RESULTS AND DISCUSSION

CHAPTER IV

RESULTS AND DISCUSSION

Textiles are intrinsically suited for use as protective material, as they are able to offer particularly good protection against environment hazards particularly, if suitable materials and constructions are used. In the present study the effect of fabric parameters on UV protection and soil-release were examined. Further influences of UV absorbers and Soil-release finishes were studied and the effects of the experimented finishes on wear properties of textiles under study were also analysed.

The results have been given and discussed under the following subsection:

4.1. Preliminary data of the fabrics under study

4.2. Comparison and influence of UV absorbers on performance property of fabrics under study.

4.3. Comparison and effect of soil-release finishes on the soiling behaviour of the fabrics under study

4.4. Effect of optimum combination of UV absorber and soil-release finishes on the selected fabrics.

4.5. S.E.M. analysis of fiber surface characteristic of untreated and treated fabric samples.

4.6. E.D.S. analysis of the sample treated with UV absorbers and soil-releases finishes.

4.1. Preliminary data of the fabrics under study

Three fiber types (Cotton, Polyester, Polyester/Cotton blend) in two different weave i.e. plain and twill were used in the study. The preliminary data of these fabrics were determined and have been given Table 4.1.

Table 4.1: Construction characteristics of experimental fabrics i.e. fiber content, thread count, yarn number, thickness and weight per unit area

Fabric Code	Fiber content	Fabric count (cm)		Yarn Number (Tex)		Thickness (mm)	Wt/Unit area (g/m^2)	Yarn Type
		Warp	Weft	Warp	Weft			
C- p	100% C	54	30	16	16	0.25	123.65	Spun
C- t	100% C	49	28	30	30	0.48	249.60	Spun
P- p	100% P	54	40	09	09	0.17	93.95	Filament
P- t	100% P	48	25	18	34	0.30	186.62	Filament
P/C - p	67% P 33% C	55	29	13	13	0.24	122.11	Spun
P/C - t	67% P 33% C	52	25	32	43	0.44	274.43	Spun

After the microscopic analysis and chemical solubility tests, it was confirmed that the fiber types tested were 100% cotton, 100%polyester and 67%/33% polyester/cotton blend.

The highest count i.e. warp X weft per cm was seen in polyester plain fabric (54 X 40), followed by cotton plain (54 X 30) and polyester/cotton twill (52 X 25). The lowest was observed in polyester twill weave fabric (48 X 25).

The yarn numbers were ranging from 13 to 43.

In thickness, the highest reading showed by cotton (0.48 mm) twill followed by polyester/cotton twill (0.44 mm).In plain weave fabric cotton showed highest reading i.e. 0.25 mm, then followed by polyester/cotton (0.24mm). The lowest was observed in polyester.

Polyester/Cotton was the heaviest among six fabrics under study (274.43 g/m^2). The lowest was polyester plain weave with 93.95 g/m2.

4.2. Comparison and influence of UV absorbers on performance property of fabrics under study.

This has been subdivided as follow:

4.2.1. Effect of fabric construction on percent UVR transmission and UPF value

4.2.2. Effect of UV absorbers on the fabrics under study

4.2.3. Effect of laundering of untreated and treated fabrics on percent UVR transmission

4.2.4. Effect of perspiration on the percent UVR transmission of untreated and treated fabrics

4.2.1. Effect of Fabric construction on percent UVR transmission and UPF value

Numbers of studies have shown the effect of fabric construction on UPF value, so an attempt was made to see the effect of fabric parameter on percent UVR transmission and UPF values of the fabrics under study.

Percent UVR transmission, UPF values and the fabric parameters-fiber type, thread count, cloth cover, thickness, weight per unit area prior to finishing have been shown in Table 4.2.

Table 4.2: Fabric Parameters and percent UVR transmission for fabrics under study

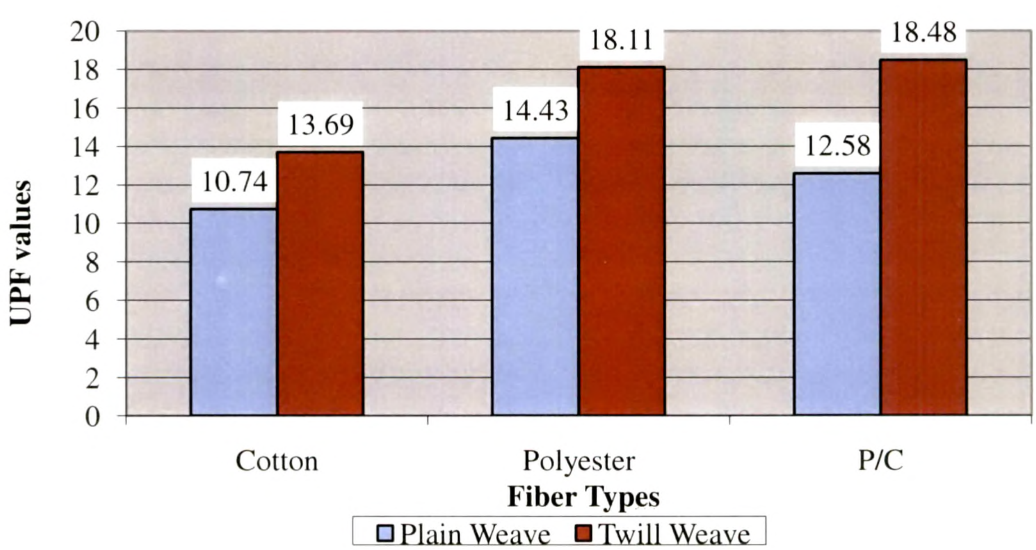
Fabric code	Total Fabric count (cm)	Cloth cover	Thickness (mm)	Wt/Unit area (g/m^2)	%T_{UVA}	%T_{UVB}	%T_{UVR}	UPF value
C-p	84	23.93	0.25	123.65	9.09	9.52	9.31	10.74
C-t	77	27.26	0.48	249.60	6.59	8.00	7.30	13.69
P-p	94	21.42	0.17	93.95	6.99	6.86	6.93	14.43
P-t	73	25.39	0.30	186.62	5.98	5.06	5.52	18.11
P/C-p	84	24.97	0.24	122.11	8.80	7.09	7.95	12.58
P/C-t	77	28.83	0.44	274.43	5.87	4.94	5.41	18.48

i) Fiber Type

The type of fiber used to construct a textile can have a substantial effect on the percent UVR transmission. When fabrics of different fiber types with a similar weave structure, were compared 100% polyester showed good UV blocking properties, as this fabric allowed relatively little UV-B transmission (6.86%). This could be attributed to the benzene rings in the polymer chains of polyester which account for the increased absorption of UV light.(15) (21) Its is conceivable that UVA tanning responses could occur through these polyester and its blends fabrics, while less damage from the UVB radiation would occur. The cotton plain weave fabric in the study had a relatively high transmittance in the UV-B (9.52%) than UV-A (9.09%) regions, and showed a low U.P.F value of 10.74. Cotton fabrics offer less protection from UV-B region than from UV-A region.

The cotton samples consistently offered less protection than other two fabrics. Because cotton fibers are so permeable to UVR radiation, the cotton fabrics transmitted much more UVR than the polyester. P/C blended fabric provided significantly better protection than cotton alone. Such a blend of P/C would give increased comfort for clothing worn in tropical weather as compared to polyester.

ii) Weave



Graph 4.1: Effect of fiber type and weaves on UPF values

Fabric construction is the primary determinant of fabric porosity, followed by fabric weight. The result showed the closer the weave the less UV radiation was transmitted.

As shown in Graph 4.1 fabrics woven with twill weave have better blocked percent UVR transmission more than those of plain weave in all the three different fiber types. It was seen that the closer the weave, the less UV radiation was transmitted.

This was supported by the study of Crews et al (1994) [(15)], who concluded that the factor which most affects the amount of UVR transmittances by fabrics is the tightness of the weave. And so in highly compact weave, they permit transmission of less UV radiation.

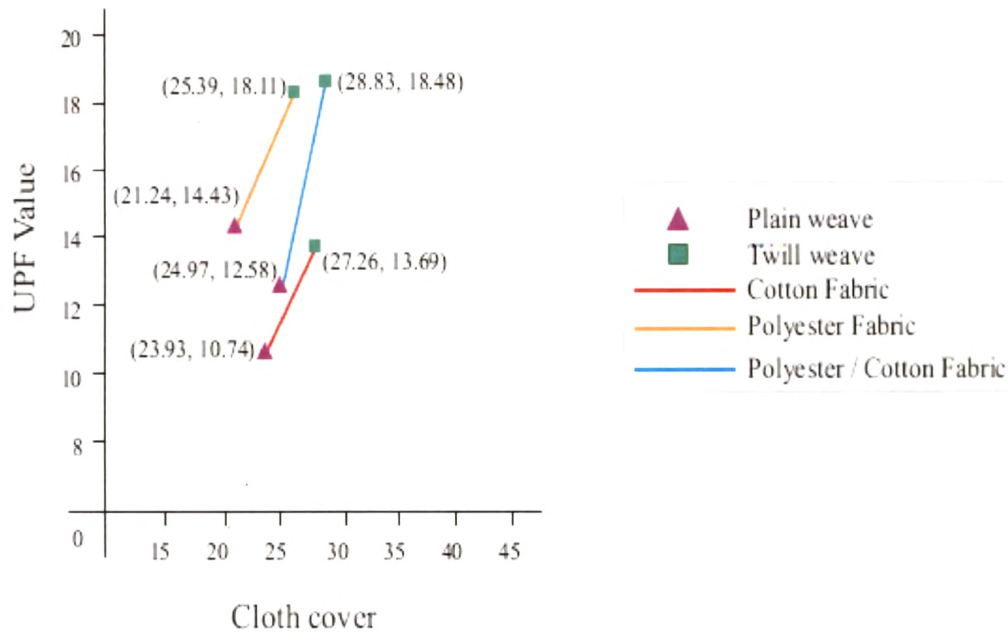
iii) Fabric count

It was seen that fabric count is positively correlated with percent UVR transmission and negatively with UPF values. Higher the thread counts lesser the UPF value, so providing less protection.

But the twill weave showed better protection than plain weave inspite of thread being lower. When fabrics made of fine and coarse yarns of identical thread counts, then fabric count could be effective fabric parameter on UPF value of the fabric.

iv) Cloth cover

Cloth cover ranged from 21.42 for polyester plain to 28.83 for polyester/cotton twill weave fabrics. Polyester plain had lowest cloth cover; however, they did not have the highest percent UVR transmission, nor the lowest UPF. Cloth cover factor of cotton plain weave was more than polyester plain weave even though cotton had the lowest UPF 10.79. This is attributed to the influence of fiber type. The polyester polymer has an inherently higher absorption of UVB radiation. In addition, delustrants incorporated in most polyester fibers exhibit a high absorption of UVA and UVB radiation. These UV-absorbing compounds boosted the UPF rating of the polyester fabrics. Polyester/cotton twill showed the highest cloth cover (28.83) with highest UPF value (18.48).

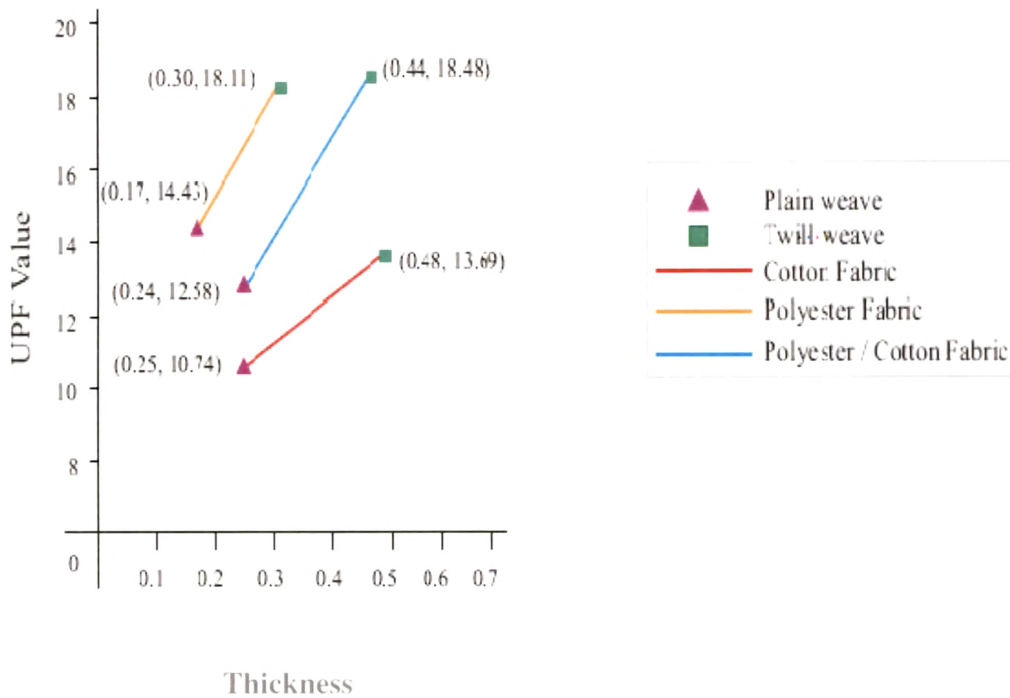


Graph 4.2: Effect of Cloth cover factor on UPF value

v) Thickness

In most studies reviewed thickness were not undertaken or reported. Except one study by Crews and coworkers (1999) [15] reported that thicker, denser fabrics transmit less UV radiation and concluded that thickness is most useful in explaining differences in UV transmission. In the present study it was seen that, thickness was the most useful fabric parameter for explaining differences in UVR transmission among or between fabrics. Thickness of the twill weave fabrics was more than plain weave fabrics. It was seen that as the thickness increases percent transmission decreases, this was seen in all the three fiber types.

Analysis of the results showed that percent UVR transmission was lowest for the cotton twill weave (7.30) with 0.48mm thickness as compare to cotton plain weave (9.31) fabrics of 0.25 thickness. Same pattern was observed in other two types of fibers also as seen in Graph 4.3

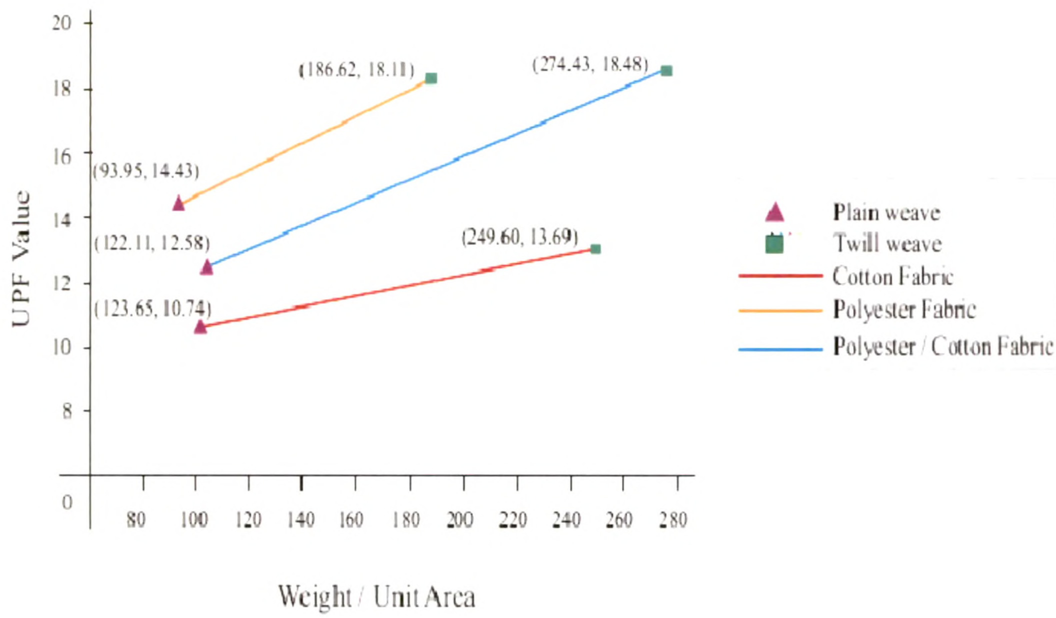


Graph 4.3: Effect of thickness on UPF value

vi) Weight per unit area

Fabric's mass or weight also appeared to be important in determining fabric protection against sunrays. An increase in weight per unit area also decreases fabric porosity. The spaces between yarns are smaller in twill weave fabrics, permitting transmission of less UV radiation.

When we compared same fiber content but different weaves it was observed from the Graph 4.4 that twill weave fabrics gave better protection as compared to plain weave fabric. The best results were seen in polyester/cotton twill weave fabric with the highest mass (274.43 g/m^2) and percent UVR transmission value of 5.41 %, which is lowest percent UVR transmission than other tested fabrics. Cotton plain and polyester/cotton plain weave fabrics had almost the same weight per unit area, but showed difference in transmission of 9.31% and 7.95% respectively. These results also indicated that fiber type has a predominant influence on UV protection.



Graph 4.4: Effect of weight per unit area on UPF value

It was seen from the results of effect of fabric construction on percent UVR transmission and UPF values that fiber types and weave influenced the percent UVR transmission of the fabric.

4.2.1 Relationship between fabric characteristic and percent UV transmission

For the study correlation coefficient analysis between the fabric parameters i.e. fabric count, cloth cover, thickness, and weight / unit area with percent UVR transmission value was calculated.

The coefficient of correlation is a numerical measure of intensity or degree of linear relationship between 2 or more variables and is denoted by “r”.

The value of correlation always lies between +1 and -1. The value of “r” obtained from a sample data if closer to +1 or -1, it indicates a stronger relation between the variables. On the other hand the value of “r” nearing zero indicates a weaker relation. There may be two types of correlation positive or negative.

Table 4.3: Values of Correlation 'r' of fabric parameters on percent UVR transmission

Sr. No.	Fabric parameter's	Correlation value 'r'
1.	Fabric count	+ 0.461
2.	Cloth cover	- 0.426
3.	Thickness	- 0.374
4.	Weight/Unit area	- 0.57

The moderate positive correlation of fabric count with percent UVR transmission (r = + 0.461) was seen from Table 4.3. Positive values indicated that as the fabric count increases values of percent transmission also increase.

The result of the Table 4.3.shows a moderate negative correlation between cloth cover factor and percent transmission (r = - 0.426), which indicates that when the value of cloth cover factor increases, values of percent transmission decreases.

Negatively moderate correlation (r = -0.374) was seen between thickness and percent UVR transmission, which meant that as thickness increases, percent transmission decreases.

The high negative correlation (r= -0.57)) was seen between weight per unit area and percent transmission was observed. As the values of weight per unit area increases, values of percent transmission decreases.

Therefore it could be concluded that weight per unit area was an important factor followed by fabric count, cloth cover and thickness of the fabric in predicting the percent UVR transmission.

4.2.2. Effect of UV absorbers on the fabrics under study

Two UV absorbers were explored for the present study i.e. commercial UV absorber and natural colourant (Acacia Catechu).

This has been subdivided as follow:

i) Effect of commercial UV absorber on percent UVR transmission and UPF value

ii) Effect of Acacia catechu (Katha) on percent UVR transmission and UPF value

i) Effect of commercial UV absorber on percent UVR transmission and UPF value

To improve UV protection, commercial UV absorbers have been applied to the fabric under study.

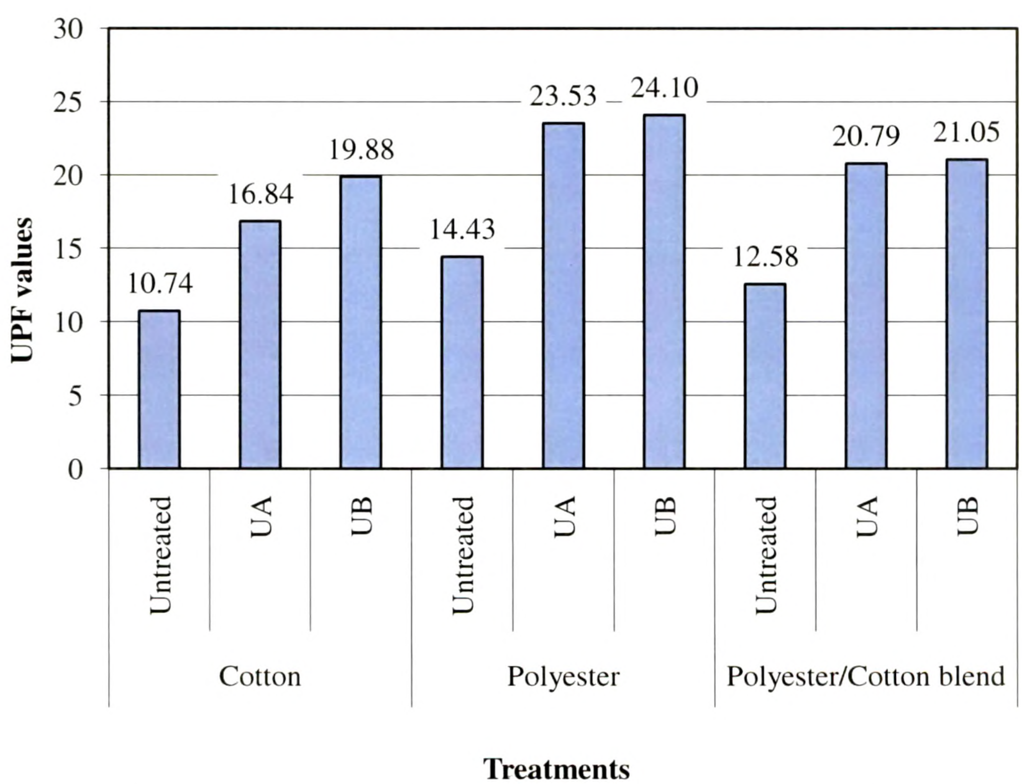
For the present study, the commercial UV absorbers were applied by selected two methods commercial UV absorber 'A' on cotton fabrics using pad-dry-cure and commercial UV absorber 'B' on polyester and combination of 'A' and 'B' on polyester/cotton blend fabrics using Pad-thermofixation process at two different add-on's, 1% ($\mathbf{U_A}$) and 3% ($\mathbf{U_B}$).

Table 4.4. shows that the percent UVR transmission values of the commercial UV absorber treated plain weave fabrics. The amount of Ultraviolet radiation transmitted at each wavelength affects the Ultraviolet Protection Factor (UPF) of the fabric. It is for this reason that spectral percent UVR transmission measurements of the fabric in UVA and UVB region were done to determine the UPF values. In case of all the fabrics percent UVR transmission was less in UVB region as compared to UVA. Commercial UV absorber treated fabric gave better protection as compared to untreated fabrics.

In a comparison of fabrics of different fiber types but similar structure, polyester consistently provided a higher level of protection followed by polyester blend even after the UV absorber treatments.

Table 4.4: Percent UVR transmission of untreated and UV absorber treated plain weaves fabrics

Fabric Code	Treatments	$\%T_{UVA}$	$\%T_{UVB}$	$\%T_{UVR}$	UPF values
C-p	Untreated	9.52	9.09	9.31	10.74
	U_A	6.57	5.31	5.94	16.84
	U_B	5.24	4.81	5.03	19.88
P-p	Untreated	6.99	6.86	6.93	14.43
	U_A	4.34	4.15	4.25	23.53
	U_B	4.29	4.01	4.15	24.10
P/C-p	Untreated	8.80	7.09	7.95	12.58
	U_A	5.14	4.48	4.81	20.79
	U_B	5.01	4.39	4.75	21.05



Graph 4.5: Effect of commercial UV absorbers on UPF value of plain fabric

Note:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on

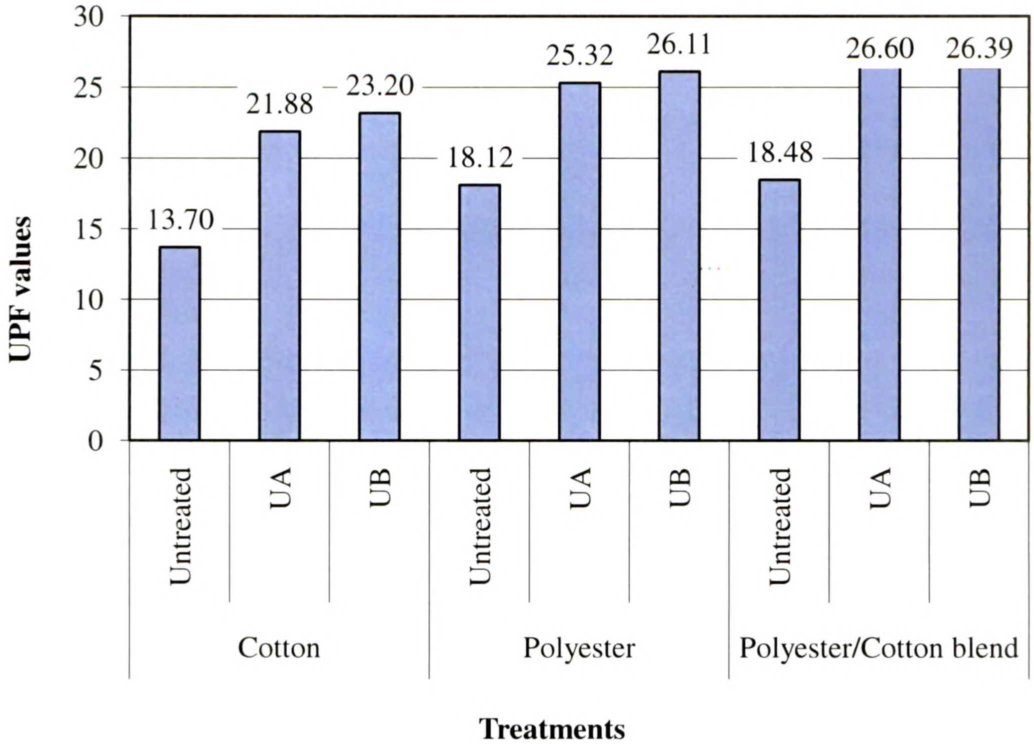
A marked decrease in the transmittance of UV radiation was observed after the treatment with UV absorber i.e. percent UVR transmission of untreated cotton was 9.31% that decreased to 5.09% after the commercial UV absorber treatment. In case of polyester, out of two add-on's commercial UV absorber 'B' provided better protection with 4.15 % transmission at 4% add-on. The analysis of the data has also shown that the higher was the commercial UV absorber concentration higher was the protection against UV radiation. For example, the percent UVR transmission of the cotton plain weave at a 1% add-on was 5.94% and that decreased to 5.09% at 3% add-on. Maximum change was noticed only in cotton plain weave fabrics as percent add-on increased.

Table 4.5: Percent UVR transmission of untreated and UV absorber treated twill weaves fabrics

Fabric Code	Treatments	$\%T_{UVA}$	$\%T_{UVB}$	$\%T_{UVR}$	UPF values
C-t	Untreated	6.59	8.00	7.30	13.70
	U_A	4.86	4.28	4.57	21.88
	U_B	4.61	4.01	4.31	23.20
P-t	Untreated	5.98	5.06	5.52	18.12
	U_A	4.12	3.78	3.95	25.32
	U_B	4.01	3.64	3.83	26.11
P/C-t	Untreated	5.87	4.94	5.41	18.48
	U_A	3.79	3.73	3.76	26.60
	U_B	3.79	3.79	3.79	26.39

Note:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on



Graph 4.6: Effect of commercial UV absorbers on UPF value of twill fabric

Note:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on

The percent UV transmission data of untreated and UV absorber treated twill weave fabrics is shown in Table 4.5. Finished sample of cotton, polyester and P/C blend showed lesser transmission in twill weaves than untreated fabrics thus providing better protection as compared to untreated fabrics. Study by Palacin [90] on the application of Rayosan products for sun protective textiles stated that UV absorbers could be effectively used on textiles to improve SPF value.

As the percent add-on increase only a minimal decrease in the percent UVR transmission value of the fabrics was noticed. Thus fabric having 1% add-on was almost similar to fabrics with 3% add-on in providing protection against ultraviolet radiation.

Result also shows that the application of commercial UV absorber on cotton fabrics improved the protection from UVB region as compared to untreated fabric which earlier showed more percent UVR transmission.

ii) Effect of Acacia catechu (Katha) on percent UVR transmission and UPF value

Fabrics, specially when dyed, can absorb significant amount of UV radiation. Sarker (2004) [107] studied the UV protection provided by cotton fabrics dyed with colourants of plant and insect origins. In another study, Gupta et al (2005) [47] have tested selected natural dyes for their anti-UV and anti-bacterial activities on cotton.

However no study has been conducted on the man-made fibers with natural dyes. In the present study based on the reviewed researches, CI Natural Brown, Acacia Catechu was selected as a natural dye for it anti-UV property. The present study dealt with the providing protective clothing for outdoor workers and this natural dye gives shades of brown to fawn when dyed with different mordant which would be suitable for uniforms of all outdoor workers regardless of their gender.

All the samples were coloured using exhaust and H.T.H.P. method for cotton & polyester respectively with Acacia Catechu (Katha). Natural dyes, in general, do not have affinity for fabrics hence are applied in combination with a mordant. Selected fabrics were dyed with different concentrations i.e. 2% (U_C) and 4% (U_D) of acacia catechu. 10% of alum was used as a mordant and simultaneous dyeing was done. All the dyed samples were tested for: K/S, percent UVR transmission, UPF value. Colour values of different fabrics with acacia catechu are shown in Table 4.5. and colours obtained are shown in Plate 4.1.

It was observed from the Table 4.6 that plain weave fabric gave darker shade as compared to twill weave fabrics however cotton fabric did not show in the weave fabrics i.e. -9.877 and -8.511 at 2% shade. Polyester and polyester/cotton blend showed darker shade.

Table 4.6: Colour values of Acacia Catechu (Katha) coloured fabrics

Fabric Code	Dye, % (owf)	A*	b*	c*	H	dE	DL	Da	Db	DC	DH	K/S
C-p	Control	1.842	-5,981	6,258	287.147	----	----	----	----	----	----	0.0324
	U_C	2.233	4.026	4.604	60.961	10.057	0.920	0.391	10.007	-1.654	-9.877	1.5620
	U_D	2.189	3.987	4.548	61.207	10.019	0.948	0.347	9.968	-1.710	-9.826	1.7536
C-t	Control	1.261	-3.906	4.105	287.921	----	----	----	----	----	----	0.0433
	U_C	2.686	4.570	5.301	59.531	8.669	-1.134	1.425	8.476	1.196	-8.511	1.8438
	U_D	2.682	4.625	5.346	59.867	8.736	-1.230	1.421	8.531	1.242	-8.559	2.4379
P-p	Control	0.721	-8.908	8.937	274.662	----	----	----	----	----	----	0.1066
	U_C	4.185	4.621	6.234	47.815	14.123	-2.101	3.464	13.529	-2.703	-13.701	1.0661
	U_D	3.910	5.316	6.599	53.643	14.703	-1.918	3.189	14.224	-2.338	-14.388	1.3005
P-t	Control	-0731	-4.964	5.018	261.590	----	----	----	----	----	----	0.0463
	U_C	2.655	3.887	4.707	55.643	9.533	-1.040	3.386	8.851	-0.310	-9.471	1.0255
	U_D	2.435	4.225	4.876	60.020	9.759	-0.883	3.166	9.189	-0.141	-9.718	1.3241
P/C-p	Control	3.997	-11.723	12.386	288.856	----	----	----	----	----	----	0.1302
	U_C	4.732	6.358	7.926	53.320	18.100	0.384	0.735	18.081	-4.460	-17.538	1.9481
	U_D	4.691	7.138	8.541	56.665	18.885	0.662	0.694	18.861	-3.844	-18.474	2.9718
P/C-t	Control	-0.315	-2.473	2.493	262.708	----	----	----	----	----	----	0.1002
	U_C	4.238	6.291	7.585	56.011	11.391	-5.677	4.553	8.764	5.092	-8.462	2.4096
	U_D	4.086	6.740	7.882	58.751	11.611	-5.528	4.401	9.213	5.389	-8.672	3.0901

Note: U_c : Dyed at 2% concentration of Acacia Catechu, U_d : Dyed at 4% concentration of Acacia Catechu

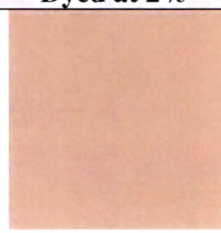
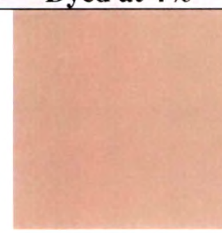
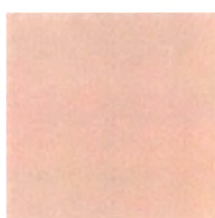
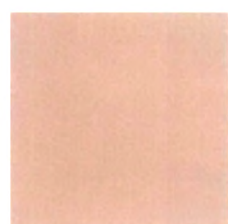
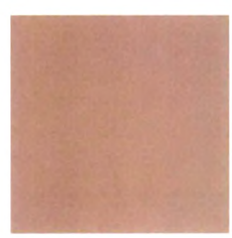
Fabric Code	Dyed at 2%	Dyed at 4%
C-p		
C-t		
P-p		
P-t		
P/C-p		
P/C-t		

Plate 4.1: Acacia Catechu coloured fabrics

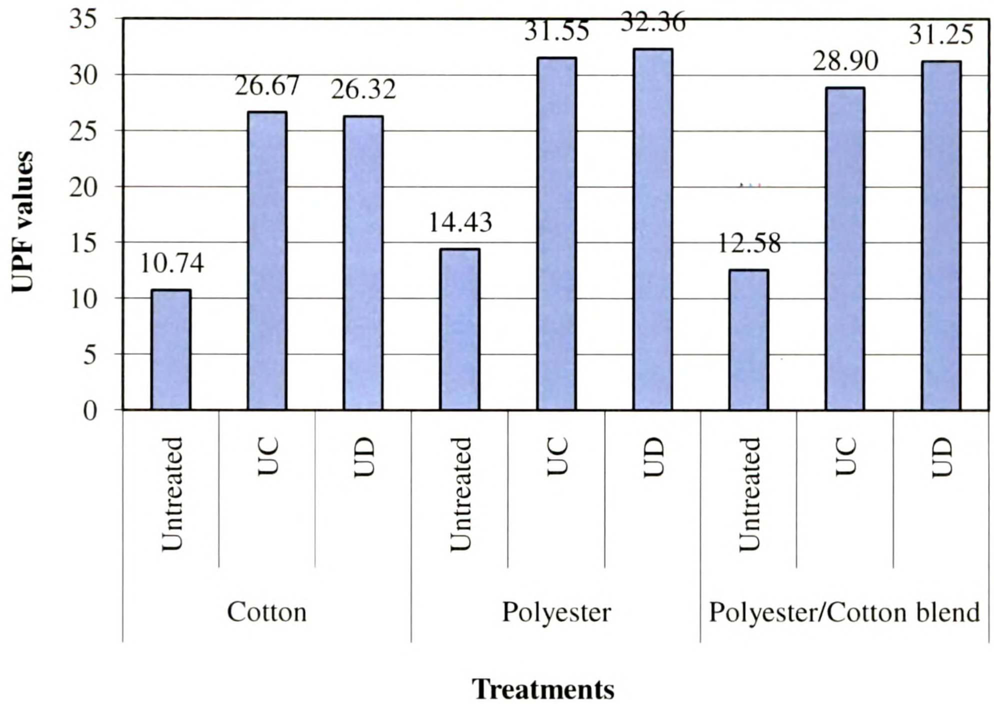
Table 4.7: Percent UVR transmission of untreated and coloured plain weave fabrics

Fabric Code	Treatments	%T_{UVA}	%T_{UVB}	%T_{UVR}	UPF values
C-p	Untreated	9.52	9.09	9.31	10.74
	U_C	3.86	3.64	3.75	26.67
	U_D	3.90	3.70	3.80	26.32
P-p	Untreated	6.99	6.86	6.93	14.43
	U_C	3.23	3.10	3.17	31.55
	U_D	3.19	2.99	3.09	32.36
P/C-p	Untreated	8.80	7.09	7.95	12.58
	U_C	3.67	3.25	3.46	28.90
	U_D	3.31	3.09	3.20	31.25

Note:

U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

Percent UVR transmission of untreated and coloured plain weave fabrics is shown in Table 4.7. It is noted that since the relative erythemal spectral effectiveness is higher in the UV-B region compared to the UV-A region, the percent UVR transmission values depend primarily on transmission in the UV-B region. Undyed plain weave fabrics had significant transmittance and consequently a very low UPF value. As in evident from the percent UVR transmission data and the corresponding UPF values all dyed samples in the study caused a dramatic reduction in UV radiation transmission in the plain weave fabric. The increase in protection thus decrease in percent transmission in the presence of colourants was significant for the acacia catechu dyed samples, Cotton which were classified as having moderate protection (transmission between10-5%) in untreated stage after dyeing it gave high protection (transmission between 5-3.3%).



Graph 4.7: Effect of Acacia Catechu colourant on UPF value of plain weave fabric

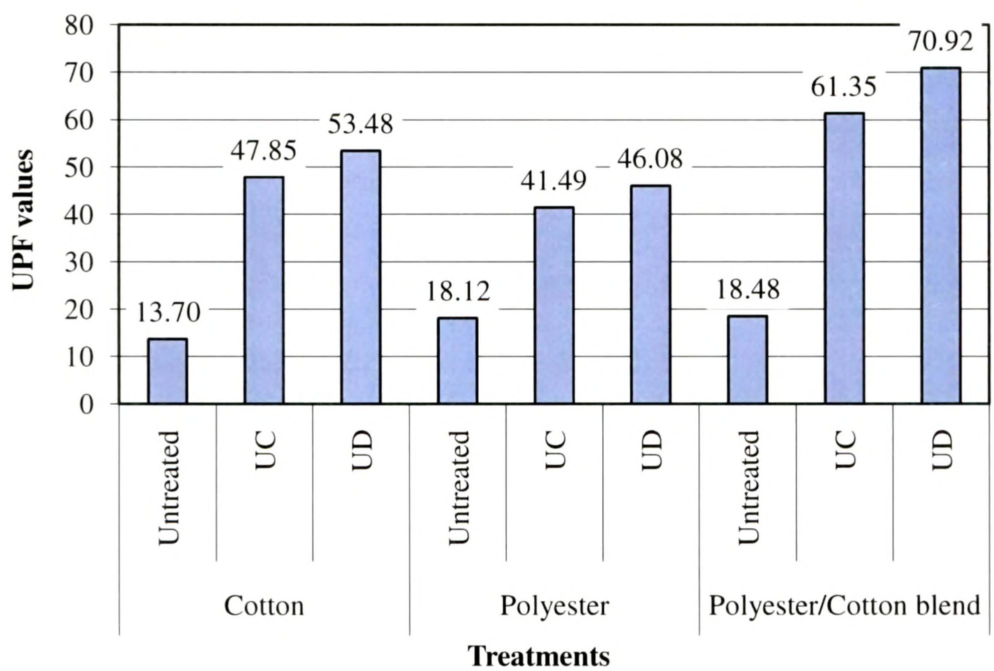
Note:

U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

The analysis of the data also shows that with increase of the dye concentration there is an increase of protection that is a decrease in the percent UVR transmission and increase in UPF values. The percent UVR transmission of the polyester plain weave at 2% shade was 3.17%, it decreased to 3.09% at 4% concentration. The result of the present study agree with the previous data reported by Reinert et al (1997) [101] who showed that pale coloured fabrics of cotton, silk, polyamide and polyamide/elastan gave less protection against intense UV radiations. In the case of cotton plain weave fabric, at 2% shade percent UVR transmission was less 3.75% as compared to 3.80% percent UVR transmission at 4% shade as shown in Graph 4.7.

Table 4.8: Percent UVR transmission of untreated and coloured twill weave fabrics

Fabric Code	Treatments	%T_{UVA}	%T_{UVB}	%T_{UVR}	UPF values
C-t	Untreated	6.59	8.00	7.30	13.70
	U_C	2.19	1.98	2.09	47.85
	U_D	2.1	1.64	1.87	53.48
P-t	Untreated	5.98	5.06	5.52	18.12
	U_C	2.3	2.51	2.41	41.49
	U_D	2.06	2.27	2.17	46.08
P/C-t	Untreated	5.87	4.94	5.41	18.48
	U_C	1.51	1.75	1.63	61.35
	U_D	1.41	1.41	1.41	70.92



Graph 4.8: Effect of Acacia Catechu colourant on UPF value of twill weave fabric

Note:

U_c: Dyed at 2% concentration of Acacia Catechu

U_d: Dyed at 4% concentration of Acacia Catechu

The percent UVR transmission of untreated and coloured twill weave fabrics has been given in Table 4.8. It was evident that all samples after dyeing achieve, regardless of the colour shades, transmittance values less than 2.30%. Due to the non-absorbance of UV rays, the colour white provides insufficient protection across the entire range. Twill weave fabric prior to dyeing was rated as offering moderate protection moved to the maximum protection classification irrespective of the concentration of dye. Again, it was found that dark colours within the same fabric types transmit less UV radiation than light colours and consequently have higher UPF values as shown in Graph 4.8. This may be due to the reason that as shade % increase, the concentration of the dye on the fabric also increases. Thus, more dye is now available on the surface to absorb harmful UV rays. Sarkar (2004) [107] also indicated that dyeing fabrics in deeper shades and darker colour improves sun protection properties. In polyester/cotton fabrics at 2% concentration of acacia catechu percent UVR transmission was 1.63%, which decreases to 1.41 percent UVR transmission at 4%shade.

Table 4.9: K/S values of dyed fabrics

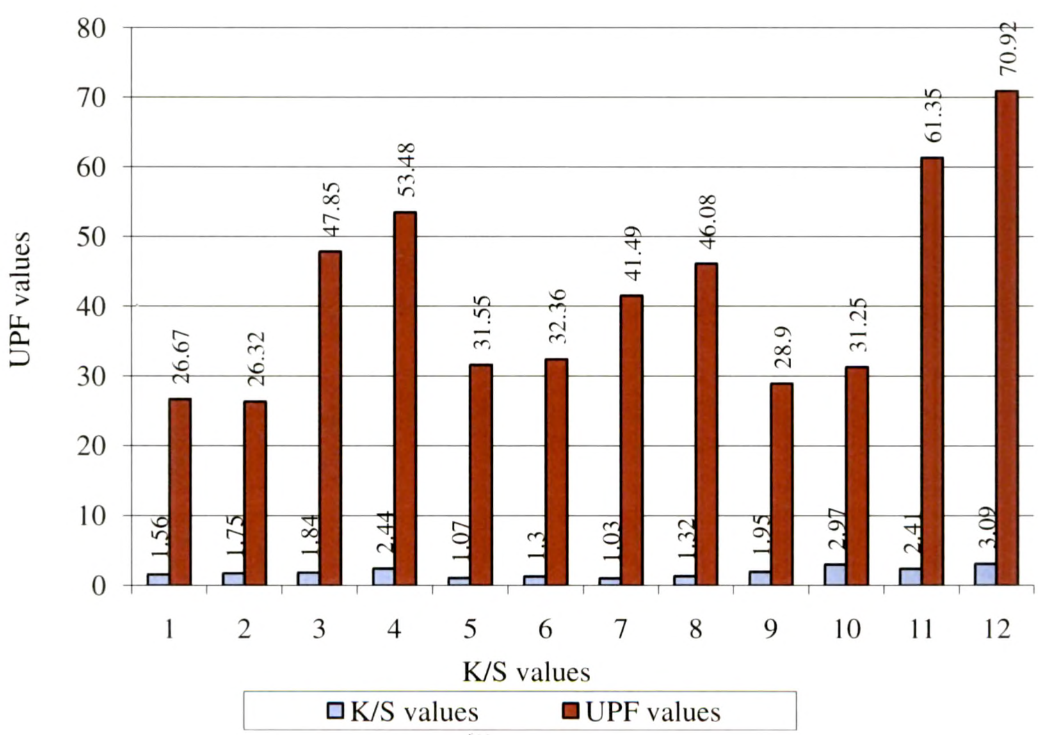
Fabric Code	% Shade	K/S value	UPF values
C-p	U_C	1.56	26.67
	U_D	1.75	26.32
C-t	U_C	1.84	47.85
	U_D	2.44	53.48
P-p	U_C	1.07	31.55
	U_D	1.30	32.36
P-t	U_C	1.03	41.49
	U_D	1.32	46.08
P/C-p	U_C	1.95	28.90
	U_D	2.97	31.25
P/c-t	U_C	2.41	61.35
	U_D	3.09	70.92

Key:

U_c: Dyed at 2% concentration of Acacia Catechu
U_d: Dyed at 4% concentration of Acacia Catechu

Increase of the dye concentration leads to the increase of values K/S value (Table 4.9). The K/S values of the dyed fabrics, which are a measure of colour depth, supported that claim that higher colour depths decreased transmission thus increases the UPF values. In the case of the acacia catechu dyed cotton samples when the k/s value increased from 1.84 to 2.44 the percent UVR transmission decrease from 2.09 to 1.83 but in case cotton plain weave fabric, even though the K/S value increased from 1.56 to 1.75 percent UVR transmissions value were not improved.

However, the relationship of K/S with percent transmission is limited to the same fabric type and the results cannot be generalized across fabrics of different weave structures. However it was also observed that K/S values of polyester plain weave fabric at 2% been higher than the K/S values of polyester twill weave i.e. 1.03 but percent UVR transmission value (2.41%) of polyester twill weave fabric was less as compare to the polyester plain weave. (Graph 4.9)



Graph 4.9: Effect of K/S values on UPF values

A primary reason for this observation would be that percent UVR transmission was dependent on a multitude of fabric construction factors such as openness in the fabric, thickness and weight, in addition to processing parameters such as dyeing and finishing. Another probable reason could be the dependence of K/S on the absorbing properties of colourants in the visible region of the spectrum and that may not influence the absorption characteristics of colorants in the UV regions.

4.2.3. Effect of launderings on percent UVR transmission of untreated and treated fabrics

The treated fabrics would have to undergo laundering as they would be used for the uniform of outdoor workers, so all the treated fabrics were subjected to laundry with non-ionic detergent. Percent UVR transmissions were studied for the laundered samples. To simulate rubbing in laundering steel balls were kept in jars to give abrasion while laundering to the samples. Three laundry cycles were given to each sample. To compare the prewash and post wash results, each samples served as its own control sample.

Table 4.10: Percent UVR transmission of cotton fabrics after 3cylces of laundering

Treatments	Plain weave (C-p)		Twill weave (C-t)	
	Before Laundry	After Laundry	Before Laundry	After Laundry
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	9.31	7.31	7.30	6.42
U_A	5.94	5.77	4.57	4.38
U_B	5.03	5.14	4.31	4.29
U_C	3.75	3.77	2.09	2.10
U_D	3.80	3.79	1.87	1.91

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

When unfinished cotton in plain and twill weave was laundered, the percent UVR transmission decreased in both the fabrics (Table 4.10). This could be because cotton fabrics undergo a combination of relaxation and consolidation shrinkage when washed. Thus, the spaces between the yarns decrease and UV protection increase. Maximum changes observed in unfinished cotton plain weave. Standord and coworkers (1995) [117] conducted laundry trial using cotton t-shirts. The results showed that UPF increased after first washing and did not change significantly with subsequent washing.

The UV finished fabrics showed no loss of efficiency as regards to UV protection in both the weaves. For the dyed samples the percent UVR transmission only marginally decreased or increased after washing, indicating that UV protection offered by these finishes is durable.

Table 4.11: Percent UVR transmission of polyester fabric after 3cycles of laundering

Treatments	Plain weave (P-p)		Twill weave (P-t)	
	Before Laundry	After Laundry	Before Laundry	After Laundry
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	6.93	6.77	5.52	5.47
U_A	4.25	4.30	3.95	3.64
U_B	4.15	4.09	3.83	3.76
U_C	3.17	3.12	2.41	2.37
U_D	3.09	3.08	2.17	2.11

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

The percent transmissions of 100% polyester fabrics in plain and twill weave after laundering are shown in Table 4.11. The sun blocking properties for untreated polyester (6.93 %transmission) decreased very slightly after laundering to 6.77 percent UVR transmission. When UV finished and dyed samples was laundered for 3cycles, the percent UVR transmission value decreased slightly after laundering, however, the changes were very minor and probably have no practical significance.

Table 4.12: Percent UVR transmission of polyester/cotton fabric after 3cycles of laundering

Treatments	Plain weave (P/C-p)		Twill weave (P/C-t)	
	Before Laundry	After Laundry	Before Laundry	After Laundry
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	7.95	6.91	5.41	4.95
U_A	4.81	4.59	3.76	3.52
U_B	4.75	4.99	3.79	3.61
U_C	3.46	3.33	1.63	1.61
U_D	3.20	3.11	1.41	1.43

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

When the polyester/cotton blend woven fabrics was laundered using non-ionic detergent, the percent UVR transmission value of the untreated fabrics in both the weave decrease, thus increased the UV protection. However maximum change was observed in plain weave as compared to twill weave (Table 4.12).

Laundry did not alter the percent UVR transmission of Commercial UV absorbers treated and Acacia Catechu dyed, thus the finishes were durable.

The K/S values of the laundered dyed samples were also measured in a spectrophotometer and the values before and after laundering were compared. Table 4.13 shows the K/S values of dyed samples before and after laundering. It was determined to compare the relationship of K/S with percent transmission. Change in colour shades after laundering have been shown in Plate 4.2.

Table 4.13: K/S values of dyed fabrics before and after laundry (3 cycles)

Fabric Code	% Shade	Colored Fabrics		Coloured Fabric after laundry (3cycles)	
		K/S value	UPF value	K/S value	UPF value
C-p	U_C	1.56	26.67	1.50	26.53
	U_D	1.75	26.32	1.57	26.39
C-t	U_C	1.84	47.85	1.42	47.62
	U_D	2.44	53.48	2.20	52.36
P-p	U_C	1.07	31.55	1.11	32.05
	U_D	1.30	32.36	1.21	32.47
P-t	U_C	1.03	41.49	1.26	42.19
	U_D	1.32	46.08	1.42	47.39
P/C-p	U_C	1.95	28.90	2.01	30.03
	U_D	2.97	31.25	3.18	32.15
P/C-t	U_C	2.41	61.35	2.18	62.11
	U_D	3.09	70.92	2.88	69.93

Key:

U_c: Dyed at 2% concentration of Acacia Catechu
U_d: Dyed at 4% concentration of Acacia Catechu

A decrease in K/S value of cotton plain and twill weave fabric was observed. As the K/S value decrease percent UVR transmission through the cotton fabric increases except in case cotton plain weave fabric, even though the K/S value increase from 1.56 to 1.50, percent UVR transmissions rose from 3.75 %to 3.77%.

In case of polyester fabrics after laundering there was decrease in K/S value except in dyed polyester plain weave fabric at 2% shade there was increase in K/S value thus decrease in the percent UVR transmission from 3.17% transmission to 3.12%. Even though the K/S decrease after laundering still the protection offered by the polyester does not change much.

The K/S values of the dyed polyester/cotton blend fabrics decrease in twill weave but it increases in plain weave fabric. The K/S decrease from 3.09 to 2.88, hence fabric percent UVR transmission increases from 1.41% to 1.43%.

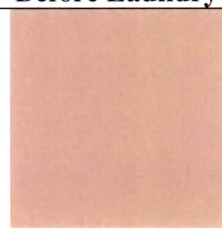
Fabric Code	Before Laundry	After Laundry
C-p		
C-t		
P-p		
P-t		
P/C-p		
P/C-t		

Plate 4.2: Acacia Catechu coloured fabrics before and after laundry (3Cycles)

4.2.5. Effect of perspiration on the percent UVR transmission of untreated and treated fabrics

Effect of perspiration on durability of finished fabrics was also studied. Percent UVR transmission values for each plain weave fabrics in both dry and wet states have been given in tables 4.14 to 4.16.

Result of the percent UVR transmission of all the fabrics under study exhibited significantly lower protection when wet as compared to fabric in dry state. This could be explained that the presence of liquid in the interstices of a fabric reduces optical scattering effects and hence increases UV transmission when wet. In a study by Parisi et al (2000) [91], it was seen that significant UV exposures may occurred beneath garments, particularly those made of white cotton fabrics when wet.

Table 4.14: Effect of perspiration on percent UVR transmission of untreated and treated cotton plain weave fabrics

Treatments	Dry state	Wet state (artificial perspiration)	
		Acid	Alkali
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	9.31	21.20	26.14
U_A	5.94	8.21	8.67
U_B	5.03	8.91	9.44
U_C	3.75	6.43	6.15
U_D	3.80	6.44	6.72

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

There was significant increase in the percent UVR transmission of untreated cotton fabric, in wet state untreated cotton transmitted three-time more than dry cotton fabric. After wetting cotton untreated fabric offers ineffective UV protection. Percent UVR transmission is more in acidic perspiration as compared to alkali perspiration.

It was found that the erythemal exposures were lowest for the dyed fabric in wet state as compared to other treatments. After wetting there was increased in percent UVR transmission values but fabrics still offering modest protection against UV rays.

Table 4.15: Effect of perspiration on percent UVR transmission of untreated and treated polyester plain weave fabrics

Treatments	Dry state	Wet state (artificial perspiration)	
		Acid	Alkali
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	6.93	7.52	8.03
U_A	4.25	5.41	5.63
U_B	4.15	5.75	5.95
U_C	3.17	4.50	4.53
U_D	3.09	4.44	4.64

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_c : Dyed at 2% concentration of Acacia Catechu
U_d : Dyed at 4% concentration of Acacia Catechu

The effect of perspiration (acidic and alkaline) on percent transmission of polyester was not much, though all the treatments showed more percent UVR transmission when wetted. It was observed that all the treated fabrics after wetting gave moderate protection in commercial UV absorbers treated fabric and high protection for dyed fabrics.

Table 4.16: Effect of perspiration on percent UVR transmission of untreated and treated polyester/cotton plain weave fabrics

Treatments	Dry state	Wet state (artificial perspiration)	
		Acid	Alkali
	$\%T_{UVR}$	$\%T_{UVR}$	$\%T_{UVR}$
Unfinished	7.95	12.86	14.27
U_A	4.81	6.42	6.98
U_B	4.75	6.64	7.02
U_C	3.46	5.15	5.24
U_D	3.09	6.06	6.17

Key:

U_A : Commercial UV absorber at 1% add-on
U_B : Commercial UV absorber at 3% add-on
U_C : Dyed at 2% concentration of Acacia Catechu
U_D : Dyed at 4% concentration of Acacia Catechu

As shown in Table 4.16 untreated polyester/cotton samples after wetting had two times more increased in percent UVR transmission value as compared to the dry sample. Percent UVR transmission was more in alkali as compared to acid perspiration. The commercial UV absorber treated fabrics with 1% add-on have less percent transmission as compared to 3% add-on of commercial UV absorber after wetting.

Fabrics treated with commercial UV absorber at 1% add-on showed almost similar result as compared to 3% add-on.

The dyed sample allows less percent UVR transmission as compared to other treatments. Increase of the dye shade leads to increase the protection against UVR rays.

Hence commercial UV absorber at 1% add-on (U_A) and 4% shade (U_D) of Acacia Catechu were selected for the future study to be used in combination with soil-release finishes.

4.3. Comparison and effect of soil-release finishes on the soiling behaviour of the fabrics under study

To improve the soil-release properties of the fabrics, all the six fabrics were treated with two different soil-release finishes i.e. Commercial soil-release finish 'C' for cotton and Commercial soil-release finish 'D' for polyester (S_{AB}) and combination of commercial soil-release finishes 'C' and 'D' for polyester/cotton blend fabrics and Carboxyl methylcellulose (CMC). CMC was applied at two different add-on's, 1% (S_C) and 3% (S_D). These two soil-release finishes were compared for their soil uptake, soil release and soil-redeposition characteristics.

After the application of finishes, both the untreated and treated fabrics were subjected to laboratory soil test using 100% artificial solvent soil. They were laundered for 3cycles along with white untreated samples.

The degree of soiling was evaluated by whiteness index using Spectrascan 5100 spectrometer and percent soil-uptake, percent soil-release and percent soil-redeposition were calculated based on whiteness index (*refer pg.121*)

The whiteness index readings for the original samples, treated, after soiling with artificial soil, after laundering have been given Table 4.17.

Table 4.17: Whiteness index of untreated and treated fabric samples

Fabric Code	Untreated	S_{AB}	S_C	S_D
C-p	89.88	89.88	89.88	89.88
Soiled samples	27.00	29.19	29.98	27.64
Soiled sample after laundry	40.95	44.49	59.16	66.80
White fabric after 3 cycles	73.82	82.10	81.69	79.69
C-t	92.50	92.50	92.50	92.50
Soiled samples	29.51	33.43	33.12	35.57
Soiled sample after laundry	43.02	47.90	64.62	75.42
White fabric after 3 cycles	84.77	84.33	86.06	86.41
P-p	82.58	82.58	82.58	82.58
Soiled samples	34.71	35.47	34.92	39.23
Soiled sample after laundry	36.36	54.71	42.05	45.73
White fabric after 3 cycles	64.31	51.74	68.14	69.71
P-t	90.56	90.56	90.56	90.56
Soiled samples	33.68	33.26	35.10	36.93
Soiled sample after laundry	36.78	60.22	42.70	50.61
White fabric after 3 cycles	72.32	54.31	78.87	78.30
P/C-p	83.45	83.45	83.45	83.45
Soiled samples	30.99	32.59	31.60	30.80
Soiled sample after laundry	41.54	50.30	45.13	48.46
White fabric after 3 cycles	68.38	62.95	65.39	66.56
P/C-t	91.35	91.35	91.35	91.35
Soiled samples	32.08	32.26	34.28	35.37
Soiled sample after laundry	37.93	44.32	45.69	47.66
White fabric after 3 cycles	76.50	76.25	76.54	77.06

4.3.1. Effect of soil-release finishes on percent soil uptake

Soiling problems on textiles generally arise from the unwanted accumulation of oily and/or particulate materials on the surfaces or interior of fibrous structures. Textile materials offer an ideal resting place for dirt. Soiling takes place when the soil which comes in close contact with the fabric is retained as a more or less stable unit. Attachment of soil to the host fiber and its removal is a complex phenomenon which is likely to be influenced by a large number of factors. Type of fiber, diffusion of soil in fiber, irregularity of fiber surface and pore structure of fiber also may influence the ease of soiling as well as soil removal.

The amount of soil taken up by the untreated and treated samples by subjecting them to artificial soil was determined by whiteness index (*refer pg 121*), which has been given in Table 4.18. The value of percent soiling also shows that the untreated fabrics picked up slightly more soil as compared to all the treated fabrics. As the complexity of fabric structure increase the soiling also increases. [70] Twill weave fabrics showed more % soiling as compared to the plain weave fabrics except in cotton where % soiling of plain weave was more as compared to twill weave cotton fabric.

Table 4.18: Percent soil uptake with artificial soil on untreated and treated fabric sample

Treatments / Fabric Code	Untreated	S_{AB}	S_C	S_D
C-p	69.96	67.52	66.65	69.25
C-t	68.10	63.85	64.19	61.55
P-p	57.97	57.05	57.72	52.50
P-t	62.81	63.27	62.35	59.22
P/C-p	62.86	60.94	62.14	63.09
P/C-t	64.88	64.68	62.48	61.28

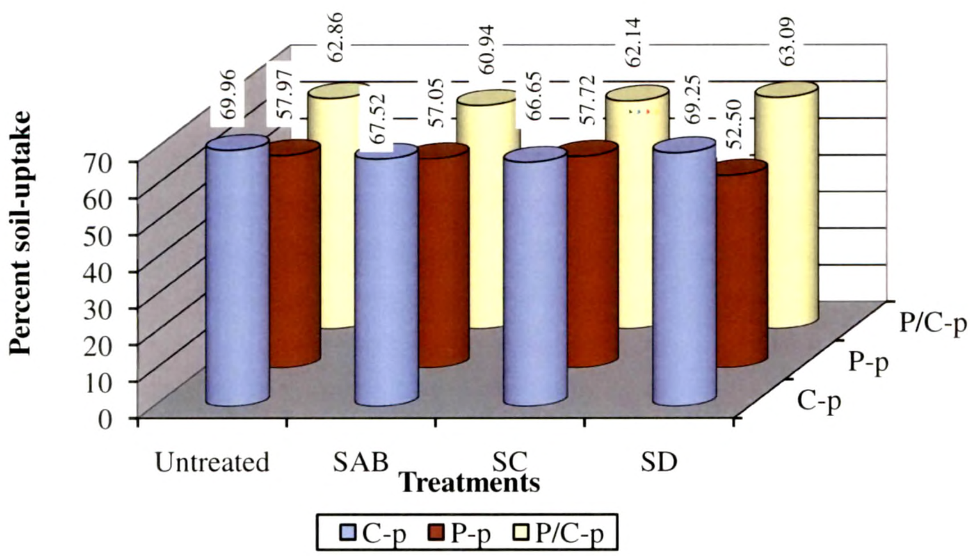
Key:

Fabric Codes:
- **C-p: Cotton plain weave fabric**
- **C-t: Cotton twill weave fabric**
- **P-p: Polyester plain weave fabric**
- **P-t: Polyester twill weave fabric**
- **P/C-p: Polyester/Cotton blend plain weave fabric**
- **P/C-t: Polyester/Cotton blend twill weave fabric**

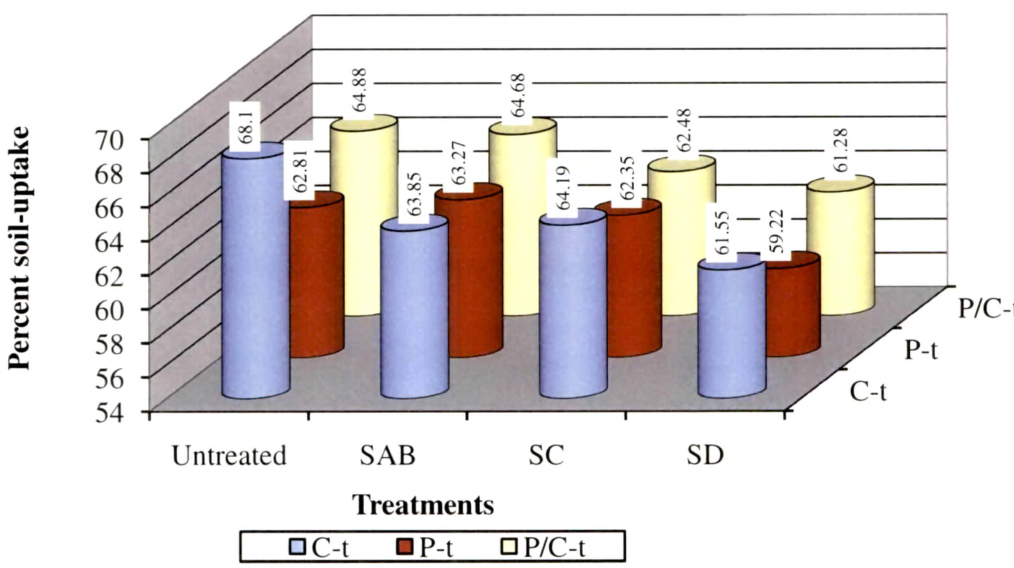
Treatments
- **S_{AB}: Commercial soil-release finish**
- **S_C: CMC at 1% add-on**
- **S_D: CMC at 3% add-on**

The influence of static electricity on soiling is not clear, whiteness index showing no correlation with the magnitude of the electrostatic charge. When we observed untreated plain and twill weave fabrics, it was found that untreated cotton fabrics gave minimum whiteness index reading in plain and twill weave (27.00, 29.51) followed by untreated polyester/cotton (30.99, 32.26) and untreated polyester (34.71, 33.68) in both weaves as shown in Graph 4.10 and 4.11.

The reason for this increase in this order may be because the hydroxyl and other groups present in the cellulosic fiber contributed to its higher surface energy than that of a hydrophobic synthetic fiber, and promote the greater accumulation of surface soil.



Graph 4.10: Percent soil uptake of treated and untreated plain weave fabrics



Graph 4.11: Percent soil uptake of treated and untreated twill weave fabrics

There are differences in soil retention by various chemical types of fiber that apparently cannot be related to differences in physical size and shape of the filaments. It was observed that the fabric treated by C.M.C. picked up less soil compared fabric treated with commercial soil-release, except in polyester/cotton blend plain weave fabric.

4.3.2. Effect of Soil-release finishes on percent soil-release

The degree of soil removal during cleaning is a function of the substrate, soil, cleaning method and interactions between these. As washing proceeds, more and more was soil released from the fabric and it gets accumulated in the solution up to a particular level after which the soil starts redeposition on the fabric. At any instant, therefore there is a competition between soil release and soil redeposition processes and the overall soil release is governed by a combination of the two.

The artificial soil samples were subjected to laundering (*refer pg 114*) and the amount of soil retained by the samples was determined by whiteness index. To evaluate the percent soil release property of the samples, percent soil release was calculated from whiteness index to compare the results.

Data on the percent soil release from fabrics of all the three fiber types in plain and twill weave after three cycles of laundering have been presented in Table 4.19. It can inferred, that the percent soil release in the untreated fabrics increase in the order Cotton>Polyester/Cotton>Polyester, as expected due to their hydrophilic and surface characteristics of these fiber materials. The crenulated surfaces of cotton fibers act as traps for particulate soil. The lower soil-release in the case of polyester fiber, is due to large surface density build up on the fiber surface by friction during use and thereby, soil particles, whether charged or not, are attracted from the wash liquor.

Table 4.19: Percent soil-release of untreated and treated fabrics after 3 wash cycles

Treatments / Fabric Code	Untreated	S_{AB}	S_C	S_D
C-p	22.19	25.21	48.71	62.92
C-t	21.45	24.48	53.06	70.01
P-p	3.44	40.84	14.98	15.00
P-t	5.45	47.06	13.72	25.52
P/C-p	20.11	34.82	26.10	33.54
P/C-t	9.87	20.41	20.00	21.96

Key:

Fabric Codes:
- **C-p: Cotton plain weave fabric**
- **C-t: Cotton twill weave fabric**
- **P-p: Polyester plain weave fabric**
- **P-t: Polyester twill weave fabric**
- **P/C-p: Polyester/Cotton blend plain weave fabric**
- **P/C-t: Polyester/Cotton blend twill weave fabric**

Treatments
- **S_{AB}: Commercial soil-release finish**
- **S_C: CMC at 1% add-on**
- **S_D: CMC at 3% add-on**

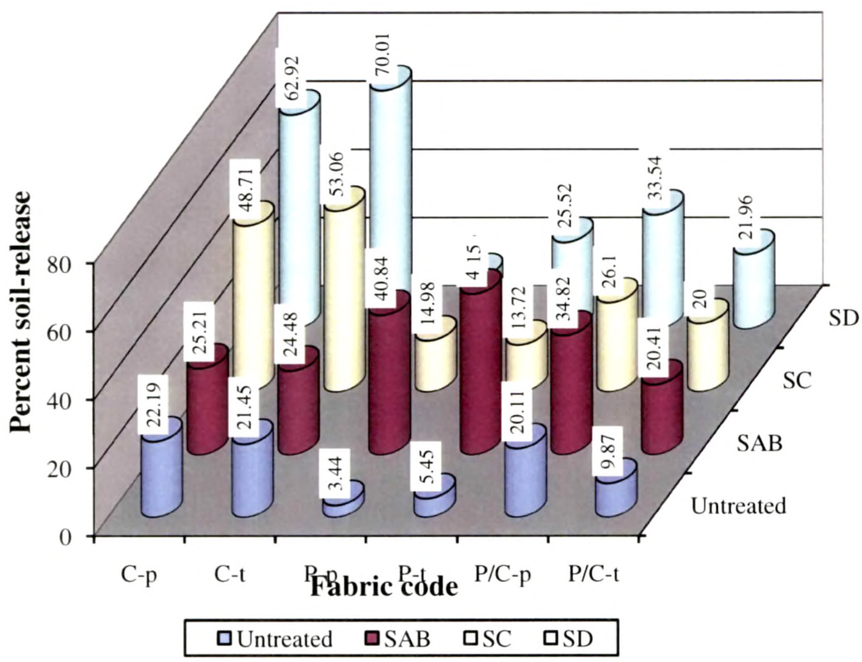
From the results it was found that both the soil-release finishes improved the soil-release performance of all the fabric under study. Soil release performance of the C.M.C. and commercial soil-release A & B finished fabrics, depended on the fiber type and fabric construction.

Soil-release behaviour of C.M.C. finished fabrics

Percent soil release of Carboxy Methyl Cellulose treated and untreated fabrics have been given in Table-4.19 and in Graph 4.12.

The percent soil-release was found to increase with application of C.M.C. for both the add-on's i.e. 1% and 3% in the order of Cotton>P/C>Polyester. The soil release performance of the C.M.C treated fabrics with 1%add-on showed less soil-release as compared to fabrics treated with 3% add-on in all the three fibers fabric. The fabric treated with CMC also had better soil release property as compared to untreated fabrics.

After application of C.M.C the percent soil-release of the cotton plain and twill weave fabric improves noticeably 62 % and 70% at 3% add-on respectively as compared to 22% and 21% for plain and twill weave of untreated cotton after washing. The reason for increased % soil-release property of cotton treated with CMC, could be that C.M.C causes changes in the chemistry of the fiber by increasing the carboxyl group content or due to electrostatic repulsive force which develops between negatively charged soil particles and negatively charged cotton surface (due to presence of carboxylic groups in C.M.C). [13]



Graph 4.12: Percent soil-release after laundry (3cylces) of untreated and treated fabrics

The polyester finished with CMC had less percent soil-release as compared to commercial soil-release finished polyester.

Percent soil-release of polyester/cotton blend fabrics in plain and twill fabrics gave almost similar result with both the finishes i.e. CMC and commercial soil-release finishes

C.M.C. when applied on the surface of the fabric physically blocks the soil particles from penetrating deeper into fabric. [87] As per observation of Frong and Laudgren [33] also showed that when C.M.C. used along with detergent in washing, the removal of soil from cloth is very efficient. It is also been demonstrated by Beninate et al [6] that when C.M.C. is incorporated with resins in the wash-n-wear finish, the soil release property of the treated fabric was found to be better and finish was also claimed to be fast to 25 launderings.

Soil-release behaviour of commercial soil-release finishes

Increased soil release and reduced soil redeposition can be attained by increasing the surface hydrophilicity of synthetic textiles. Commercial soil-release finishes increase the hydrophilic character of synthetic fibers which allows the soil to penetrate the fabric during wear but it comes into the action during washing when its special functional groups transfer the soil from the fabric to washing liquor. By this it improves soil release and prevents soil redeposition.

Table 4.19 shows the maximum difference in the amount of soil removed in commercial soil-release treated polyester fabrics. After the application of the commercial soil-release finish 'B' the percent soil-release of the polyester fabric improves noticeably to 41% and 47% in plain and twill weave fabrics respectively as compared to 3% and 4% in plain and twill weave untreated polyester fabrics and CMC treated polyester fabrics also showed less percent soil-release i.e. 15% and 25% in plain and twill weave fabrics respectively as compared commercial soil-release finish 'B'.

In case of polyester blend fabric also there was increase in %soil release property of the fabric after the application of commercial soil-release finish. Soil-release finishes helps to reduce static charge on the fabric and assists the penetration of washing liquors when the soiled fabric is washed. Therefore, accumulated dirt on the fabric is more easily removed during the washing operation.

4. 3.3. Percent soil-redeposition during laundering on untreated and treated fabrics

A widely recognized difficulty with efficient soil removal is that during the washing of a dirty fabric, when soils separated from the fabrics and suspended in wash liquors may redeposit on fibers before the soil is flushed from the system.

The mechanism of wet soiling is based on the concept that the soil becomes attached to a fiber by displacement of water from the surfaces of both the fiber and the soil. When wet soling takes places, a soil-fiber interface is formed at the expense of water-fiber and soil-fiber interfaces. [9]

This parameter evaluates the amount of soil which is picked up by the fabric from the washing liquor during washing/laundering.

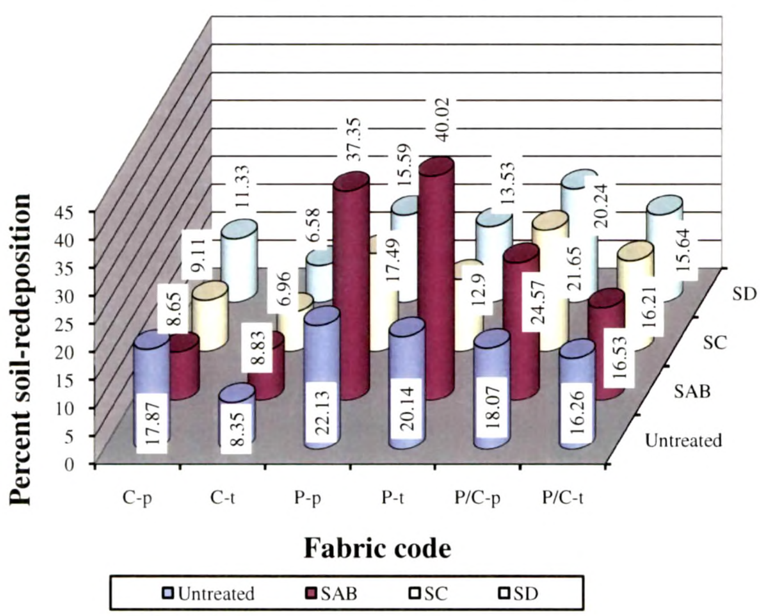
The scoured white unsoiled unfinished fabric was stitched and laundered together with the soiled fabrics in the same bath, to evaluate the soil-redeposition on the white fabric during washing of soiled samples.

Percent Soil-redeposition during laundering on untreated and treated fabrics was shown in Table 4.20. The untreated, commercial soil-release finishes and CMC treated fabrics showed more soil-redeposition in plain weave fabrics as compared to twill weave fabrics except in case of commercial soil-release finish 'B' treated polyester twill weave fabric. In case of untreated fabrics the minimum soil-redepositon was found in cotton fabrics, followed by polyester/cotton blend fabric. Maximum soil-redepostion was found in polyester fabrics; hence it shows that the soil-redeposition is greatly influenced by fiber types. The affinity is high between the oleophilic fabrics, such as polyester or its blends and the oleophilic soils, which is carbon black.[138] Being oleophilic; it picks up grease or fatty based dirt from wash liquor resulting in soil re-deposition which again leads to fabric graying.

In treated fabrics, it has been seen that in commercial soil-release finish A & B finished fabric redeposition was maximum in polyester fabrics, followed by polyester/cotton blend and minimum was seen in cotton fabrics.(Graph 4.13)

Table 4.20: Percent soil-redeposition during laundering on untreated and treated fabrics

Treatments / Fabric Code	Untreated	S_{AB}	S_C	S_D
C-p	17.87	8.65	9.11	11.33
C-t	8.35	8.83	6.96	6.58
P-p	22.13	37.35	17.49	15.59
P-t	20.14	40.02	12.90	13.53
P/C-p	18.07	24.57	21.65	20.24
P/C-t	16.26	16.53	16.21	15.64



Graph 4.13: Percent Soil-redeposition during laundering on untreated and treated fabrics

Key:

Fabric Codes:
- **C-p: Cotton plain weave fabric**
- **C-t: Cotton twill weave fabric**
- **P-p: Polyester plain weave fabric**
- **P-t: Polyester twill weave fabric**
- **P/C-p: Polyester/Cotton blend plain weave fabric**
- **P/C-t: Polyester/Cotton blend twill weave fabric**

Treatments
- **S_{AB}: Commercial soil-release finish**
- **S_C: CMC at 1% add-on**
- **S_D: CMC at 3% add-on**

Within the C.M.C finished at both the add-on's polyester and polyester/cotton blend fabrics showed maximum soil redepostion as compared with CMC treated cotton fabrics. At 1% add-on soil-redeposition was 17% and 12% in plain and twill weave of polyester and 22% and 16% in plain and twill weave of polyester/cotton blend fabrics respectively which were more as compares to CMC treated fabrics i.e. 9% and 7% in plain and twill cotton fabrics respectively. A logical explanation for the decrease in wet soiling after CMC treatment is the negatively charge provided by the materials, which would electrosatically repel negatively charged soil. Of course soil would be removed during washing along with the water soluble polymers as with starch. [13] Second reason may be as CMC inclusion (as low as even 0.25%) in final rinse improves soil-resistance and soil-release, besides preventing soil re-deposition. This action is attributed to its electrostatic repulsive force, its greater affinity towards fiber thus blocking entry of dirt particles and its capacity to envelop dirt particles thereby preventing their re-deposition.

For cotton fabrics treated with CMC i.e. Sc and S_D gave better results. When 1% (Sc) and 3% (S_D) add-on's were compared, 1% add-on (Sc) was selected for the further work as increase in percent add-on negligible changes were observed in percent soil uptake, percent soil-release and percent soil-redeposition. Polyester plain and twill weave fabrics showed better result with commercial soil-release finishes. However polyester/cotton blend fabric gave similar results with both the finishes i.e. commercial soil-release finishes and CMC. Polyester/cotton blend plain and twill weave fabrics gave good results with both the soil-release finishes i.e. commercial soil-release finish and CMC at both the add-on. And so commercial soil release (S_{AB}) and CMC at 1% add-on (S_C) were selected for further work to be used in combination with UV absorbers finishes.

4.4. Results of optimum combination of UV absorber and soil-release finishes on selected fabrics

The effect of two UV absorbers at different add-on and percent shade was seen on the six fabrics as well as the effect of two soil-release finishes was studied. The results showed that from the six fabrics under the study, polyester/cotton blend in plain and twill exhibited the best properties for %UV transmission as well as soil-release. Nair [86] (2007) also stated in his study that P/C 67/33 blended fabric were widely used for uniforms of outdoor workers because processing of polyester/cotton blend ratio 67/33 provides a balance of properties to give optimum performance in suiting for uniforms.

When comparisons were made between the finishes for the UV absorbers Acacia catechu gave the best results. In case of soil release finish CMC showed better soil-release and soil-redeposition characteristics. After analysis of results four optimum combination were purposively selected. The combinations were with lower add-ons as with the higher add-on not much improvement in properties was seen as well as when two finishing treatments were to be given together the higher add-on's would increase the weight of the fabrics under study. However the natural colourant Acacia Catehu higher percent shade of 4% was selected. The four combinations taken for further study have been listed below in Table.21.

Table 4.21: Four selected combinations of UV absorber and soil-release finish.

Combination code	Commercial UV absorber (U_A) 1% add-on	Acacia catechu (U_D) 4% shade	Commercial soil-release finishes (S_{AB})	CMC (S_C) 1% add-on
O_A	√			√
O_B	√		√	
O_C		√		√
O_D		√	√	

Above four combination were applied to the polyester/cotton plain and twill fabrics and treated fabrics were tested for %UVR transmission, soiling parameters and wear properties.

The results of treated fabrics have been given and discussed under the following subsection:

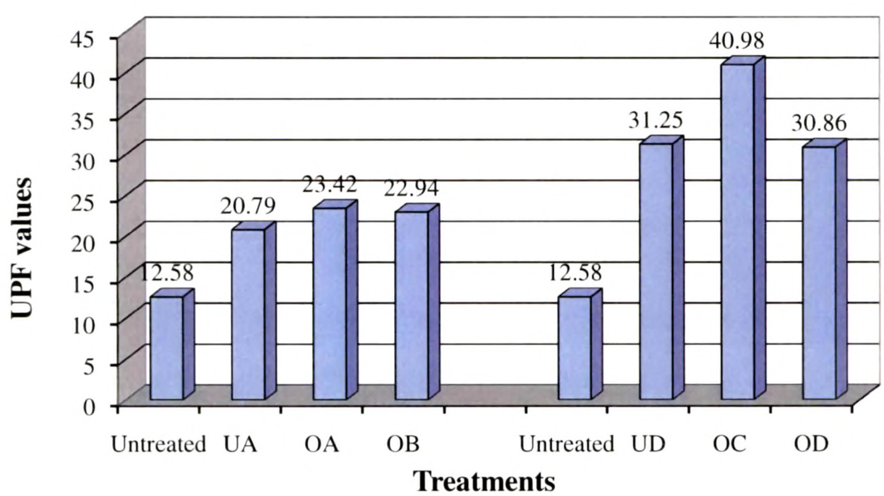
4.4.1 Comparison and influence of finishes in combination on %UVR transmission.
4.4.2 Comparison and effect of finishes in combination on the soiling behaviour.
4.4.3 Effects of finishes in combination on the wear properties of the fabrics under study.
4.4.4 Theoretical Costing of the fabrics

4.4.1 Comparison and influence of finishes in combination on percent UVR Transmission.

Effect of finishes in combination on polyester/cotton plain weave fabrics were studied for percent UVR transmission and UPF values.

Table 4.22: Percent UVR transmission of untreated and treated polyester/cotton blend plain weave fabric with finishes in combination

Treatments	$\%T_{UVA}$	$\%T_{UVB}$	$\%T_{UVR}$	UPF values
Untreated	8.80	7.09	7.95	12.58
O_A	4.44	4.10	4.27	23.42
O_B	4.36	4.36	4.36	22.94
O_C	2.57	2.31	2.44	40.98
O_D	3.28	3.20	3.24	30.86



Graph 4.14: Effect of various finishes individually and in combination on UPF value of polyester/cotton blend plain weave fabric

Key:
U_A : Commercial UV absorber 1% add-on
O_A : UV absorber at 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
U_D : Dyed at 4% concentration of Acacia Catechu
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

Table 4.22. shows the percent UVR transmission values of the untreated, the four combinations finishes on polyester/cotton blended plain weave fabric. After the application of various finishes in combination, polyester/cotton blend plain weave fabrics showed lesser transmission than the untreated fabric, thus providing better protection.

It was also seen from Graph 4.14 that when the fabrics was treated with the four combination finishes they gave better protection than the fabrics treated with the UV absorber individually.

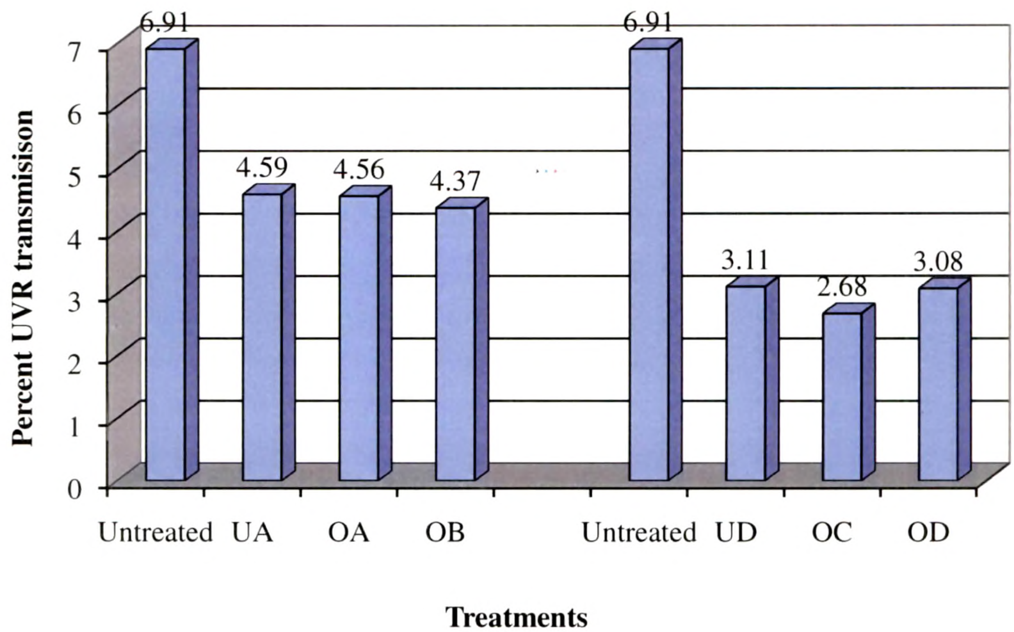
Result also shows that the applications of UV absorbers with CMC (O_A and O_C) on polyester/cotton fabrics have more protection against ultraviolet radiation as compared to combination of UV absorbers with commercial soil-release finish (O_B and O_D).

4.2.3. Effect of launderings on percent UVR transmission of untreated and treated fabrics with combination of finishes on polyester/cotton blend plain weave fabric

The treated fabrics would have to could go laundering as they would be used for the uniform of outdoor workers, so all the untreated and finished were subjected to laundry with non-ionic detergent and percent UVR transmissions were studied after 3cycles of laundry.

Table 4.23: Percent UVR transmission of polyester/cotton fabric after 3cycles of laundering

Treatments	Before Laundry	After Laundry
	$\%T_{UVR}$	$\%T_{UVR}$
Untreated	7.95	6.91
O_A	4.27	4.56
O_B	4.36	4.37
O_C	2.44	2.68
O_D	3.24	3.08



Graph 4.15: Effect of launderings on percent UVR transmission of untreated and treated fabrics with combination finish

Key:
U_A : Commercial UV absorber 1% add-on
O_A : UV absorber at 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
U_D : Dyed at 4% concentration of Acacia Catechu
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

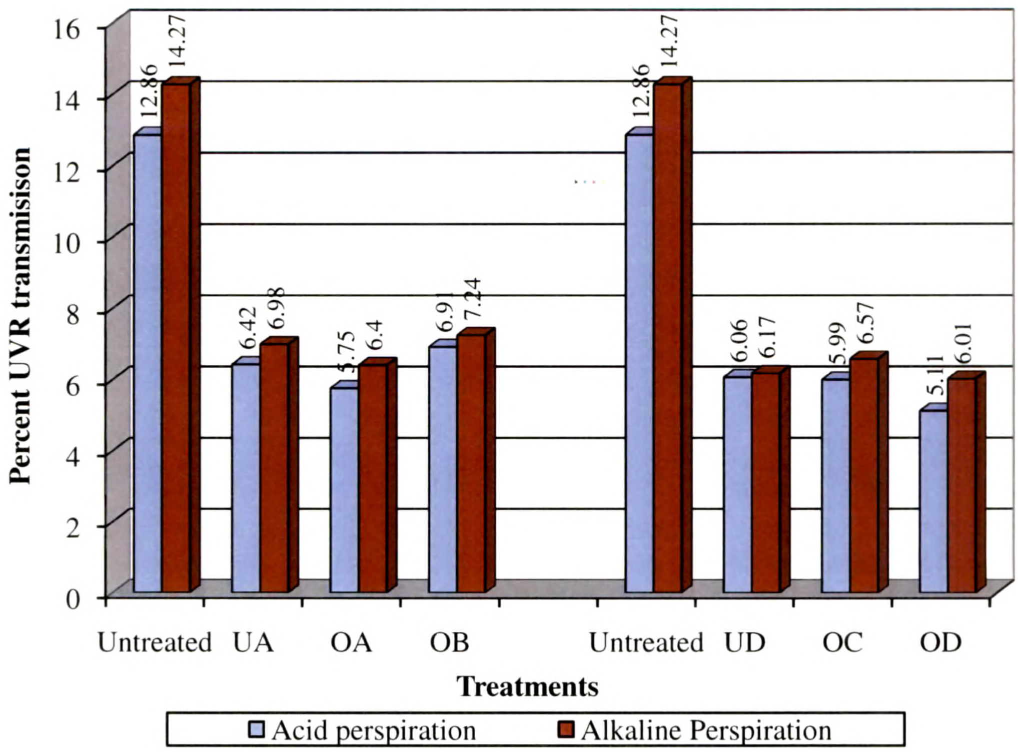
The Table 4.23 and Graph 4.15 clearly showed that when the treated polyester/cotton plain weave fabric was laundered there was no noticeable change seen in the percent UVR transmission. Similar results were seen when the combination finishes were compared to the UV absorber finishes when studied individually. However the combination with Acacia Catechu (O_C and O_D) gave better results as compared to combination O_A and O_B.

4.2.5. Effect of perspiration on the percent UVR transmission of untreated and treated polyester/cotton blend plain weave fabric with finishes in combination

Perspiration affects the fabrics when worn and so its effect on percent UVR transmission values was also studied. The effects of acidic as well as alkaline perspiration were seen on the polyester/cotton blend plain weave fabric treated with the four finishes in combinations. The results have been given in Table 4.24. Result of the percent UVR transmission of all the fabrics under study exhibited significantly lower protection when wet (with perspiration) as compared to fabric in dry state.(Graph 4.6) The commercial UV absorber treated fabrics with commercial soil-release finishes (O_B) have less percent transmission as compared to commercial UV absorber + CMC (O_D) treated fabrics. Even in dyed samples same pattern was observed. It was also observed that even though percent UVR transmission increased in various combinations treated fabrics, treated fabrics still provided moderate protection as compared to untreated fabric which showed poor protection in wet state.

Table 4.24: Effect of perspiration on percent UVR transmission of untreated and treated fabric with finishes in combination

Treatments	**Dry state**	**Wet state (artificial perspiration)**	
		Acid	**Alkali**
	$\%T_{UVR}$	**$\%T_{UVR}$**	**$\%T_{UVR}$**
Untreated	7.95	12.86	14.27
O_A	4.27	5.75	6.4
O_B	4.36	6.91	7.24
O_C	2.44	5.99	6.57
O_D	3.24	5.11	6.01



Graph 4.16: Effect of perspiration on percent UVR transmission of untreated and treated fabrics with finishes in combination

Key:
U_A : Commercial UV absorber 1% add-on
O_A : UV absorber at 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
U_D : Dyed at 4% concentration of Acacia Catechu
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

It was observed that while the treated fabric with all the combination showed slight increase in percent UVR transmission, but they still gave moderate protection to percent UVR transmission. However in the case of untreated fabrics when subjected to perspiration their protection decreases to poor category. It was also seen that in acidic perspiration the percent UVR transmission was lower as compared to alkaline perspiration.

4.25 Comparison and effect untreated and treated fabric with finishes in combination on the soiling behaviour

Whiteness index of polyester/cotton blend fabrics the optimum fabrics without or with various treatments after artificial soiled and laundering (3cycles) is given in Table 4.25.

Table 4.25: Whiteness index of polyester/cotton blend fabrics with various treatments

Treatments	Fabric code	
	P/C-p	P/C-t
Untreated		
Soiled samples	30.99	32.082
Soiled sample after laundry	41.54	37.932
White fabric after 3 cycles	68.38	76.495
O_A	82.76	90.05
Soiled samples	26.12	30.8
Soiled sample after laundry	50.84	50.89
White fabric after 3 cycles	78.42	88.78
O_B	82.69	87.070
Soiled samples	32.34	35.120
Soiled sample after laundry	49.74	49.010
White fabric after 3 cycles	77.29	84.710
O_C	46.15	45.73
Soiled samples	23.70	25.24
Soiled sample after laundry	41.06	37.11
White fabric after 3 cycles	45.61	45.07
O_D	46.63	44.42
Soiled samples	29.27	25.91
Soiled sample after laundry	39.78	35.21
White fabric after 3 cycles	45.50	43.25

Key:

O_A : UV absorber at 1% add-on + carboxymethylcellulose at 1% add-on
O_B : UV absorber at 1% add-on + commercial soil-release finshes
O_C : Acacia catechu dyed at 4% shade+ carboxymethylcellulose at 1% add-on
O_D : Acacia catechu dyed at 4% shade + commercial soil-release finishes.

The degree of soiling was evaluated by whiteness index using Spectrascan 5100 spectrometer and percent soil-uptake, percent soil-release and percent soil-redeposition were calculated based on whiteness index (*refer pg 121*).

a) Percent soil-Uptake

After the application on finishes percent soil uptake was more in untreated fabrics as compared to treated fabrics.

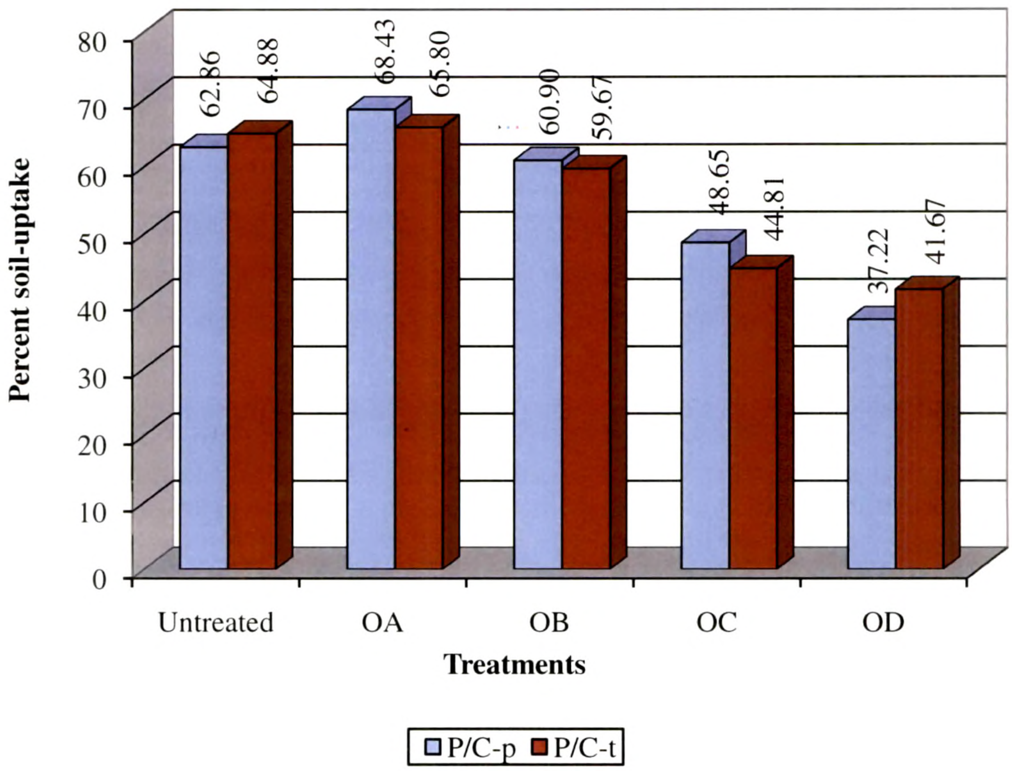
When the percent soiling of the four finishes in combination were compared it was seen that the combination with CMC ($O_A + O_C$) took more soil as compared to the combination which has commercial soil-release finish (O_B + O_D). Also the commercial UV absorber combination i.e. O_A and O_B picked up more soil as compared to natural colorant in combination i.e. O_C and O_D. (Table 4.26, Graph 4.17)

Table 4.26: Percent soiling with artificial soil on untreated and treated fabric with finishes in combination

Treatments	**Fabric code**	
	P/C-p	**P/C-t**
Untreated		
O_A	68.43	65.80
O_B	60.90	59.67
O_C	48.65	44.81
O_D	37.22	41.67

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.



Graph 4.17: Percent soil-uptake of on untreated and treated fabric with finishes in combination

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

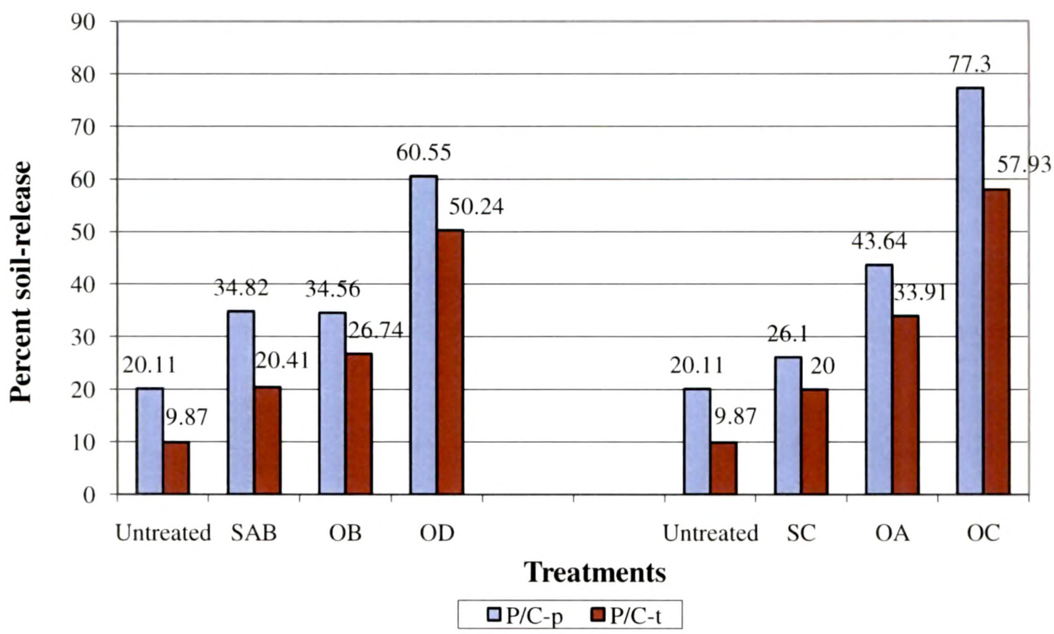
b) Percent soil-release property

Soil-release is the term used for finish, which allows the soil to penetrate the fabric during wear, but it comes into action during washing when its special functional groups transfer the soil from the fabric to the washing liquor.

All the four finish combination gave better percent soil release as compared to untreated fabrics.(Table 4.27)

Table 4.27: Percent soil-release after laundering (3cylces) of untreated and treated fabrics with finishes in combination.

Treatments	Fabric code	
	P/C-p	P/C-t
Untreated		
O_A	43.64	33.91
O_B	34.56	26.74
O_C	77.30	57.93
O_D	60.55	50.24



Graph 4.18: Effect of various finishes individually and in combination on percent soil-release of polyester/cotton blend plain and twill weave fabrics

Key:

S_{AB} : Commercial soil release finish
S_C : Carboxymethyl cellulose 1% add-on
O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

It was also observed from Graph 4.18 that after the application of O_A i.e. UV absorbers + CMC percent soil-release noticeably increased in both the weaves as compared to the application of O_B i.e. UV absorber + commercial soil-release finished. The reasons for this may be that CMC when applied it physically block the surface of the fabric there by preventing the soil particulate from penetrating into the fabric. This helps in removing the soil easily during laundering.

The soil-release performance of the Acacia catechu with CMC (O_C) showed maximum value as compared to the other combination for both the fabric. It was expected because they picked up less soil as compared to commercial UV absorber with commercial soil-release finish.

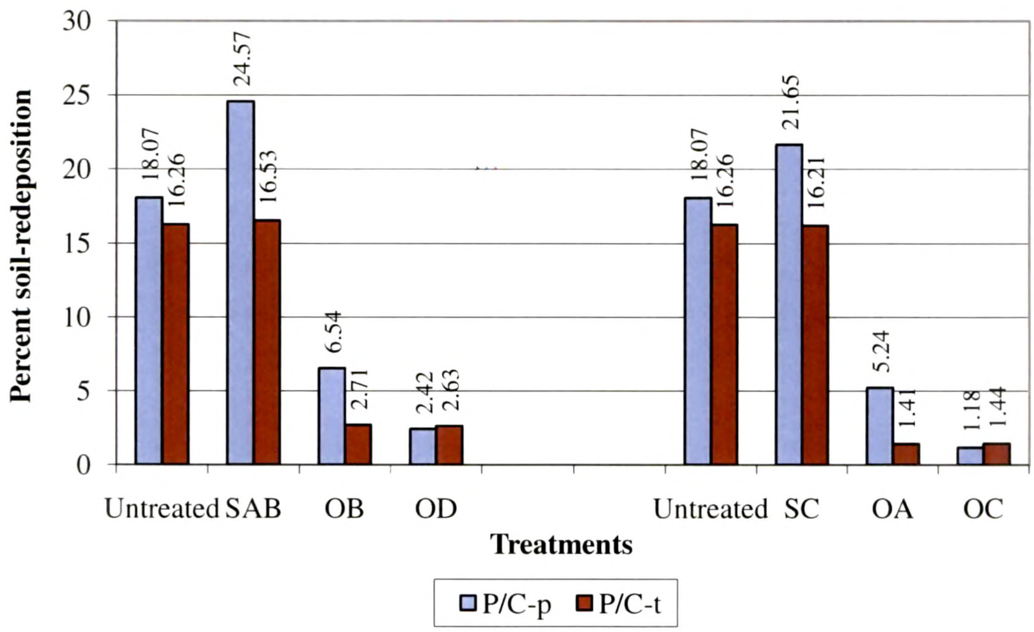
c) Percent soil-redeposition characteristics:

Soil redepositon may be defined as deposition of soil which has already been released from the fabric during washing of fabrics. Sometimes this released soil is present in wash liquor as dispersion of fine particles which is deposited back on to the same fabric or the fabric accompanying. The composition of the redeposition soil is different to cotton and synthetic fabrics due to difference in their chemical and physical properties. On the cotton it is essentially particulate soil, whereas on synthetics it is fatty nature redeposition of soil during washing produces grayness to the fibers, particular.

The fabric treated with the same chemical composition was stitched and laundered alone with soiled fabric of same chemical composition, to evaluate the soil redepostion.

Table 4.28: Percent soil-redeposition during laundering of on untreated and treated fabric with finishes in combination

Treatments	Fabric code	
	P/C-p	P/C-t
Untreated		
O_A	5.24	1.41
O_B	6.54	2.71
O_C	1.18	1.44
O_D	2.42	2.63



Graph 4.19: Percent soil-redeposition during laundering of untreated and treated fabrics

Key:

S_{AB} : Commercial soil release finish
S_C : Carboxymethyl cellulose 1% add-on
O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

All the combination gave good readings for percent soil redeposition and it was seen from the Table 4.28, Graph 4.19 that after treatments the percent soil redeposition was considerably reduced when compared with the untreated fabric samples.

The least soil redeposition occurred with the combination of acacia catechu and CMC (O_C), 1.18 and 1.44 in plain and twill weave respectively.

d) SEM studies of untreated and treated polyester/cotton twill weave soiled fabrics before and after laundry

The Scanning Microscopic studies were carried out to examine the effect of finishes on the fiber surface characteristics, soil affinity, location of soiled area in the fabric and distribution of soil on the surface area of fiber which has been shown in Plate-4.3 and Plate 4.4.

Optimum selected fabric (Polyester/cotton 67/33%) was previously treated with combination of commercial UV absorber and CMC finishes (O_A). These treated fabrics were then coated with artificial soil (Carbon black) with standard procedure. All these samples were viewed under a Scanning Electron Microscope (Joel JSM-5610V S.E.M.) at different magnifications. The untreated and soiled samples after washing were also examined for comparison purpose.

Photomicrographs (Plate 4.3.c and d) were taken at 15kv x 1000 magnification to locate the soil in the fabric structure. It shows that in the case of untreated polyester/cotton blend (Plate 4.3.c.) twill weave fabric, much larger amount of soil particles were ambient forming clusters and hills on the fibre surface, which modified the surface of the fiber, where as in the case of combination of U.V absorber and CMC treated fabric (Plate 4.3.d.), such detrimental effect was not visible, soil was distributed evenly on the fibre surface and fibrous structure was largely intact, this may be due to the effect of soil-release finish applied on the fabric.

The distribution of soil on the surface-surface was also examined at 15v x 2000 magnification. Here it was observe from the photomicrographs that untreated polyester/cotton fabrics (Plate 4.4.a.) shows surface irregularities and aggregation of soil particles on the fiber surface, where as soil release polyester/cotton twill weave treated fabrics (Plate 4.4.b.) exhibit the regular and less uptake of soil which reduces the brightness of the fiber and gives duller and darker appearance.

The removal of soil particles under investigation from the fiber surface shows that in the case of polyester/cotton untreated fabric (Plate 4.4.c.), after laundering surface area is much uniform but the fibrous structure still contains some soil particles, it was not completely removed. Thus the removal of soil is depend on the extend of laundering.

In case of treated fabric with combination O_A (Plate 4.4.d) when washed greater was the release of soil from the fabric and increase the brightness. Thus after laundering the efficiency of soil removal is dependent on the conditions of the actual process.

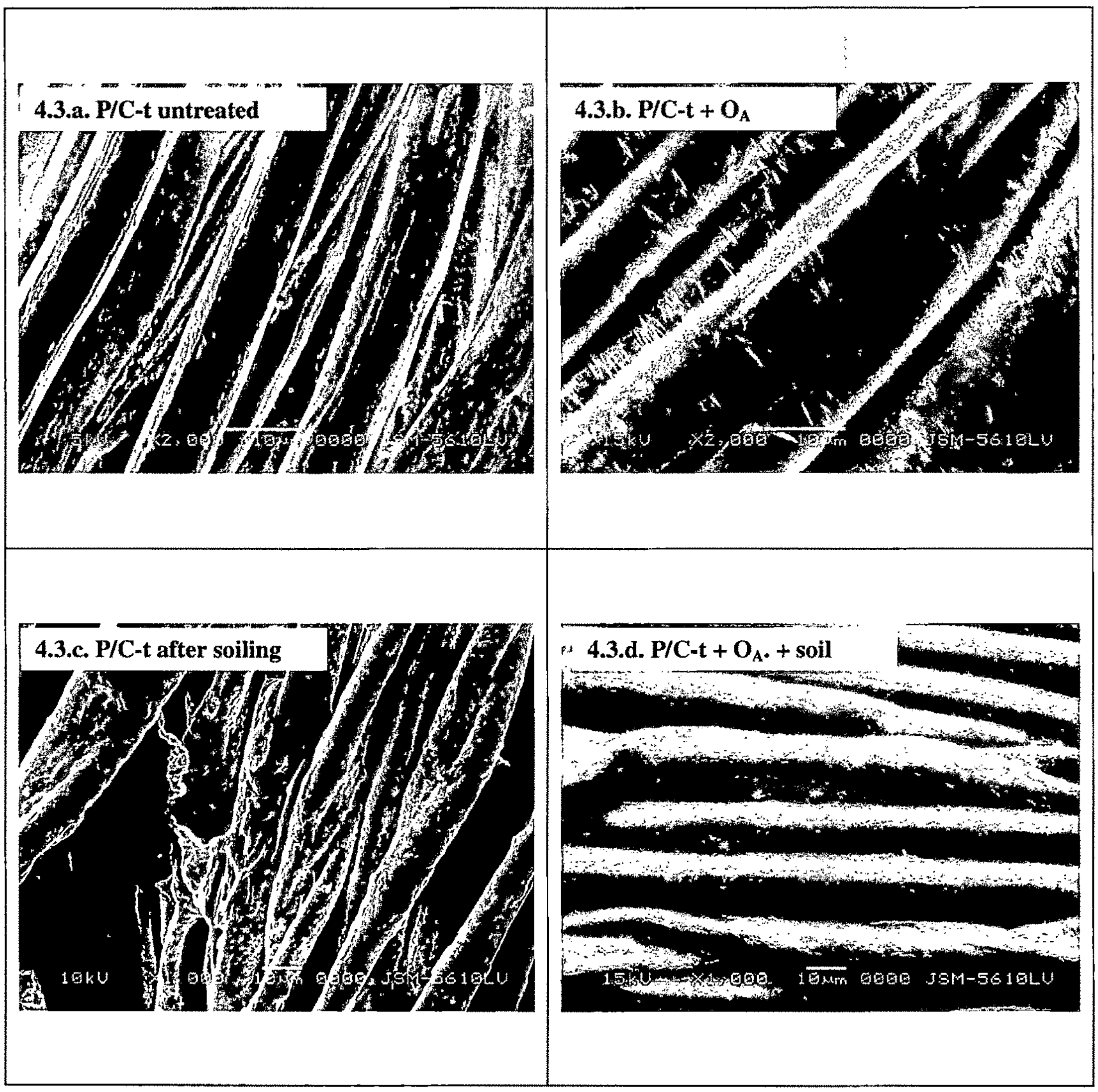


Plate 4.3: S.E.M images of the untreated, treated with combination O_A P/C blend samples with and without soil

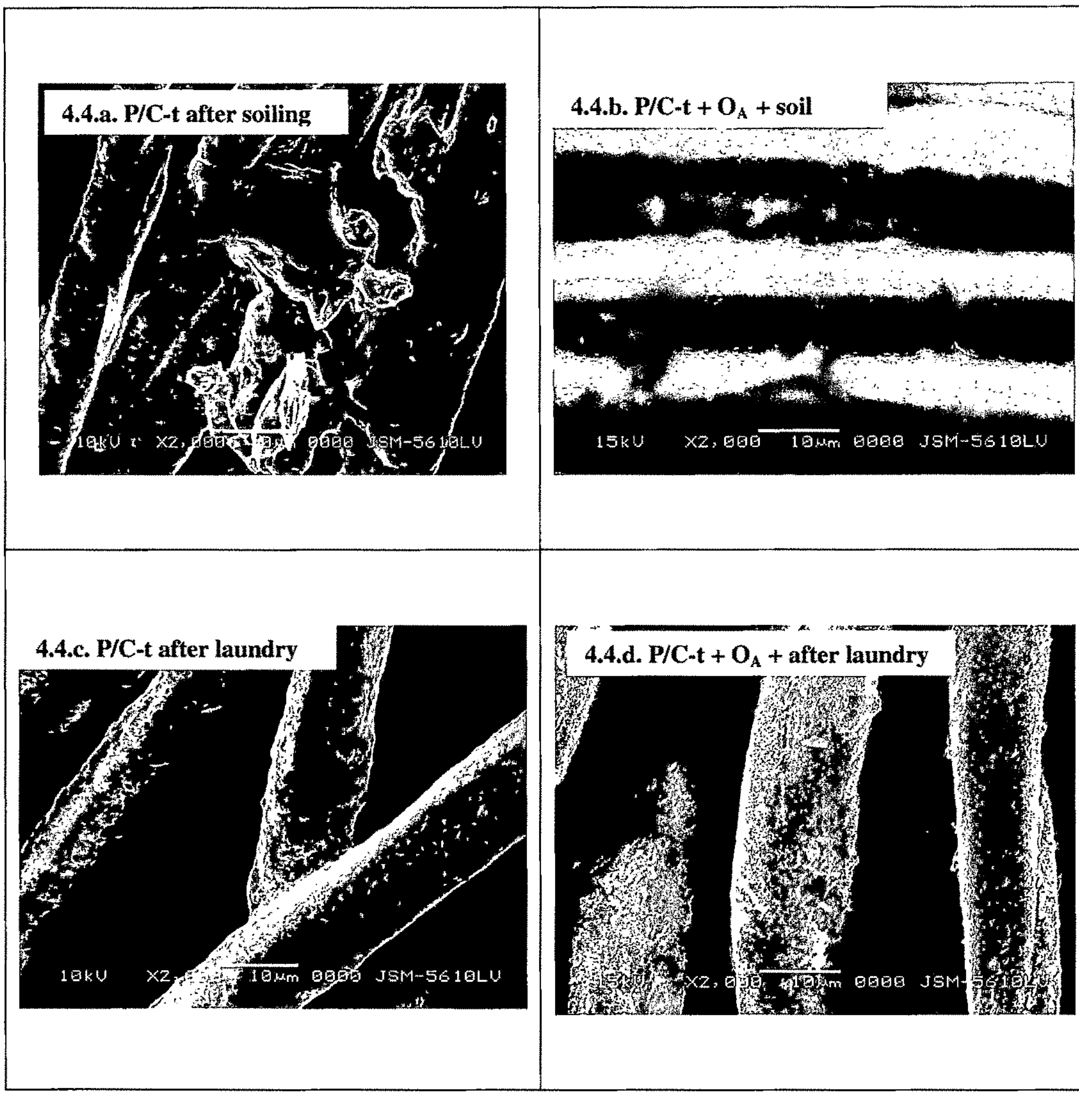


Plate 4.4: S.E.M images of the untreated, treated with combination O_A P/C blend samples soiled fabrics before and after laundry

4.3. Effect of finishes in combination on the wear properties of the fabrics under study

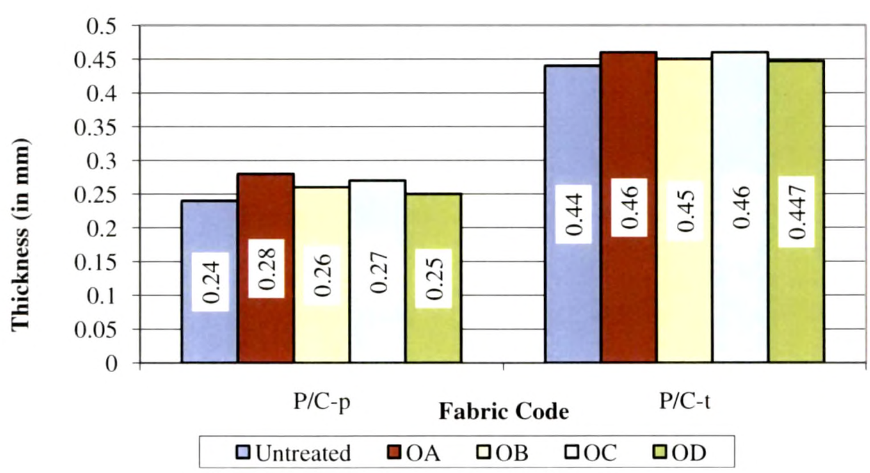
Wear properties of textile is important, as they influence the personal comfort of the user. Hence after the application of finishes on the fabrics, the wear properties of the fabrics were evaluated as per established standards

i) Thickness

The O_A an O_C treated fabrics were thicker as compared to the O_B and O_D treated fabrics. Both the combinations that had CMC showed an increase in thickness. (Table 4.29 and Graph 4.20)

Table 4.29: Thickness of the untreated and treated fabrics with finishes in combination

Treatments	Fabric code	
	P/C-p Thickness (mm)	P/C-t Thickness (mm)
Untreated	0.24	0.44
O_A	0.28	0.46
O_B	0.26	0.45
O_C	0.27	0.46
O_D	0.25	0.447



Graph 4. 20: Thickness of untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

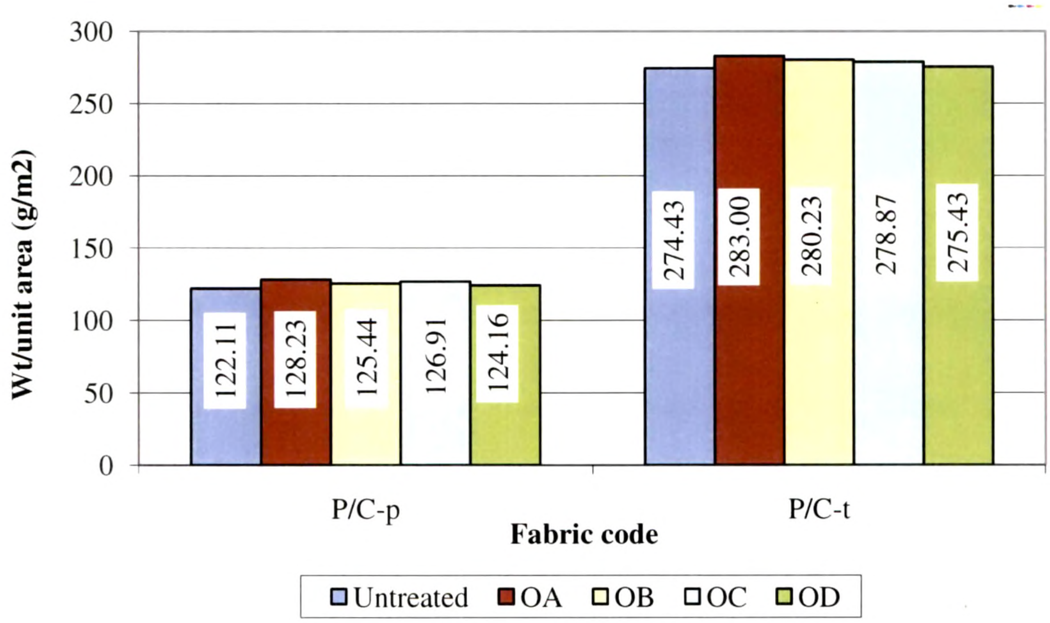
O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

ii) Weight per unit area

It was found that O_A an O_C treated samples weighed more than O_B and O_D treated fabrics. Here again the combinations with CMC showed higher weight per unit area.

Table 4.30: Weight per unit area of the untreated and treated fabrics with finishes in combination

Treatments	Fabric code	
	P/C-p Wt/unit area (g/m^2)	**P/C-t** Wt/unit area (g/m^2)
Untreated	122.11	274.43
O_A	128.23	283.00
O_B	125.44	280.23
O_C	126.91	278.87
O_D	124.16	275.43



Graph 4.21: Weight per unit area of untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

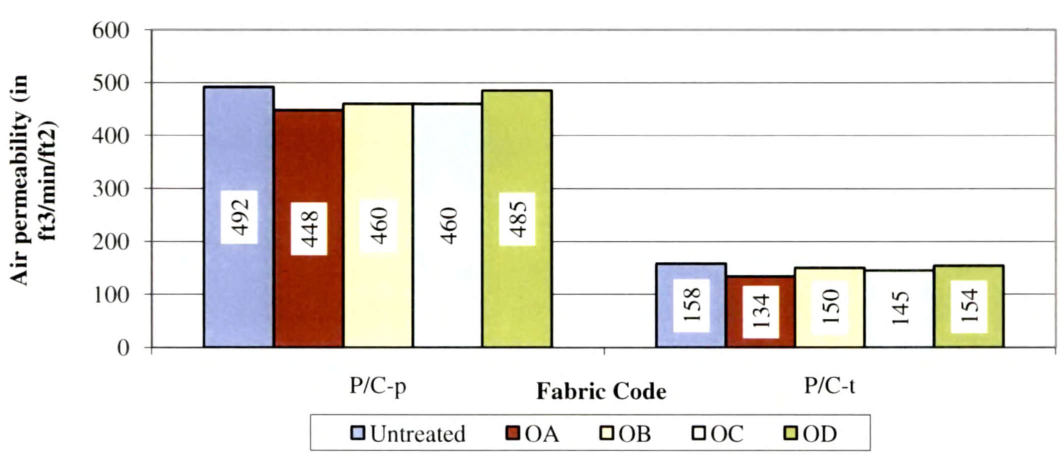
O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

iii) Air permeability

Air permeability is one of the important comfort properties. Higher readings indicate more air passage. Plain weave provides more permeability than twill. It was observed from the data in Table 4.31 and Graph 4.22 the air permeability of O_A treated plain and twill were less than the other treated fabrics.

Table 4.31: Air permeability of the untreated and treated fabrics with finishes in combination

Treatments	Fabric code	
	P/C-p Air permeability $ft^3/min/ft^2$	**P/C-t** Air permeability $ft^3/min/ft^2$
Untreated	492	158
O_A	448	134
O_B	460	150
O_C	460	145
O_D	485	154



Graph 4.22: Air-permeability of untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

iii) Bending length

The bending length of untreated and treated with finishes in combination in warp and weft directions is given in Tables.4.32 - 4.33.

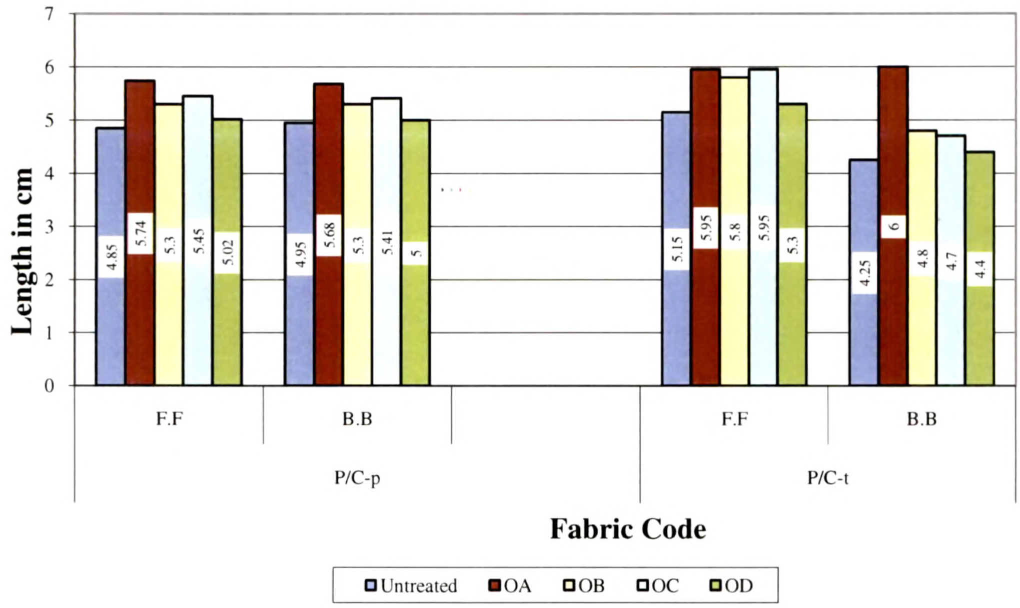
When fabrics are treated with finishes they would have an effect on the bending length due to the additional weight acquired by the fabric, which makes it stiffer.

Table 4.32 and Graph 4.23 showed variation in bending length of warp face to face and back to back readings of treated fabric with finishes in combination. In all the samples bending length is more in twill weave fabric as compared to plain weave. Maximum change in the bending length was seen in polyester/cotton twill weave fabric treated with O_A combination as compared with untreated (5.15 to 5.95 i.e. 22.68%) and in comparison to all the other combinations.

Table 4.32: Warp bending length of untreated and treated fabrics with finishes in combination on plain and twill weave

Treatments	P/C-p Bending length (cm)			P/C-t Bending length (cm)	
	F.F	**B.B**		**F.F**	**B.B**
Untreated	4.85	4.95		5.15	4.25
O_A	5.74	5.68		5.95	6.00
%Change	18.35	14.75		22.68	21.21
O_B	5.30	5.30		5.80	4.8
%Change	9.28	7.07		12.62	12.94
O_C	5.45	5.41		5.95	4.70
%Change	12.37	9.29		15.53	10.59
O_D	5.02	5.00		5.30	4.40
%Change	3.51	1.01		2.91	3.53

* The sign (-) before the digit indicates decrease in bending length.



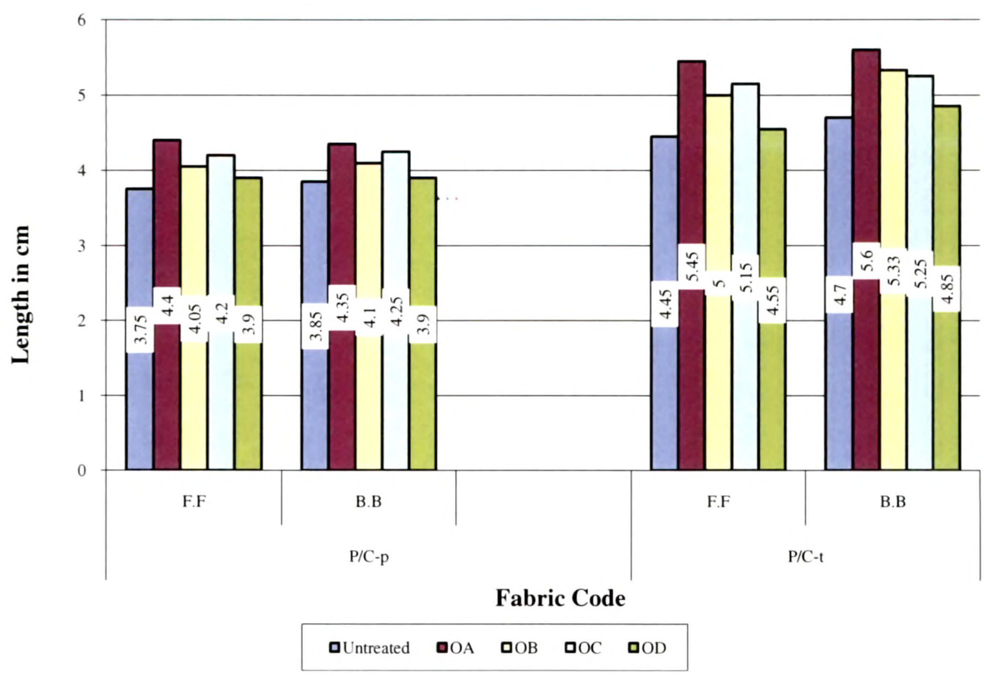
Graph 4.23: Warp bending length of untreated and treated fabrics with finishes in combination on plain and twill weave

Table 4.33: Weft bending length of untreated and treated fabrics with finishes in combination on plain and twill weave

Treatments	**P/C-p** Bending length (cm)		**P/C-t** Bending length (cm)	
	F.F	**F.F**	**F.F**	**B.B**
Untreated	3.75	3.85	4.45	4.7
O_A	4.40	4.35	5.45	5.60
%Change	17.33	12.99	22.33	19.15
O_B	4.05	4.10	5.00	5.33
%Change	8.00	6.49	12.23	12.77
O_C	4.20	4.25	5.15	5.25
%Change	12.00	10.40	15.70	11.70
O_D	3.90	3.90	4.55	4.85
%Change	4.00	1.30	2.25	3.19

* The sign (-) before the digit indicates decrease in bending length.

When bending length of warp and weft were analyzed, it was observed the fabrics face to face warp showed more stiffness. Here again the O_A and O_C combinations showed more bending length as compared to O_B and O_D combinations.



Graph 4.24: Weft bending length of untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

iii) Dry crease recovery angle of the fabrics

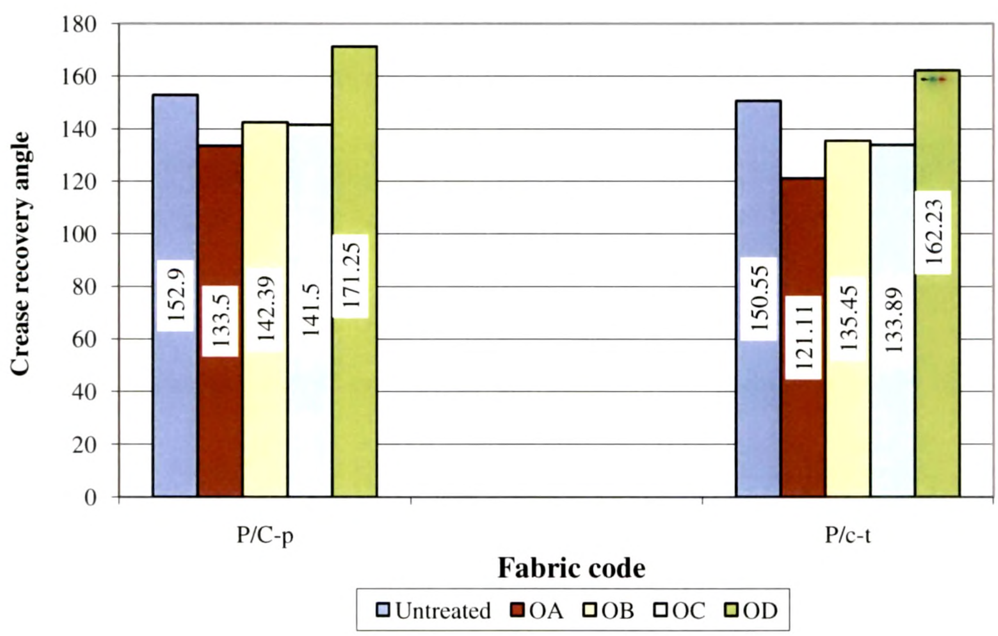
Dry crease recovery of the fabric depends on the type of finish applied, amount of weight gained, fiber content and fabric construction (weave). The dry crease recovery values of untreated and treated fabrics with finishes in combination on plain and twill weave were tabulated and given in Table 4.34 and compared in Graph 4.25.

The total crease recovery angles (TCRA) of untreated polyester/cotton plain fabrics in warp direction was lower than weft direction and in polyester/cotton twill weave fabric it showed an angle of 81^0 in warp than 69^0 in weft.

Table 4.34: Percent crease recovery angle of untreated and treated fabrics with finishes in combination

Treatments	P/C-p				P/C-t		
	Warp	Weft	TCRA		Warp	Weft	TCRA
Untreated	76.4	76.5	152.9		81.11	69.44	150.55
OA	68	65.5	133.5		68.89	52.22	121.11
% change			-12.69				-19.55
OB	70.83	71.56	142.39		71.45	64	135.45
% change			-6.87				-10.03
OC	70.95	70.56	141.5		78.89	55	133.89
% change			-7.46				-11.07
OD	84.97	86.28	171.25		85.56	76.67	162.23
% change			12				7.76

*** The sign (-) before the digits shows the decrease in Total crease recovery angle.**



Graph 4.25: Total crease recovery angle of the untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

In O_A treated polyester/cotton fabric in plain and twill weave TCRA reduced maximum as compared to other fabric treated with finishes in combination.

It was observed that highest TCRA was observed in O_D treated polyester/cotton plain weave fabric (171^0) and minimum was seen in O_A treated polyester/cotton plain weave fabric (121^0).

iv) Tensile strength of the fabrics

Tensile strength of fabrics reflects the characteristics of the fiber or fabrics from which they have been built up, modified according to methods used in their construction e.g. Twist, weave, physical and chemical finish.

Load elongation values of warp and weft were tabulated separately in Table 4.35 and 4.36.

Table 4.35: Warp-wise elongation (in cm) and Load (in Kg) of untreated and treated fabrics with finishes in combination

Treatments	P/C-p			P/C-t	
	Load	Elongation		Load	Elongation
Untreated	30.50	19.40		50.5	42.37
O_A	34.65	17.60		59.3	41.15
%Change	13.61			17.43	
O_B	29.75	20.70		50.00	42.40
%Change	-2.74			0.99	
O_C	32.00	18.97		53.85	42.25
%Change	4.95			6.63	
O_D	27.67	19.25		46.86	42.55
%Change	-9.25			-7.20	

* The sign (-) before the digits shows the decrease in Load

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

Warp: In warp direction O_A treated fabrics showed increase in load i.e. 13.61 kg and 17.43 kg in plain and twill weave respectively. Both the fabric showed increase and decrease in strength. In polyester/cotton twill weave fabric percent change were from-7.20 to 17.43. O_D treated twill weave fabric showed reduction in load. There was increase in elongation of O_B and O_D fabrics. This was attributed to the increase in elasticity of the fiber. Commercial soil-release finishes has softener, which increase the elasticity property of the fabric.(Graph 4.26 and 4.27)

Table 4.36: Weft-wise elongation (in cm) and Load (in Kg) of untreated and treated fabrics with finishes in combination

Treatments	P/C-p			P/C-t	
	Load	Elongation		Load	Elongation
Untreated	13.9	16.2		30.5	18.4
O_A	15.13	15.00		34.82	17.63
%Change	8.81			14.26	
O_B	13.76	16.60		30.88	18.80
%Change	-1.01			1.25	
O_C	14.08	16.10		31.50	18.0
%Change	1.26			3.28	
O_D	13.24	17.10		30.75	19.80
%Change	- 4.75			0.82	

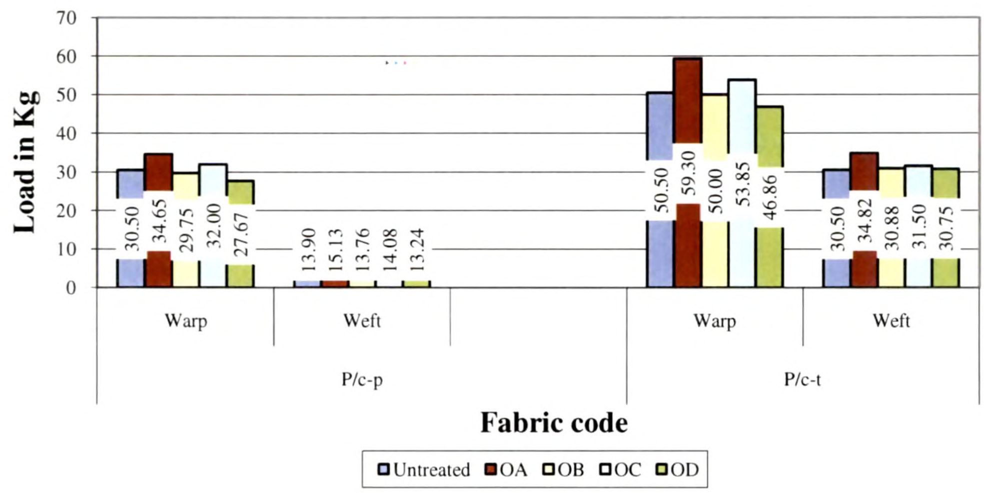
* The sign (-) before the digits shows the decrease in Load

Key:

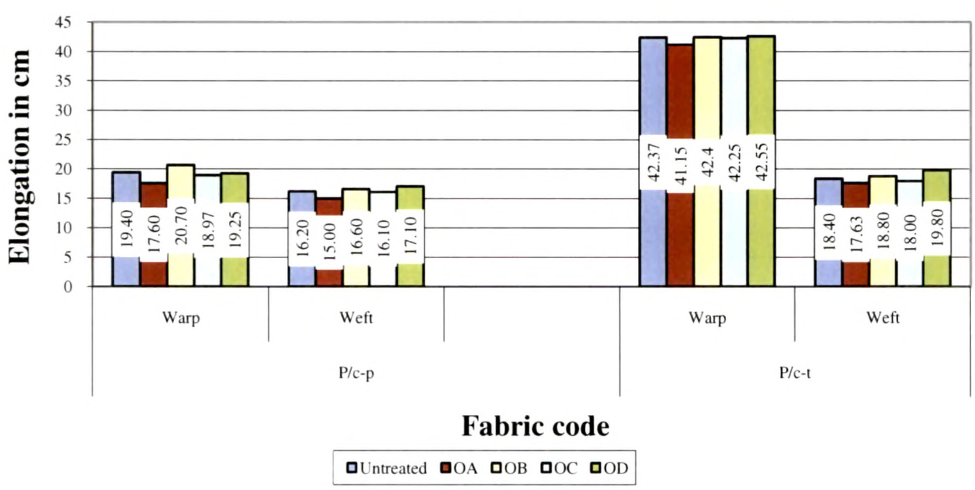
O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

Weft: Polyester/cotton plain weave finished fabric when compared to untreated fabric showed both increase and decrease in strength. Polyester/cotton plain and twill weave fabric with O_A showed increase of 8.81% and 14.26% respectively and polyester/cotton plain weave with OB and OD treatment showed decrease of 1.01% and 4.75%

respectively. There was increase in elongation in commercial soil-release finishes treated fabric.



Graph 4.26: Load in kg of the untreated and treated fabrics with finishes in combination on plain and twill weave



Graph 4.27: Elongation in cm of the untreated and treated fabrics with finishes in combination on plain and twill weave

Key:

O_A : Commercial UV absorber 1% add-on + carboxymethyl cellulose 1% add-on
O_B : Commercial UV absorber 1% add-on + commercial soil-release finishes
O_C : Acacia catechu dyed 4% shade+ carboxymethyl cellulose 1% add-on
O_D : Acacia catechu dyed 4% shade + commercial soil-release finishes.

The study of the wear properties have shown that the combination O_A (Commercial UV absorber1% + CMC 1%) gave the highest increase in thickness ,weight per unit area and stiffness and therefore maximum decrease in air permeability. The crease recovery was also minimum in fabrics treated with this combination and maximum decrease in tensile strength. This could be because the total add-on in this combination is 2% as compared to the others where the total was maximum 1%.

4.4. Theoretical costing of the fabrics treated with the four finish combination

If the treated fabrics are to be used for clothing of the outdoor worker it would be useful to see the commercial viability of these protective fabrics. Keeping this in mind the theoretical cost per liter of the finishes in combination was calculated.

The market price of the ingredient used in the recipes for the various treatments has been given in Table 4.37. The theoretical costing has been calculated according to the amounts that have been used in the recipes given in the chapter material and methods. The calculated price per liter has been shown in Table 4.38.

Table 4.37: Market price of individual finishes and auxiliaries

Chemical Name	**Rs per Kg**
Commercial UV absorber 'A'	450 /-
Urea	270/-
Soda ash (Sodium carbonate)	230/-
Commercial UV absorber 'B'	100/-
Commercial Auxiliary 'A'	65/-
Commercial Auxiliary 'B'	200/-
Acacia catechu	280/-
Alum (Aluminum potassium sulphate)	240/-
CMC (Carboxymethyl Cellulose)	800/-
Commercial soil-release finish 'C'	1600/-
Commercial soil-release finish 'D'	75/-
Commercial Auxiliary 'C'	1157/-
Commercial Auxiliary 'D'	156/-
$MgCl_2$(Magnesium chloride)	220/-
Isopropyl Alcohol	580/-

Table 4.38: Theoretical cost of the four combinations of finishes

Combination code	Commercial UV absorber (U_A) 1% add-on	Acacia catechu (U_D) 4% shade	Commercial soil-release finishes (S_{AB})	CMC (S_C)1% add-on	Total cost (Rs.)
O_A	41/-			16/-	57/-
O_B	41/-		26/-		67/-
O_C		35/-		16/-	51/-
O_D		35/-	26/-		61/-

Charge of the electricity consumed = Rs 2 per kg

It is seen from the Table 4.38 that the prices was almost similar for all the four combination. The cost of the O_C (Acacia catechu + CMC) combination is least among four combinations of finishes and this combination gave best protection against UV rays and soiling as well as wear properties as compared to other combinations.

4.5. Determination of fibre surface characteristics of treated fabrics using scanning electron microscope.

The SEM permits the observation of materials in macro and submicron ranges. The instrument is capable of generating three-dimensional images for analysis of topographic features. To compare the morphological characterization of cotton, polyester and polyester/cotton blend twill weave fabric before and after the application of various treatments, images were got from SEM, Joel JSM-5610V.

SEM Studies of polyester/cotton plain and twill weave untreated and treated fabrics

Scanning Electron Micrographs of all the five categories (*1. Untreated P/C,* O_A : UV absorber at 1% add-on + carboxymethyl cellulose at 1% add-on, O_B : UV absorber at 1% add-on + commercial soil-release finishes, O_C : Acacia catechu dyed at 4% shade+ carboxymethyl cellulose at 1% add-on, O_D : Acacia catechu dyed at 4% shade + commercial soil-release finishes) of fabrics were taken at 15v x 2000 to analyze the changes occurring in the fibre surface characteristics.

Polyester/Cotton (P/C) twill weave fabrics:

When fabric is treated with UV absorber at 1% add-on + carboxymethyl cellulose at 1% add-on (O_A) (Plate 4.5.b.), it shows modification in the surface area of fibrous structure (layer of starch and starch globules were present).

It was observed from these micrographs that in combination of UV absorber at 1% add-on + commercial soil-release finishes (O_B) fabric (Plate 4.5.c.), the samples shows shiny needle like attachment on the fiber surface as compared to that of untreated P/C twill sample (Plate 4.5.a.). In the combination of dyed with Acacia catechu at 4% shade+ carboxymethyl cellulose at 1% add-on (O_C) on fabric (Plate 4.5.d.) showed the accumulation of layer of starch along with starch globules. In case of P/C twill weave fabric dyed with Acacia catechu at 4% shade + commercial soil-release finishes (O_D) (Plate 4.5.e.) shows some globules attached to the fibrous structure.

Polyester/Cotton (P/C) plain weave Fabrics:

Plate 4.6. shows the SEM images of untreated and various treated P/C- plain weave fabrics. The treated fabric with UV absorbers + CMC on fabric (O_A and O_C) (Plate: 4.6.b. and 4.6.d) showed the accumulation of layer of starch along with starch globules. Treated

fabrics with UV absorbers + commercial soil-release finish (O_B and O_D) 4.6.c. and 4.6.e. fabric, a few smaller particles were seen in both the treated fabric but in the case of O_B treated fabric shiny needle particles were also seen on the surface of the commercial UV absorber and commercial soil-release finishes treated fabrics.

Thus, the modifications in the fibrous structure by application of Acacia catechu, commercial U.V absorber, commercial soil-release finish and CMC finishes, in case of cotton, polyester, and polyester/cotton blend fabric had certain bearing on the improvement of UPF and soil release values.

Cotton twill weave fabrics:

The ribbon and fibrils of the untreated cotton fiber (Plate-4.7.a.) could be observed clearly by SEM, whereas the surface of the treated cotton fiber. The images of SEM showed a smooth coating with a continuous thin layer when treated with commercial soil-release finish (Plate 4.7.c.) and a thick layer with CMC (Plate 4.7.b.), with no cracks on the layers.

Polyester twill weave fabrics:

From the SEM images of the treated fabrics (Plate 4.8.a and 4.8.b) it was seen that the thickness of the CMC treated fabric was more as compared to commercial soil-release treated fabric. SEM image shows that the surface of the treated polyester fibers was smoother, indicating the homogenous distribution of both the soil-release finishes on the fabric.

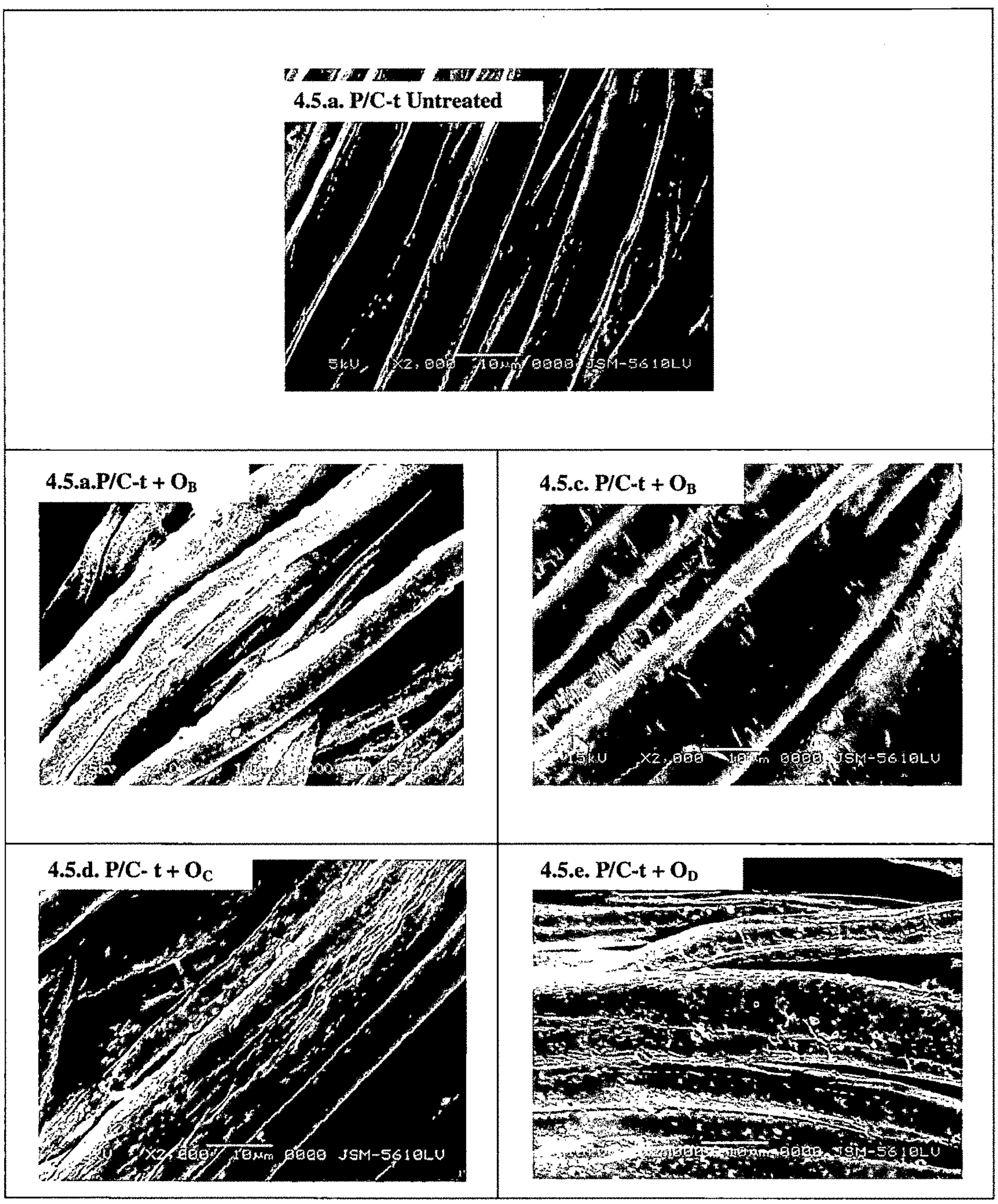


Plate 4.5. S.E.M images of polyester/cotton twill weave fabric with combination of finishes

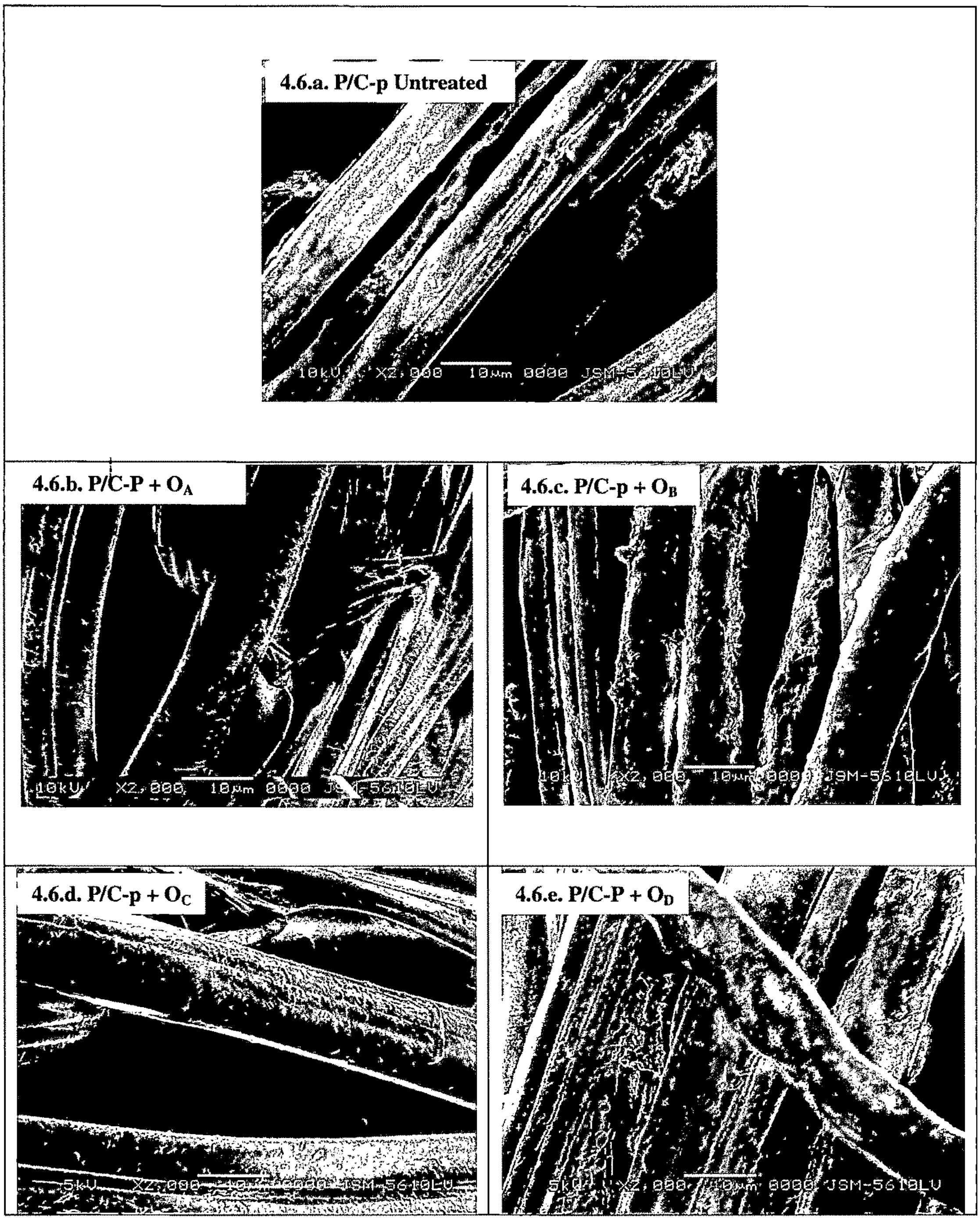


Plate 4.6. S.E.M images of polyester/cotton plain weave fabric with combination of finishes

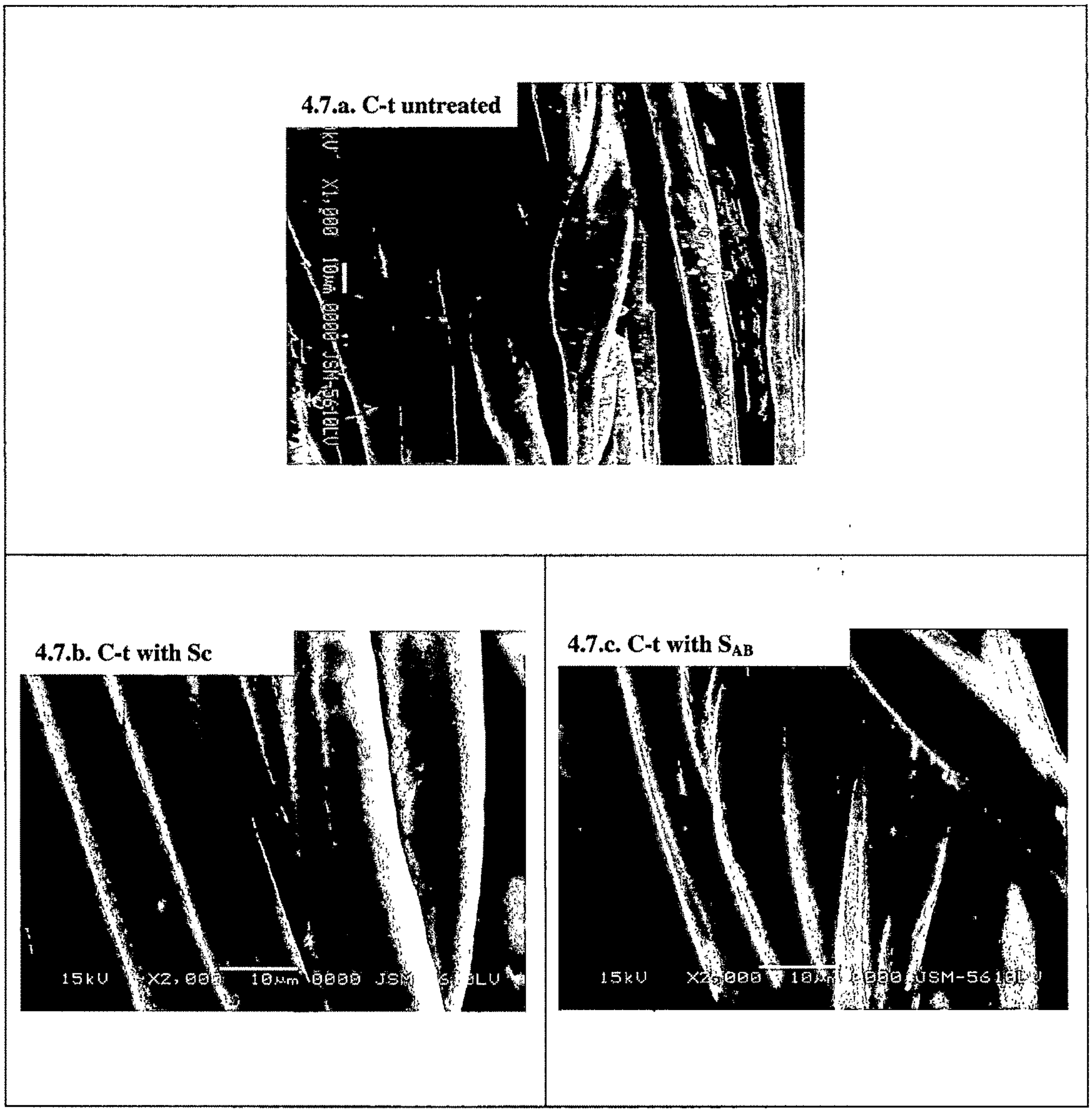


Plate 4.7. S.E.M images of cotton twill weave fabric with soil-release finishes

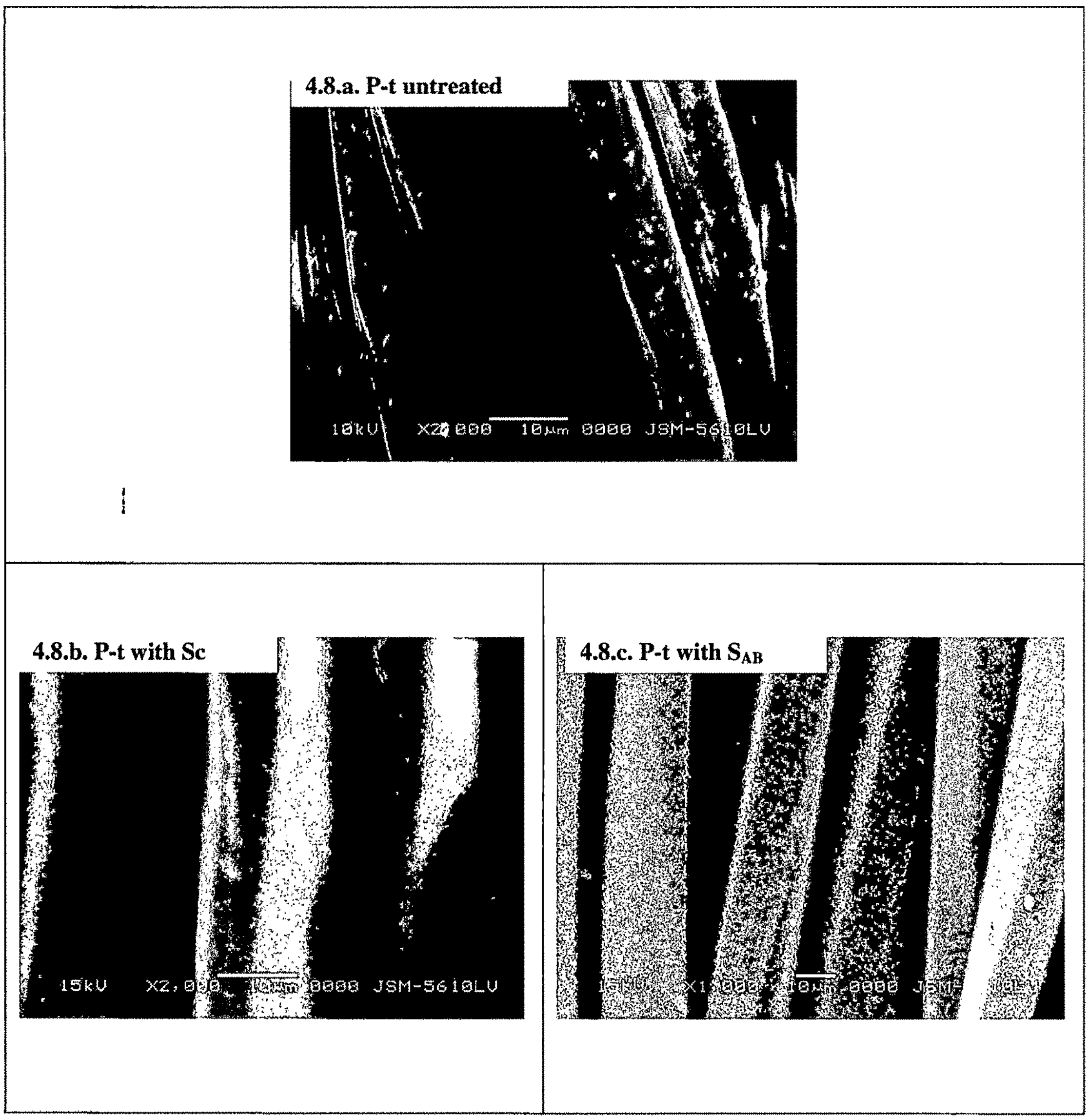


Plate 4.8. S.E.M images of polyester twill weave fabric with soil-release finishes

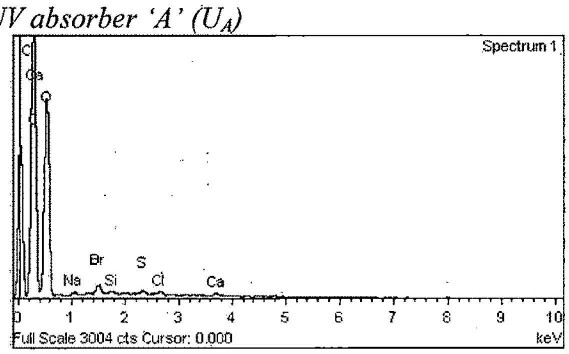
4.6. E.D.S. analysis of the finished samples with UV absorbers and soil-release.

EDS is an analytical technique which utilizes x-rays that are emitted from the specimen when bombarded by the electron beam to identify the elemental composition of the specimen. The E.D.S analysis was undertaken for the present study to see whether the elements in the finishing recipes were present in permissible limits as well as to identify the composition of the finishing recipes used for the work.

Commercial UV absorber treated cotton and polyester fabrics

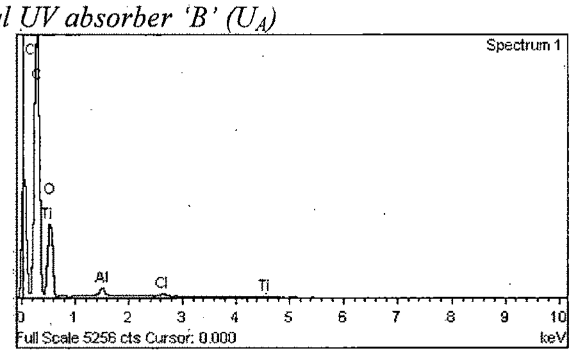
Cotton fabric treated with commercial UV absorber 'A' (U_A)

Element	Weight%	Atomic%
C	47.17	55.04
O	50.45	44.19
Na	0.30	0.18
Si	0.13	0.07
S	0.32	0.14
Cl	0.25	0.10
Ca	0.23	0.08
Br	1.15	0.20
Total	100.00	



Polyester fabric treated with commercial UV absorber 'B' (U_A)

Element	Weight%	Atomic%
C K	61.70	68.55
O K	37.11	30.95
Al K	0.66	0.33
Cl K	0.26	0.10
Ti K	0.27	0.08
Totals	100.00	



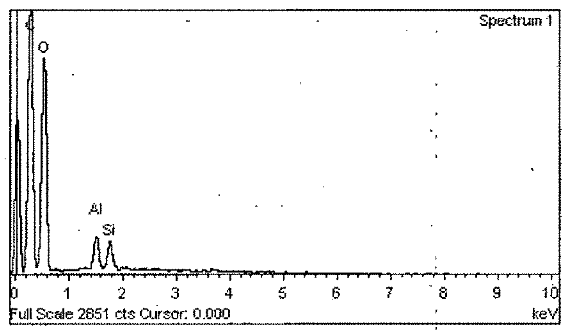
Commercial UV absorber 'A' treated cotton fabric shows higher peak of calcium element along with carbon and oxygen. Sodium was present as soda ash was used in the recipe. Silicon, Sulphur, Calcium, Chlorine and Bromine are present. Bromine was there in very negligible amount.

Titanium was detected in commercial UV absorber 'B' polyester fabrics. Titanium impart UV absorber property in polyester fabric.

Acacia Catechu dyed cotton and polyester fabrics

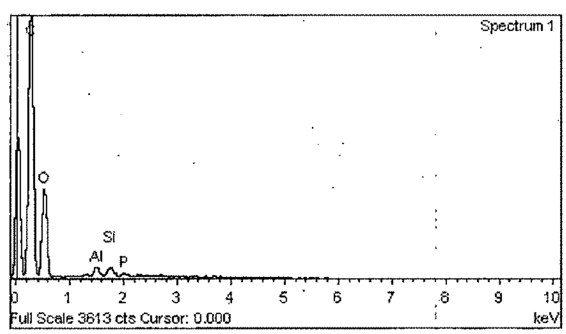
Cotton fabric dyed with Acacia Catechu (U_D)

Element	Weight%	Atomic%
C	46.56	54.40
O	49.95	43.82
Al	1.84	0.96
Si	1.65	0.82
Total	100.00	



Polyester fabric dyed with Acacia Catechu(U_D)

Element	Weight%	Atomic%
C K	58.99	66.10
O K	39.36	33.11
Al K	0.75	0.37
Si K	0.69	0.33
P K	0.22	0.09
Totals	100.00	



It can be seen that the aluminum (Al) and silicon (Si) are clearly separate elemental phases other than carbon (C) and Oxygen (O) in Acacia Catechu dyed cotton fabric.

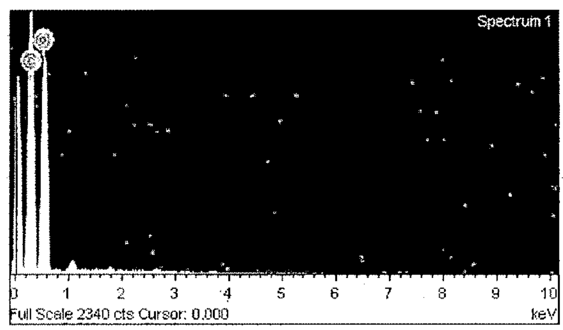
Aluminum (Ai), Silicon (Si) and Phosphorus (P) elements are seen in acacia catechu dyed polyester fabrics.

For dyeing alum was used as a mordant hence silicon element may be present in the Acacia Catehu dye. All the elements present in the Acacia Catehu dyed samples were in very negligible amount.

CMC treated cotton and polyester fabrics

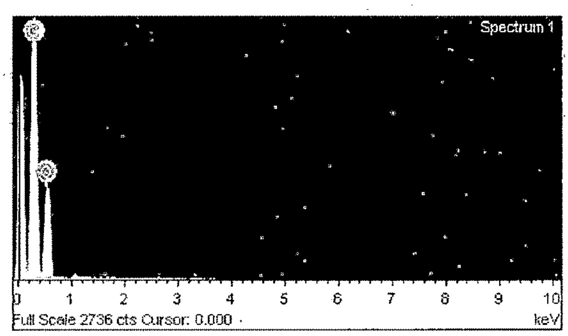
Cotton fabric treated with CMC (S_C)

Element	Weight%	Atomic%
C	44.60	51.75
O	55.40	48.25
Total	100.00	



Polyester fabric treated with CMC (S_C)

Element	Weight%	Atomic%
C	57.46	64.28
O	42.54	35.72
Total	100.00	

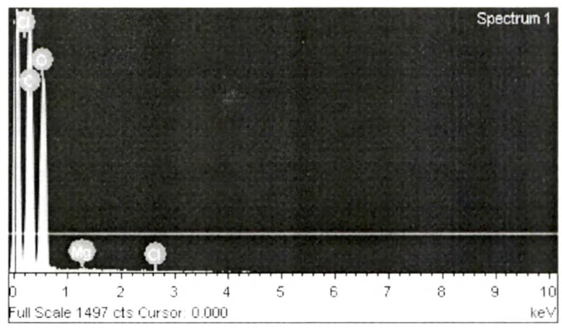


C.M.C treated cotton and polyester fabrics confer the presence of only carbon and oxygen.

Commercial soil-release treated cotton and polyester fabrics

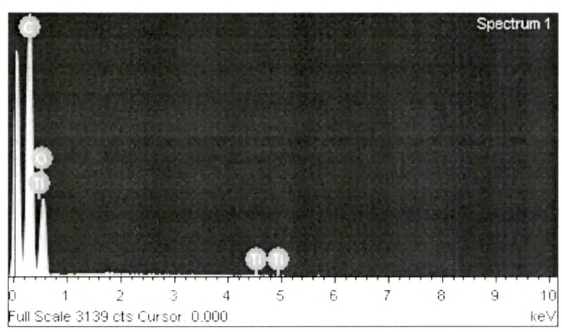
Cotton fabric treated with commercial soil-release finish (S_{AB})

Element	Weight%	Atomic%
C	46.18	53.38
O	53.64	46.54
Mg	0.07	0.04
Cl	0.10	0.04
Total	100.00	



Polyester fabric treated with commercial soil-release finish (S_{AB})

Element	Weight%	Atomic%
C	60.42	67.15
O	39.28	32.77
Ti	0.29	0.08
Total	100.00	



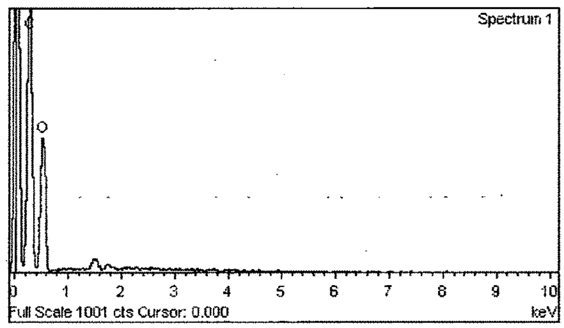
Chlorine (Cl) and magnesium (Mg) are detected along with carbon (C) and Oxygen (O) in commercial soil-release finished cotton element, this may be because of Magnesium Chloride was used in the recipe.

Commercial soil-release treated polyester fabrics showed the presence of titanium but in negligible amount.

E.D.S analysis of untreated and treated Polyester/cotton blend fabric with four combination finishes

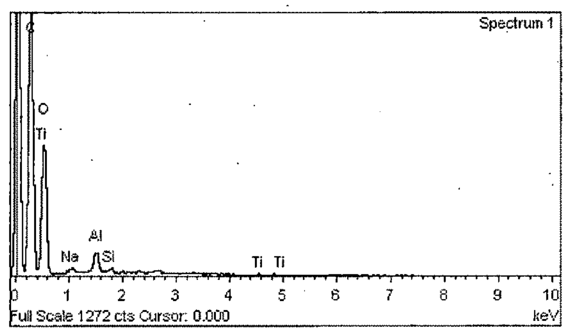
Polyester/Cotton twill untreated

Element	Weight%	Atomic%
C	51.94	59.01
O	48.06	40.99
Total	100.00	



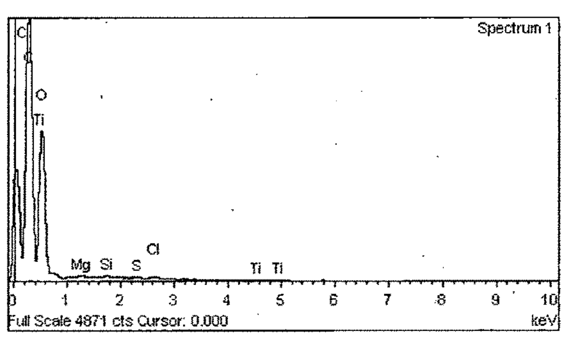
Polyester/Cotton fabric with commercial UV absorber + CMC (O_A)

Element	Weight%	Atomic%
C	53.19	60.70
O	44.48	38.10
Na	0.48	0.29
Al	1.53	0.78
Si	0.21	0.10
Ti	0.11	0.03
Total	100.00	



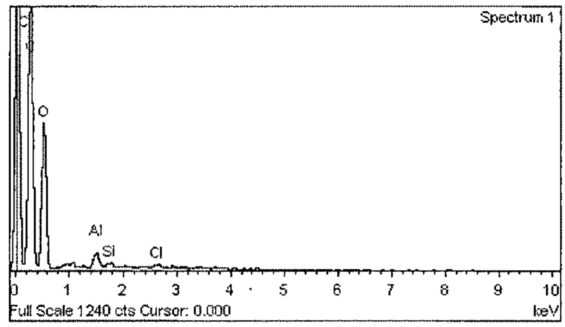
Polyester/Cotton fabric with commercial UV absorber + commercial soil-release finish 'C' and 'D' (O_B)

Element	Weight%	Atomic%
C	47.67	54.98
O	51.63	44.71
Mg	0.11	0.06
Si	0.19	0.10
S	0.17	0.07
Cl	0.22	0.09
Ti	0.01	0.00
Total	100.00	



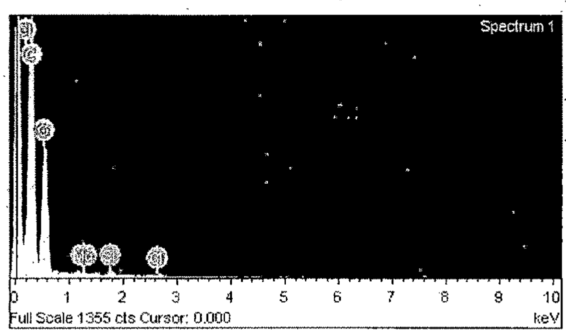
Polyester/Cotton fabric dyed with Acacia Catechu + CMC (O_C)

Element	Weight%	Atomic%
C	51.61	59.05
O	46.78	40.18
Al	0.98	0.50
Si	0.29	0.14
Cl	0.34	0.13
Totals	100.00	



Polyester/Cotton fabric dyed with Acacia Catechu + commercial soil-release finish 'C' and 'D' (O_D)

Element	Weight%	Atomic%
C	52.24	59.45
O	47.06	40.22
Mg	0.13	0.07
Si	0.38	0.18
Cl	0.19	0.08
Total	100.00	



Polyester/cotton untreated fabric when compared with the four combination treated fabrics shows the presence of various elements which were not seen in untreated fabric.

O_A treated fabric shows sodium, silicon, sulphur and titanium elements in them. In O_B treated fabrics shows the presence of magnesium, silicon, sulphur, chlorine and titanium

Aluminum, silicon and chlorine were seen in polyester/cotton treated with O_C. In the fabrics treated with the fourth combination O_D, presence of magnesium, silicon, and chlorine was detected.

It was seen from the EDS analysis that all the elements found in the finishes were in permissible limit.

The four combinations of finishes used for the study individually and in combination were effective in providing protection from ultraviolet radiation and soiling without altering the wear properties.