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A Novel Approach in Single Stage Combined Bleaching and Protease Enzyme Treatments on Wool Fabrics

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Abstract: Today's scenario of textile wool industry has been radically changed to use ecofriendly chemicals and enzymes in preparatory and finishing processes due to pollution in the process of chemical treatments. In this research work, a single stage combined bleaching and biopolishing treatment technique for wool fabric was carried out by using acid and alkaline protease enzymes to analyse degradation of wool fabrics. The wool fabrics used were woven wool fabric which undergoes different treatment techniques like bleaching and acid protease, bleaching and alkaline protease, only bleaching treatment, only acid protease and only alkaline protease. The treated wool fabric samples at various process conditions were tested for their low stress mechanical properties such as tensile, shear, bending, compression, and surface. These test results were analyzed and their significant differences in terms of multivariant ANOVA analysis using Design Expert software 8.0 were reported. This novel technique has the ideal effect on wool textile in terms of better softness, weight loss, bending, shear, compression, and tensile strength. Because of mild reaction conditions of alkaline protease enzyme with hydrogen peroxide combined preparatory technique for wool textile treatment would be a promising and prospective method in bioprocessing of wool fabrics.

Keywords: Wool fabric, Alkaline protease, Acid protease, Biopolishing, Low stress mechanical properties and bleaching

Introduction

Wool fiber is a natural protein fiber made of different amino acids joined by a peptide bond [1]. The cuticular layer is the outer surface of the wool fiber and made of flat, irregular horny scales which overlap with the projecting edges pointing towards the fiber tip [2]. The cortex constitutes main portion or body of the wool fiber. It consists of long, slightly flattened spindle shaped cells [3,4]. As an oxidizing agent, hydrogen peroxide (H_2O_2) in an aqueous alkaline medium favors the formation of the unstable perhydroxy (HO_2) species that transfers oxygen [5,6]. Under bleaching conditions, disulfide bond is attacked and, theoretically, the disulfide oxidation products from ruptured -S-S- bonds are cysteic acid and intermediate sulfoxides [7]. This process renders the surface of wool susceptible to enzyme attack. The bleaching with H_2O_2 processes with protease enzyme, and the selectivity of these processes to remove wool's hydrophobic layer and form an anionic surface charge while causing scale smoothing to achieve shrinkage control [8]. Protease enzymes specifically act on the peptide bonds of proteins and hydrolyze [9]. This reduces the protein chain length, and complete hydrolysis yields free amino acids [10,11]. Proteases are known to reduce the felt shrinkage of wool fabrics. Disulphide bond splitting owing to an oxidative or sulfite pretreatment of wool opens up the wool fiber surface more, and consequently the enzymatic attack on the cuticle can be selectively activated [12]. As a consequence of oxidative pretreatments, the wettability of wool increases, and thus the effectiveness of polymers used for shrink-proofing are improved.

In the enzymatic treatments of wool to control shrinkage, hydrolytic attack must be limited to the fiber surface for selective scale (cuticle) modification without permeation into the fiber's cortex, the stress-bearing constituent [13,14]. Generally H_2O_2 is applied to break the surface layer and outer layer of the scaly layer; then, acid protease, acid cellulose, and alkaline protease are added to degrade inner layer and outer layer in order to peel off the scaly layer of wool fiber effectively [15]. Enzymatic treatment of textiles has also been of great interest because of its effectiveness under mild treatment conditions [16]. The perceived drawback to their use is the production of absorbable organic halogens. Chlorination for shrinkage control is generally associated with chemical degradation with fiber erosion to minimize fiber movements when wool is agitated in aqueous solutions. Alternative systems relying on peroxide acids with or without enzymes are now under investigation [14-17]. In the past, oxidation, halogenations, alcoholysis, or enzyme treatments have been used for partial or complete modification or removal of the cuticular surface scales of wool to improve shrinkage resistance, luster, and softness. The oxidation of wool's disulfide bonds to sulfonic acid is the most important reaction in shrinkage resistance [18]. Chlorination for shrinkage control is generally associated with chemical degradation with fiber erosion to minimize fiber movements when wool is agitated in aqueous solutions [19]. It becomes imperative to study the possibility of combined bleaching and biopolishing of wool textile [20-23]. In this study, wool fabrics are treated with bleaching agent and acid protease, bleaching and

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alkaline protease, only with bleaching agent, only with acid protease, and only with alkaline protease, and the effect on low stress mechanical properties of the wool fabrics have been studied.

Experimental

100 % woven wool fabric was purchased from M/s. Himachal Emporium, Shimla, Himachal Pradesh, India and wool fabric particulars are 36 ends per inch, 56 picks per inch, 31 tex as warp, 29.5 tex as weft, 17.09 cloth cover factor and 364 g/m^2 fabric mass. The chemicals and enzymes were supplied by M/s. Resil Chemicals Pvt Ltd., Tirupur. Table 1 show the chemicals and enzymes used for treating the wool fabrics. The methods adopted for treating the wool fabric was five different enzyme treatments and their process specifications are given in Table 2. The detailed process conditions for treating wool fabrics with five different process conditions are shown in Figures 1-5.

Kawabata Evaluation System (KES)

The low stress mechanical properties of wool fabrics such as tensile, bending, shear, compression, and surface properties are tested using a Kawabata Evaluation System (KES) instrument. Table 3 shows the low stress mechanical properties tested for wool fabrics.

Tensile Property

The wool fabric of sample size (20 cm×20 cm) is clamped and extension is applied up to a maximum load of 5 N/cm as per the settings of a KES-FB1 tester. Rate of tensile strain is 0.004/s. This deformation mode is much easier to use than simple uniaxial extension for theoretical property prediction.

Table 1. Details of chemicals and enzymes

Sample no.	Chemicals and enzymes	Concentration (g/*l*)
1	Bleaching agent (H_2O_2)	40
2	Wetting agent (CWLF)	2.0
3	Acid cellulase (DPEZ 214)	0.15
4	Soaping agent (DW)	0.3
5	Acid protease (MITOZYME FL)	0.15
6	Alkaline protease (ALKALI BATE EX)	0.15
7	Softening agent (ULTRAFAB HCS)	20
8	Softening agent (NANO CELLE G6)	20
9	Enzyme degradation ($NaHSO_3$)	10
10	Neutralizing agent (Acetic acid)	0.5

Table 2. Wool fabric treatment conditions

Sample code	Treatments
S1	H_2O_2+Acid protease+Acid cellulase
S2	H_2O_2+Alkaline protease
S3	H_2O_2
S4	Acid protease+Acid cellulase
S5	Alkaline protease

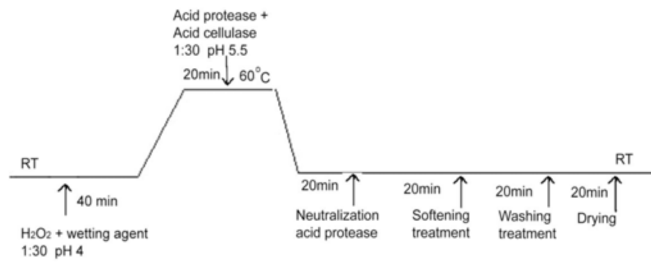

Figure 1. Wool fabric (S1) combined treatment with hydrogen peroxide; acid protease and acid cellulose.

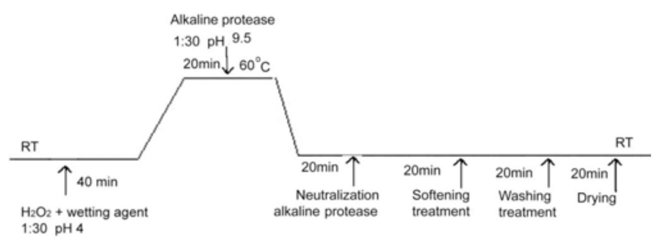

Figure 2. Wool fabric (S2) combined treatment with hydrogen peroxide and alkaline protease.

Figure 3. Wool fabric (S3) treatments with hydrogen peroxide.

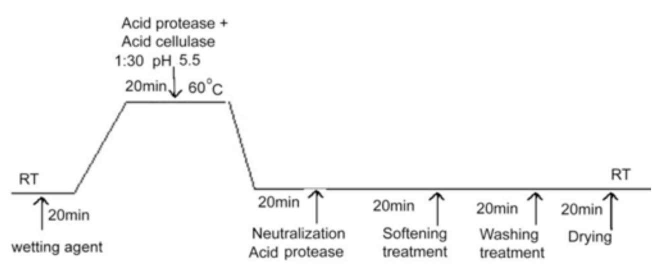

Figure 4. Wool fabric (S4) treatments with acid protease and acid cellulose.

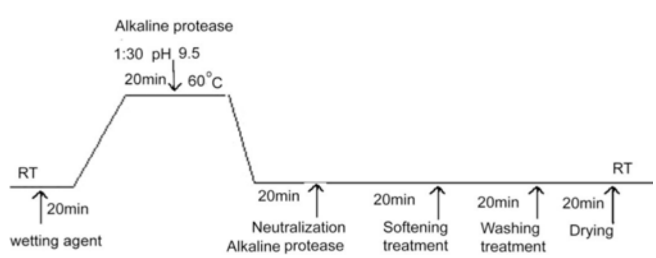

Figure 5. Wool fabric (S5) treatments with alkaline protease.

Table 3. Low stress mechanical and surface properties

Parameters	Description	Unit
LT	Linearity of load/extension curve	None
WT	Tensile energy	N/m (gf cm/cm^2)
RT	Tensile resilience	%
G	Shear stiffness	N/m deg (gf/cm degree)
2HG	Hysteresis of shear force at 0.5 degrees of shear angle	N/m (gf/cm)
2HG5	Hysteresis of shear force at 5 degrees of shear angle	N/m(gf/cm)
LC	Linearity of compression/thickness curve	None
WC	Compressional energy	N/m (gf/cm^2)
RC	Compressional resilience	%
MIU	Coefficient of friction	None
MMD	Mean deviation of coefficient of friction (frictional roughness)	None
SMD	Geometrical roughness	μm

Shear Property

A rate of shear strain of 0.00834/s is applied under a constant extension load 10 N/m up to a maximum shear angle of 8 degrees as per the settings of the KES-FB1 tester.

Compression Property

A fabric specimen is compressed in the direction of thickness to a maximum pressure of 50 gf/cm^2, at a constant velocity, 20 μm/s as per the settings of the KES-FB1 tester.

Surface Property

Surface geometrical smoothness and frictional smoothness of wool fabrics are measured. The contact surface of the frictional sensor is 10 parallel piano wires 0.5 mm in diameter, and the surface shape is similar to that of a human fingerprint. A weight is used to apply 0.5 N (50 gf) contact force during measurement as per the settings of the KES-FB1 tester.

Tensile Strength Test

The tensile strength of the wool fabric was determined using a cloth tensile strength tester which works under the principle of constant rate of extension.

Stiffness Test

The stiffness characteristics of wool fabric samples are tested using a Shirley stiffness tester. The wool fabric flexural rigidity and bending modulus were calculated using following formula.

$$\text{Fabric flexural rigidity } (G),\ \mu\text{Nm} = M \times C^3 \times 9.807 \times 10^{-6} \quad (1)$$

where

M: fabric weight per square area (g/m^2)

C: fabric bending length (mm)

Table 4. Tensile, shear, compression, and surface test results

Properties \ Fabric samples	S1	S2	S3	S4	S5	Grey fabric
Tensile						
LT	0.759±0.012	0.805±0.017	0.803±0.013	0.757±0.021	0.743±0.017	0.845±0.011
WT	14.90±0.60	18.80±1.20	18.80±0.90	20.50±1.44	20.30±0.53	9.73±0.62
RT%	57.55±1.03	53.91±0.73	50.40±0.69	50.22±1.21	55.30±0.80	53.89±0.78
EM%	7.84±0.93	9.29±1.07	9.48±0.73	10.97±0.89	10.95±0.83	4.60±0.70
Shear						
G	0.56±0.02	0.59±0.03	0.54±0.06	0.47±0.04	0.56±0.02	0.69±0.04
2HG	0.95±0.30	1.17±0.21	0.99±0.18	0.98±0.32	1.09±0.20	2.94±0.27
2HG5	1.45±0.28	1.71±0.29	1.41±0.22	1.34±0.30	1.55±0.21	3.49±0.20
Compression						
LC	0.353±0.018	0.373±0.021	0.408±0.019	0.384±0.023	0.421±0.017	0.416±0.016
WC	0.759±0.023	0.867±0.032	0.999±0.024	0.662±0.028	0.820±0.025	0.770±0.021
RC%	48.75±0.98	45.79±0.87	50.05±0.92	50.91±1.02	50.61±0.89	44.16±0.81
Surface						
MIU	0.307±0.04	0.225±0.002	0.133±0.003	0.272±0.001	0.255±0.004	0.441±0.002
MMD	1.193±0.018	1.219±0.020	1.033±0.015	1.094±0.022	0.878±0.017	1.625±0.016
SMD	5.394±0.812	6.53±0.790	3.834±0.596	2.154±0.621	2.775±0.816	6.544±0.439
Bending						
B	0.0132±0.0016	0.0061±0.0011	0.0067±0.0010	0.0121±0.0014	0.0079±0.0012	0.0379±0.0018
2HB	0.0143±0.0019	0.0054±0.0010	0.0059±0.0010	0.0137±0.0017	0.0068±0.0010	0.0212±0.0016

$$\text{Bending modulus } (BM),\ \text{N/m}^2 = 12 \times G \times 10^3/T^3 \quad (2)$$

where

G: flexural rigidity, μNm

T: fabric thickness (mm)

Results and Discussion

The low stress mechanical properties and handle value of fabrics were produced from fabric sample S1-S5 and were compared with grey fabric. The results obtained from KES-FB instruments are listed in Table 4.

Effect on Tensile Properties of Wool Fabric

After treatments with acid protease and alkaline protease enzymes with and without hydrogen peroxide bleaching process, the test results of the low stress mechanical characteristics of these enzyme treated wool fabrics are analyzed and results are given in Table 4. From the test results, it was observed that the linearity of load elongation (*LT*) curve was found maximum for grey wool fabric with 0.845 and minimum for fabric S5 with 0.743, because the wool fabric S5 was treated with alkaline protease enzyme that causes higher hydrolysis and weight loss upto 4.72 %. The smaller values of linearity of stress-strain curve make the fabric softer and more extensible in the small region, which is related to wearing comfort. The tensile energy (*WT*) for fabric S4 and S5 was found to be 20.50 and 20.30 respectively, which are higher than other fabrics; it may be due to enzyme treatment of wool fabric without bleaching. The higher value of *WT* corresponds to lower extensibility. The tensile resiliency % is higher for fabric S1 with 57.55 % and minimum for fabric S4 with 50.22 % due to enzyme treatment of fabric with bleaching and without bleaching treatments. Extensibility (*EMT* %) is maximum for fabric S4 with 10.97 % and minimum for fabric S1 with 7.84 % when compared with treated samples alone. This is because fabric S1 is treated with both enzyme and bleaching agent but other sample is treated only with enzymes. Table 5 shows multivariant ANOVA analysis of tensile properties of wool fabrics treated at various condition S1-S5 and their tensile values are compared with grey sample and between treatment conditions. From the ANOVA analysis, wool fabric effect on linear tensile strength in various sample treatments conditions and their significant differences are shown at $F_{(2,29)\text{actual}} > F_{\text{critical}}$ using Design Expert Software 8.0. It may be due to enzyme hydrolysis of the peptide groups on surface of the wool fiber and it causes weight loss of fabric up to 4.72 % [9].

Effect on Shear Properties of Wool Fabric

The shear properties of wool fabric treated with acid and alkaline protease enzymes using KES-FB1 and their test results are given in Table 4. The value of *G* is found to be maximum for grey fabric with 0.69 and minimum for fabric S4 with 0.47, since the fabric is enzyme treated. The hysteresis of shear force at 0.5 degree of shear angle is found to be maximum for grey fabric with 2.94 and minimum for fabric S1 with 0.95, since the fabric S1 is treated with both bleaching agent and enzyme. The hysteresis of shear force at 5 degree of shear angle is found to be maximum for grey fabric with 3.49 and minimum for fabric S4 with 1.34, since the fabric S4 is treated with enzyme alone. Table 6 shows the significant differences of wool fabric treated at various conditions (S1-S5) and compared with grey fabric for analyzing the shear properties.

Table 5. Multivariant ANOVA analysis of tensile properties

Source of variance	F	P-value	F_{crit}	Significance
LT				
Between S1 and S4	4.749	0.0208	3.178	S
Between S1 and grey fabric	4.478	0.0284	3.178	S
Between S4 and grey fabric	4.234	0.0379	3.178	S
Between S2 and S5	4.592	0.0249	3.178	S
Between S2 and grey fabric	3.754	0.0312	3.178	S
Between S5 and grey fabric	4.913	0.1730	3.178	S
Between S2 and S3	4.440	0.0881	3.178	S
WT				
Between S1 and S4	4.527	0.021	3.178	S
Between S1 and grey fabric	4.781	0.034	3.178	S
Between S4 and grey fabric	3.542	0.027	3.178	S
Between S2 and S5	2.641	0.024	3.178	NS
Between S2 and grey fabric	3.245	0.031	3.178	S
Between S5 and grey fabric	3.752	0.054	3.178	S
Between S2 and S3	2.458	0.021	3.178	NS
RT%				
Between S1 and S4	2.524	0.034	3.178	NS
Between S1 and grey fabric	4.215	0.042	3.178	S
Between S4 and grey fabric	3.568	0.034	3.178	S
Between S2 and S5	2.458	0.021	3.178	NS
Between S2 and grey fabric	2.452	0.036	3.178	NS
Between S5 and grey fabric	3.425	0.087	3.178	S
Between S2 and S3	1.568	0.214	3.178	NS
EM%				
Between S1 and S4	3.246	0.034	3.178	S
Between S1 and grey fabric	3.457	0.021	3.178	S
Between S4 and grey fabric	3.253	0.096	3.178	S
Between S2 and S5	3.045	0.044	3.178	NS
Between S2 and grey fabric	3.458	0.021	3.178	S
Between S5 and grey fabric	5.241	0.042	3.178	S
Between S2 and S3	2.425	0.067	3.178	NS

S: significant, NS: not significant.

Table 6. Multivariant ANOVA analysis of shear properties

Source of variance	F	P-value	F_{crit}	
G				
Between S1 and S4	1.254	0.011	3.178	NS
Between S1 and grey fabric	3.258	0.034	3.178	S
Between S4 and grey fabric	3.264	0.028	3.178	S
Between S2 and S5	2.136	0.114	3.178	NS
Between S2 and grey fabric	4.562	0.361	3.178	S
Between S5 and grey fabric	5.214	0.057	3.178	S
Between S2 and S3	1.247	0.052	3.178	NS
2*HG*				
Between S1 and S4	2.064	0.024	3.178	NS
Between S1 and grey fabric	4.526	0.031	3.178	S
Between S4 and grey fabric	3.261	0.058	3.178	S
Between S2 and S5	2.634	0.014	3.178	NS
Between S2 and grey fabric	3.684	0.024	3.178	S
Between S5 and grey fabric	3.197	0.058	3.178	S
Between S2 and S3	2.561	0.124	3.178	NS
2*HG*5				
Between S1 and S4	1.684	0.024	3.178	NS
Between S1 and grey fabric	6.234	0.031	3.178	S
Between S4 and grey fabric	5.241	0.027	3.178	S
Between S2 and S5	2.640	0.052	3.178	NS
Between S2 and grey fabric	3.648	0.069	3.178	S
Between S5 and grey fabric	4.527	0.052	3.178	S
Between S2 and S3	2.680	0.034	3.178	NS

Table 7. Multivariant ANOVA analysis of compression properties

Source of variance	F	P-value	F_{crit}	Significance
LC				
Between S1 and S4	2.581	0.014	3.178	NS
Between S1 and grey fabric	4.526	0.275	3.178	S
Between S4 and grey fabric	4.007	0.314	3.178	S
Between S2 and S5	2.864	0.218	3.178	NS
Between S2 and grey fabric	5.314	0.016	3.178	S
Between S5 and grey fabric	4.521	0.624	3.178	S
Between S2 and S3	2.854	0.021	3.178	NS
WC				
Between S1 and S4	2.451	0.031	3.178	NS
Between S1 and grey fabric	4.025	0.112	3.178	S
Between S4 and grey fabric	4.147	0.024	3.178	S
Between S2 and S5	3.869	0.051	3.178	S
Between S2 and grey fabric	3.695	0.011	3.178	S
Between S5 and grey fabric	2.869	0.096	3.178	NS
Between S2 and S3	3.068	0.102	3.178	NS
RC%				
Between S1 and S4	1.058	0.034	3.178	NS
Between S1 and grey fabric	5.621	0.027	3.178	S
Between S4 and grey fabric	4.520	0.014	3.178	S
Between S2 and S5	2.061	0.152	3.178	NS
Between S2 and grey fabric	4.025	0.364	3.178	S
Between S5 and grey fabric	3.691	0.142	3.178	S
Between S2 and S3	2.514	0.241	3.178	NS

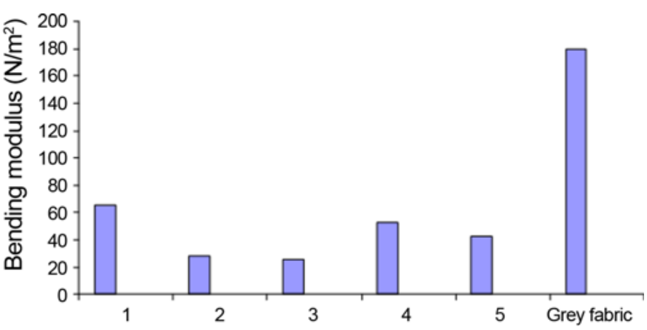

Figure 6. Bending modulus of the fabric (warp way).

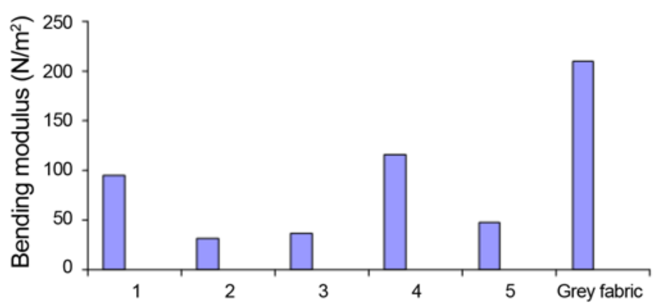

Figure 7. Bending modulus of the fabric (weft way).

Effect on Compression Properties of Wool Fabric

The compression properties of wool fabric treated with acid and alkaline protease enzymes using KES-FB3 and their test results are given in Table 4. The linearity of compression-thickness curve (*LC*) is found to be maximum for grey fabric and minimum for fabric S1 which reveals that fabric S1 is extremely non linear which is shown in Figure 9. The compressional energy (*WC*) is maximum for fabric S3 and minimum for fabric S4 since the fabric is enzyme treated. The compressional resistance (*RC*%) is higher for fabric S4 with 50.91 and minimum for fabric S2 with 45.79 which is shown in Figure 8. Table 7 shows the significant differences of wool fabric treated at various conditions (S1-S5) and compared with grey fabric for analyzing the compressional properties.

Effect on Surface Properties of Wool Fabric

The surface properties of wool fabric treated with acid and alkaline protease enzymes using KES-FB4 and their test

Figure 8. Wool fabric (s2) treated with alkaline protease enzyme.

Figure 9. Wool fabric (s1) treated at acid protease and cellulase enzyme.

Table 8. Multivariant ANOVA analysis of surface properties

Source of variance	F	P-value	F_{crit}	Significance
MIU				
Between S1 and S4	4.526	0.024	3.178	S
Between S1 and grey fabric	3.561	0.028	3.178	S
Between S4 and grey fabric	3.564	0.031	3.178	S
Between S2 and S5	5.630	0.037	3.178	S
Between S2 and grey fabric	4.089	0.112	3.178	S
Between S5 and grey fabric	3.850	0.028	3.178	S
Between S2 and S3	4.231	0.114	3.178	S
MMD				
Between S1 and S4	2.568	0.321	3.178	NS
Between S1 and grey fabric	5.631	0.024	3.178	S
Between S4 and grey fabric	4.529	0.011	3.178	S
Between S2 and S5	2.164	0.014	3.178	NS
Between S2 and grey fabric	3.684	0.025	3.178	S
Between S5 and grey fabric	3.245	0.092	3.178	S
Between S2 and S3	3.890	0.037	3.178	S
SMD				
Between S1 and S4	3.074	0.002	3.178	NS
Between S1 and grey fabric	3.624	0.041	3.178	S
Between S4 and grey fabric	3.480	0.078	3.178	S
Between S2 and S5	2.985	0.056	3.178	NS
Between S2 and grey fabric	5.024	0.038	3.178	S
Between S5 and grey fabric	5.620	0.041	3.178	S
Between S2 and S3	4.529	0.027	3.178	S

results are given in Table 4. The maximum value of *MIU* is for grey fabric with 0.441 and minimum for fabric S3 with 0.133. The maximum value of *MMD* is for grey fabric with 1.625 and it is minimum for fabric S5 with 0.878. The maximum value of *SMD* is for grey fabric with 6.544 and minimum for fabric S4 with 2.154. Table 8 shows the

Table 9. Multivariant ANOVA analysis of bending properties

Source of variance	F	P-value	F_{crit}	Significance
B				
Between S1 and S4	1.658	0.024	3.178	NS
Between S1 and grey fabric	5.241	0.036	3.178	S
Between S4 and grey fabric	3.648	0.011	3.178	S
Between S2 and S5	1.452	0.561	3.178	NS
Between S2 and grey fabric	5.645	0.024	3.178	S
Between S5 and grey fabric	4.257	0.031	3.178	S
Between S2 and S3	2.651	0.089	3.178	NS
2*HB*				
Between S1 and S4	2.564	0.032	3.178	NS
Between S1 and grey fabric	5.145	0.024	3.178	S
Between S4 and grey fabric	4.235	0.011	3.178	S
Between S2 and S5	2.684	0.017	3.178	NS
Between S2 and grey fabric	3.634	0.024	3.178	S
Between S5 and grey fabric	3.851	0.063	3.178	S
Between S2 and S3	2.564	0.024	3.178	NS

significant differences of wool fabric treated at various conditions (S1-S5) and compared with grey fabric for analyzing the surface properties.

Effect on Bending Properties of Wool Fabric

The bending moduli of the treated and grey fabrics are shown in Figures 6 and 7, which are for warp and weft, respectively. Bending modulus is found using the stiffness tester and it is found that the fabric when treated with alkali protease enzyme showed a substantial decrease on its stiffness property compared to grey fabric. From Figures 6 and 7, it was noticed that the fabric treated with alkali protease showed a drastic reduction in its stiffness. When the bending modulus is very high, it makes the fabric rigid and will have a high resistance to bending. On treatment with alkali protease the bending modulus is reduced and hence the fabric's handle property is also improved. Table 9 shows the significant differences of wool fabric treated at various conditions (S1-S5) and compared with grey fabric for analyzing the bending properties of wool fabrics.

Conclusion

A combined process for bleaching and biopolishing was carried out by treating the wool fabric with hydrogen peroxide and protease enzymes. Effective protease enzyme treatment to change surface and the physical properties of fabric in terms of low stress mechanical characteristics such as tensile, shear, compression, and bending has been studied and analyzed. The research work highlights the potential for wool pretreatments by sufficiently modifying the wool surface in order to obtain shrink resistance. The grey fabric and alkaline protease treated wool fabric was noticed extremely non linear. The tensile energy for grey and acid protease enzyme treated wool fabrics was found maximum which corresponds to lower extensibility. The tensile resiliency was noticed maximum for fabric combined bleached and alkaline enzyme treated wool fabric which corresponds to good elasticity. The shear stiffness was noticed maximum for grey and acid protease treated wool fabric. Linearity of compression is lower for combined bleached and acid protease treated fabric when compared to alkaline protease treated wool fabric which corresponds to linearity. In case of compressional energy and compressional resilience was also noticed maximum for acid and alkaline protease treated fabric which corresponds to higher compressibility and elasticity. Coefficient of friction was found higher for grey and acid protease treated fabric which corresponds to lower friction. Geometrical roughness was found low for alkaline treated fabric which corresponds to lower geometrical rough surface. Percentage of weight loss of wool fabric was noticed higher in alkaline protease enzyme treatments with combined bleaching. There was no significant difference found in bending stiffness test for combined bleached and enzyme treated wool fabric between acid and alkaline protease enzymes. The thickness of the wool fabric was decreased for combined bleached and acid protease treated fabric, which may be due to higher hydrolysis and weight loss of fabric. The breaking strength and elongation were found to be lower for combined bleached and alkaline protease enzyme treated on wool fabric when compared to acid protease enzyme treated fabric. It is concluded that the combined bleaching and biopolishing treatment of wool fabrics with alkaline protease enzyme can be a viable technique for wool industry. The research work can be further extended by studying wool blended fabrics, wool knitted fabrics, and different treatment techniques with different concentration of protease enzymes.

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