the resin used is three fold. Firstly, it reacts with FR and forms highly insoluble crosslinked polymer. Secondly, it contributes nitrogen which in association with phosphorus compound enhances the level of retardancy through P-N synergism. Thirdly, it acts as a binding agent, thereby helping in meeting the durability requirements. Even though the use of melamine resin imparts a stiffer hand than that obtained with urea formaldehyde resin, the polymer formation is more efficient in the former as it readily condenses with FR. The high stiffness values observed in treated fabrics may also be attributed to FC treatment and high curing temperature used in both single process and two-step process.

Stiffness values are lowest for the sample S₁ (12.2% add-on) both after flame-retardant and water-repellent treatments (Table 4). Although the bending length values follow a definite trend in warp direction, no clear trend is observed in the weft direction. The bending length values after FR treatment increase with the increase in add-on level from 11.4% to 19.6%, showing an increase of 78-130% (warp) compared with the control fabric. However, it is observed that the increase in the values of bending

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Breaking strength retention, %</th>
<th>Stiffness, cm</th>
<th>Tear strength, kg</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Warp</td>
<td>Weft</td>
<td>Warp</td>
</tr>
<tr>
<td>S₁ FR</td>
<td>69</td>
<td>81</td>
<td>4.1</td>
</tr>
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<td>S₁ FR+FC</td>
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</tr>
<tr>
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<td>77</td>
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</table>
Fig. 3—SEM photographs of FR and FR+FC treated cotton fabrics with different add-on levels: (a) S2FR (16.7%), Single fibre, 2000x; (b) S2FR (16.7%), Yarn, 200x; (c) S2FR (19.6%), Yarn, 200x; (d) S2FR+FC (17.7%), Yarn, 200x; (e) S2FR+FC (20.4%), Single fibre, 2000x; and (f) S2FR+FC (16.4%), Single fibre, 2000x.
length after FC treatment is marginal. The increase in values of bending length observed after FC treatment may be due to the double curing employed after FR and FC treatments. However, the fabric treated in single bath and subjected to single curing shows high bending length values contrary to our above observations. This may be due to the superfluious FR chemical on the fabric surface which remained there as no washing was carried out after the single-bath treatment, unlike in the two-step process wherein washing was carried out after the FR treatment. The absence of softeners like polyethylene wax emulsion in the flame-retardant formulation also contributes for high stiffness.

It may be seen from the results that the add-on level plays a significant role in tear strength. Sample S1:FR with low add-on of 11.4% shows highest tear strength among all the treated samples. The reduction in tear strength (warp) has been found to be proportional to the add-on in the present work. This may be ascribed to the minimum fibre-to-fibre bonding and more freedom for the bunching of threads due to low add-on level, which is mainly responsible for high tear strength observed for sample S1:FR.

The tear strength results are basically a function of single thread strength, relative movement of yarns at the time of testing and cloth cover. In the present work, the high cloth cover of the fabric, which further increases after treatment, reduces the tear strength as it prevents yarn slippage which offers resistance to tear. The tear strength values remained more or less same in all the treated samples after FC treatment.

3.5.3 Surface Behaviour

The surface behaviour of fabrics treated with FR and FR+FC has been studied under SEM at different magnifications for both fibre and yarn and is shown in Fig 3.

4 Conclusions

Cotton drill fabric was sequentially treated for flame retardancy and water and oil repellency in two-step process as well as in a single-step process, wherein the flame retardant and water-repellent was combined in single bath to study the overall functional performance of fabric in terms of flame retardancy and water and oil repellency. Cotton fabric modified with the increasing amount of flame retardant suggests the synergistic role of nitrogen in enhancing the flame retardant properties when N-P combination systems are compared. Satisfactory results achieved in the sequential step (two-step) process with an overall add-on level of 17.7% (FR+FC) suggest that there is an optimum level of add-on at which the mutual antagonistic influence of flame retardant and fluorocarbon is minimum. The functional and physical properties of fabric treated to an add-on level of 17.7% at 3.4% N and 1.2% P contents have been found to be better compared to those of the samples treated to add-on levels of 12.2%, 20.4% and 16.4%. Practical experience has shown the difficulty in achieving combined flame retardancy and water and oil repellency with satisfactory physical properties, because of the complexity of the combination of flame retardant (FR) and fluorocarbon (FC) and the complex nature of reaction that takes place between FR and FC. The physical presence of fluorocarbon on the surface of the fabric creates a layer which prevents the catalytic function of FR on cellulose, which, in turn, results in the deterioration of level of flame retardancy achieved after fluorocarbon treatment. Comparable tear strength values were obtained with the single-step process, while high stiffness and lower retention of strength were observed in the case of single-step process compared to two-step process after FR+FC treatment.

Thermal studies carried out have demonstrated more clearly the interaction that occurs between the FR and FC and the cellulose, thereby giving a further insight into the operating mechanism of the flame retardant.

Acknowledgement

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