Introducing Old-look, Soft Handle, Flame Retardant, and Anti-bacterial Properties to Denim Garments Using Nano Clay

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ABSTRACT
In this paper, nano clay as a novel garment finishing technique termed "nano-washing," was applied to cotton denim garments and compared with conventional washing involving amylase and cellulase. Color changes of the garment samples were investigated by using a reflectance spectrophotometer and the garment surfaces were observed by Scanning Electron Microscopy. Air permeability, crease recovery angle, bending strength, abrasion resistance, thermal properties, and antibacterial activity of the treated samples were investigated and reported. It was found that treatment of denim garment with nano clay produced old look garment with soft handle, enhanced thermal and rubbing or washing fastness properties. Overall, this novel nano-washing process on the denim garment was an easy, economical, and simple method with a great deal of advantages.

Keywords: Denim; Nano clay; Soft handle: Old-look; Thermal property; Antibacterial Activity

INTRODUCTION
Denim fabric, having a serge weave and being highly dense, is woven with blue indigo warp and white or tinted weft yarns. Various methods; such as rinse washing, bleaching, sand blasting, moon washing, stone washing, scrubbed-look washing, damaged-look washing, and over dyed-look washing [1-4]; are used in industrial washing and finishing of denim. These methods impart a beautiful and new appearance to denim garments.

Denim fabric, unlike other textile materials, is put in the hands of consumers in the form of garments and washed end-products. These washing systems have two main objectives. The first is to obtain a faded color, and the second is to obtain a soft handle with some special effects such as surface-polishing, water-repelling, antimicrobial finishing [5-7].

The abrasive action is carried out using pumice stone in rotary drum washing machines, with or without any oxidant agent, such as potassium permanganate. This leads to discoloration and can reduce fabric strength to an authorized limit. The stonewashing effect on denim can be attained using acidic and neutral cellulase, alone or along with pumice stone. The use of cellulase along with mechanical action results in the bio polishing of the garment and does not reduce of fabric strength considerably [8, 9]. With increased cellulase concentration, the brightness (lightness), color change, and back-staining are increased. Back-staining depends upon pH and type and concentration of the enzyme [10- 11].

Based on this study, it was clear that desizing, desizing/cellulase, desizing/cellulase/bleaching, and desizing/cellulase/stone washing resulted in good moisture management capacity of the treated denim [12].

Air permeability, bending stiffness, strength and crease ability of the denim garment treated with different industrial methods were investigated. The use of softener resulted in a decrease in air permeability and bending rigidity. Chlorinated bleaching and enzymatic methods decreased strength and increased crease ability [2, 13, and 14].

Card el al reported that the main processes in washing and finishing of denim garment include desizing, biowashing/stonewashing with pumice stone, discoloration, neutralization, enzyme deactivation, treatment with optical brightener and soaping [15].

Laminar silicates are referred to as natural clay soils. Silicate layers like magadiite, mika, saponite, fluorohectorite, and montmorillonite. Montmorillonite include silicate, magnesium, aluminum, calcium, and sodium. Clays have many applications in textiles and are widely-used for making clay nano composites as fillers [16-18]. Organo silicates have a great influence on mechanical properties of polymers. As the clay content increases, the tensile strength, modulus, and stiffness also increases. Modification of montmorillonite and increasing of its weight percentage in composites were reported to enhance the thermal properties (TGA) of composites [19, 20].

Natural fibers contain hydrophilic groups, oxygen, and required nutrition which provides a very favorable medium for the growth of microorganisms. Denim as a cellulosic substrate with a very high moisture adsorption is prone for the growth of bacteria. Antimicrobial agents in textiles are mainly used to control the growth of bacteria, fungi, molds, and algae; and they also prevent problems such as rotting, stain ability and odor. Currently, attempts to attain antimicrobial textiles are substantially increasing. Many nano metallic particles have an effect on microbes; the inner protein molecules of microbes react with metal particles and as a result the microbe will be killed. Metals such as copper, zinc, cobalt, and silver are used as antimicrobial agents [21-23]. The antimicrobial properties of four clay minerals intercalated by quaternary phosphonium salt (tetradecyl tributyl phosphonium bromide, TDTB) were studied. According to the results antimicrobial activity of organ-clay minerals depended on three factors: the released amount of TDTB, surface charge, and particle size of organ-clay minerals. It is shown that antimicrobial activity was the synergic effect of the three factors. Mt -TDTB exhibited the highest antimicrobial activity, due to its amount of organic antimicrobials released [24].

There are various methods for denim stonewashing including conventional method using pumice stone and novel methods using enzymes, laser and plasma; in addition, a combination of these can also be applied. In this paper, a denim washing process with nano clay was investigated and interesting results, including old-look with enhanced thermal resistance, handling, and color fastness were reported and subsequently analyzed.

EXPERIMENTAL

Materials and Instrument

The denim fabric (blue jean) used was 100 % cotton with twill 2/1 weave construction, weft and warp count of 8 Ne with z twist, weft density of 20/cm, warp density of 26/cm, and fabric weight of 322 g/m^2. In order to prepare experimental garment samples of 20×30 cm^2 sewed from sides. A piece of white woven cotton pocket, with 26/cm of weft and warp density was sewed as the backside pocket with weft yarn count of 20 Ne and warp yarn count of 15 Ne and fabric weight of 166 g/m^2 (*Figure 1-a*).

The chemicals used were: 70% acetic acid, dispersing agent (Super jean) combined with polyacrylate and alkyl phosphate purchased from Alkemi Inc., Turkey, with nonionic structure to prevent back-staining, anti-creasing agent, Alkasol Ac combined with nonionic polyacrylamide purchased from Alkemi Inc., Turkey, to prevent creasing in fabric as anti-creasing agent in biowashing, nano washing and desizing process. Enzymes used in this research were neutral cellulase (Denimax XT), acid cellulase (Denimax 992 L), and alpha amylase (Aquazym® XT-L) respectively with activities of 1600 DAU/g (Dyed Avicel Units), 750 ECU/g (Endo Cellulase Units) and 120 1000 NDU/g (Novozymes Desizing Unit) from Novozymes Co., Denmark. The clay used was Cloisite® 10A made of modified Montmorillonite with quaternary ammonium with typical dry particle sizes:(10% less than 2μm, 50% less than 6μm, and 90% less than 13μm) from SCP, U.S.A. In order to simulate the industrial denim washing, a rotary drum washer with 100 g or 3 L capacity, steel basket, 25 r.p.m, with temperature control along with 7 heavy dense plastic balls to create mechanical pressure and abrasion was used (*Figure 1-b*).

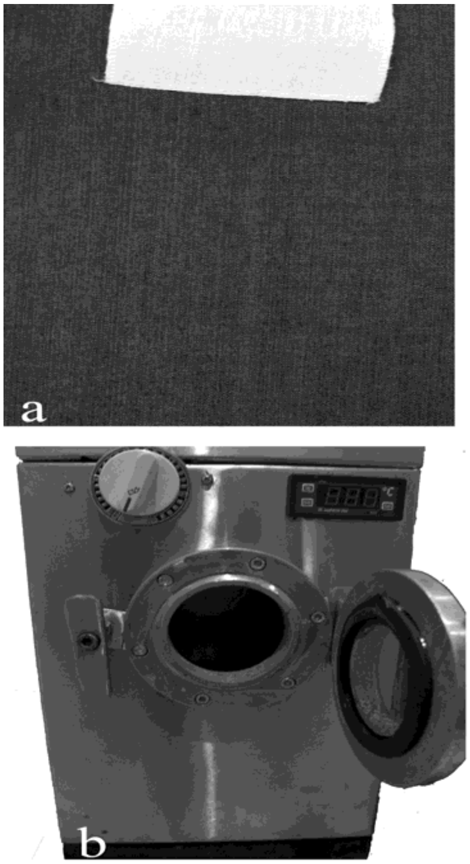

FIGURE 1. Denim garment sample (face and back) with white pocket on the back (a) and image of drum washer (b).

To determine spectrometric reflection values, a Datacolor spectrophotometer was used, and color values were calculated at 10° and D65. Each sample was composed of three parts: face of the sample, back of the sample, and white pocket. In order to prevent any possible errors, color data were gathered five times. Mean values of lightness (L*), redness-greenness (a*), yellowness-blueness (b*), and color difference with desized sample (ΔE) were reported. In addition, the whiteness index (W) for the white pocket and back of the fabric, along with the value of staining, were recorded. Wash-fastness tests were carried out according to ISO 105-CO2:1998(E). Rubbing fastness was evaluated according to AATCC Test Method 8-2004. The color difference (ΔE) with references samples was obtained with a Datacolor spectrophotometer.

0.5 × 0.5 cm^2 pieces of fabric were cut out and then covered with gold using a sputter coater machine from BAL-TEC Co., model SCD00S, Switzerland. Microscopic images were taken from each sample using an SEM from Philips, Netherlands, model XL30.

The abrasion resistance was carried out by a Martindale instrument from Shirley Devices (S.D.L) with 10,000 rounds according to ASTM D4966. The weight of samples was calculated before and after abrasion. Percent weight loss was calculated according to Eq. (1), where G is the weight loss percent, W1, the initial weight before treatment and W2, the weight after treatment.

$$G = \frac{W_1 - W_2}{W_1} \times 100 \quad (1)$$

Each denim sample was cut to 2.5×5 cm^2, and the crease recovery angle was measured according to AATCC 66-2003. For each sample, these experiments were repeated three times, and the average was reported.

The air permeability of the fabrics was measured using a Shirley Devices (S.D.L) under 100 Pa pressure according to ASTM D7371.

For evaluating the stiffness properties of fabrics, samples of 2.5×20 cm^2 were prepared in the warp direction. Bending rigidity of samples was measured using a Shirley Bending Length apparatus (Shirley Developments Limited, England), according to ASTM D 1388-96 and Eq. (2), where G is the bending rigidity (mg.cm), M fabric weight (g/cm^2) and C, average bending length (cm).

$$G = 10^{-3} MC^3 \quad (2)$$

Selected samples were thermally analyzed according to ISO IEC 17025 standard at 30°C to 800°C with rate of 10 °C/min using a Thermal Analysis System apparatus, model Pyris-1 (Perkin Elmer Co., U.S.A) with rate of 10 °C/min. Limited Oxygen Index (LOI) was determined by a Qualitest 3612 (China) according to ASTM D 2863.

Selected samples were exposed to X-rays by an XRD device from Siemens. Co, D5000 with lamp Cu ka at 40 kV/ 20 Ma.

Quantitative experiments were conducted according to AATCC 100-2004, using Gram-positive *Staphylococcus aureus*, Gram-negative *Escherichia coli* and *Candida albicans* fungi. In this method, the number of colonies of bacteria was counted according to colony forming unit. (CFU) and the decrease in microbial agents (C) were determined using Eq. (3).

$$C = \frac{M_1 - M_2}{M_1} \times 100 \quad (3)$$

Where $M_1$is the number of colonies in control microbial suspension and M_2 is the number of colonies existing in the suspension after being co-located adjacent to treated samples.

EXPERIMENTAL METHODS

Desizing with Amylase

Samples were desized using 3 g/L of amylase for 15 min, at pH 7 and 70^o C. In all experiments the L:G (Liquor to Goods Ratio) was 40:1, dispersing agent 3g/L, and anti-creasing agent 5 g/L.

Washing with Neutral and Acidic Cellulase

One desized sample was treated with 10 g/L of neutral cellulase at pH 7 and 55^oC for 1 h (**Nc**) and another desized sample was treated with 10 g/L acidic cellulase at pH 5.5 and 55oC for 1 h (**Ac**).

Washing with Nano Clay in Neutral and Acidic Media

One desized sample was treated with 30% nano clay on weight of garment at pH 7, 60^oC (L) for 1 h coded (**D C N**). A second desized sample was treated with 30% nano clay at pH 5, 60°C for 1 h coded (**D C A**). Both were rinsed at pH=7 and 60°C for 10 min (five times).

The dispersion of the nano clay particles in denim washing was stabilized by using a dispersing agent and mechanical action by the drum washer.

RESULTS AND DISCUSSION

Color Changes

The results of chromaticity indexes, color changes, and whiteness of samples treated with cellulases and nano clay in acidic and neutral media are illustrated in *Table I*. The L* values of sample face show that the enzymatic process increased the lightness compared to the desized sample.

TABLE I. The Colorimetric Properties of face, back, and white pocket of treated denim garments with nano clay.

Sample	Face		Back	White pocket	
	L*	ΔE	b*	b*	W
Desized	21	0	-4.2	4.9	31.5
Nc	23.2	2.2	-5.5	2.4	30.5
Ac	22.3	1.3	-5.4	2.9	31.3
D C N	28.8	6.8	-3.3	5.6	36.9
D C A	29.4	7.6	-3.6	5.1	41.4

The results also show that L* values (lightness) of samples treated with nano clay were higher than samples treated with cellulases. However, the L* values of nano clay in acidic media were higher than that treated in neutral media,

Thus, desized sample treated with nano clay in acidic media was lighter than the sample treated with nano clay in neutral media because of the higher absorbance properties of clay in acidic media and increased contact surface. Overall, nano clay was efficient in discoloration of the desized sample, and acidic media was more effective. Therefore, nano clay, as a silicate absorbent, can be said to absorb indigo dye from the denim surface (based on physical discoloration on dyed surface fabric).

The b* values for the back of samples show that nano clay caused a decrease in back staining. The back staining on the samples treated with nano clay was lower than the samples treated with cellulases. The L* values for the back of treated samples with nano clay increased and were higher than cellulases-treated samples. Samples treated with nano clay in the acidic media were discolored more with decreased backstaining and increased lightness. The b* values of pocket and back of treated samples with cellulases indicated higher back staining than desized samples.

The W values show that the whiteness of white pocket of enzymatic treated garments decreased and became blue as the b* value increased. Nano clay in the washing process changed the values of b*of white pocket to positive value. Nano clay was more effective than cellulases in lowering of staining on white pocket and even discolored denim garment surface. Whiteness index values show that nano clay improved the whiteness of white pocket and also produced a whiter pocket than those samples treated with cellulases and desized samples. Although, samples treated with nano clay in acidic media were whiter than neutral media. On the other hand, in comparison to cellulase, using nano clay decreased pocket staining and even removed the indigo from the garment surface. The W value of white pocket showed that acidic media made the pocket whiter than neutral. The surface area of nano clay in acidic media was increased which indicates that clay treatment in acidic media is effective.

SEM Images

Microscopic pictures of treated fiber surfaces are shown in *Figure 2*. The fiber surfaces can be clearly observed on the untreated sample (desized denim), and they are unchanged (*Figure 2-a*). It can be seen on samples treated with cellulases (*Figure 2-b*) that the surface of outer fibers was damaged and some fibers were broken. However, inner fibers seem to have been unchanged and without damage. In other words, during bio washing only surface fibers of outer fibers were damaged and inner fibers were not affected. The picture of the sample treated with nano clay (*Figure 2-c*) shows that the fibers on the surface also remained unchanged and were not damaged by nano washing. Also the clay particles settled on the fibers surface and penetrated into fibers layers and were distributed more appropriately compared to the biowashing samples.

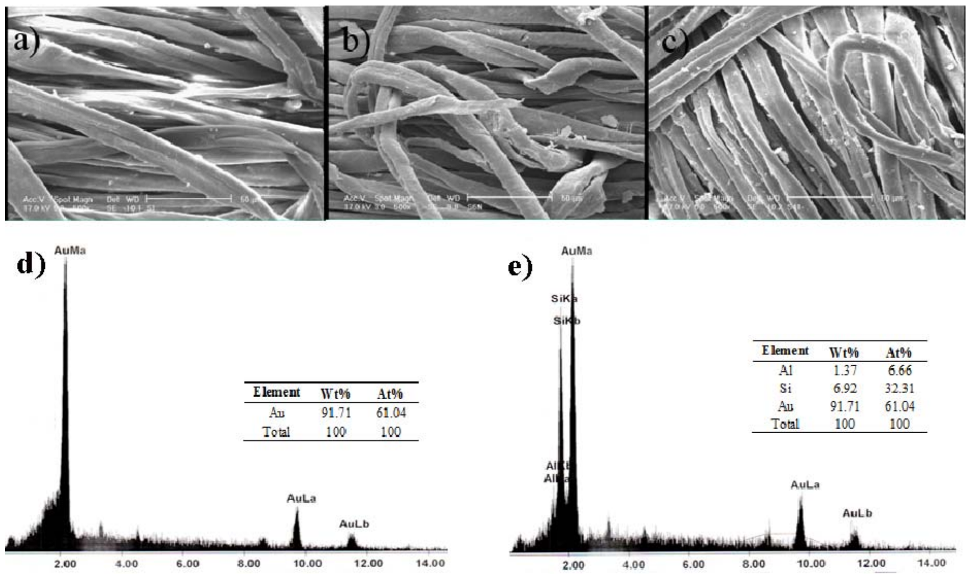

FIGURE 2. SEM images of different treated denim garments (500×); desized (a), treated with cellulases (b), treated with clay (c), EDAX of desized or treated with cellulase (d) and treated with nanoclay (e).

Figure 2-d shows the elemental analysis of the desized sample with no element except the gold; however, the denim treated with the clay included silicon and aluminum (*Figure 2-e*). This confirmed loading of the nano clay on the surface of fibers.

By comparing *Figure 3-a and Figure 3-b*, it can be inferred that in the sample treated with nano clay, nano-particles penetrate into the fiber layers and settle on their surfaces. *Figure 3-c* showed the SEM images of nano clay particles on fiber surfaces of samples treated with nano clay particles. It is obvious that nano clay particles were dispersed on the fibers surface. The dimensions of particles were at nano-scale, and some of them were demonstrated in images in the range of 63nm.

Air Permeability

Air permeability is an important factor in the performance of textile material and provides an indication of the breathability of a garment. The values of air permeability of the samples are shown in *Table II*. Due to cellulose hydrolysis by enzymatic treatment, the air permeability of denim treated with cellulases increased. Data in *Table II* show that nano the air permeability of samples treated with nano clay had lower air permeability than the biowashed sample. This is due to clay loading on the denim surface and decreased the breathability of garment.

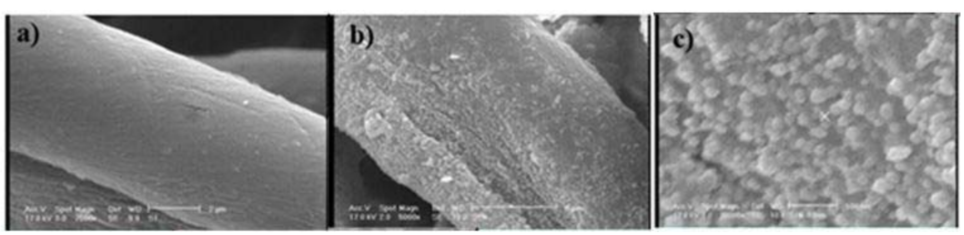

FIGURE 3. SEM images of different treated denim garments with cellulases (a), nano clay (b), and morphology of nano clay on surface of treated fiber (c).

TABLE II. Air permeability, bending rigidity and abrasion resistance of treated denim garments.

Sample	*Desized*	*Nc*	*Ac*	*D C N*	*D C A*
Air permeability ($cm^3/cm^2/s$)	13.5±0.2	23.2±0.2	23±0.2	15.5±0.2	15.4±0.2
Bending rigidity (mg.cm)	37.2±1	9.4±1	10.1±1	13±1	11±1
Abrasion Resistance (%Weight loss-G)	4.1±0.01	2.1±0.01	2.1±0.01	2.8±0.01	2.9±0.01

Bending Rigidity

The bending rigidity of the desized sample and treated sample with cellulases and nano clay is shown in *Table II*. The enzymatic nano washing treatment affected the bending characteristics of the samples. The desized sample had the highest bending rigidity. Also, the samples treated with nano clay in acidic and neutral media had bending rigidity similar to the sample treated with cellulases. Thus, nano washing with nano clay caused reduction in stiffness and improved the handle of fabric similar to the enzymatic treatment.

Abrasion Resistance

The weight loss of the treated samples after abrasion testing is illustrated in *Table II*. The results reveal that the variation of weight for different samples was not significant. Therefore, abrasion of 10,000 cycles by the Martindale device showed no significant difference between samples, and the abrasion resistance of treated samples was good. The desized sample contained anchor fibers on the surface subjected to abrasion and were removed from the fabric surface thus yielding the highest weight loss related to this sample. Cellulases reduced the anchor fibers on the fabric surface, and consequently, the abrasion had a lower impact on the abrasion resistance of the fabric. Nano clay improved abrasion resistance. This is due to the presence of clay on fabric surface that may reduce anchor fibers on the fabric surface. The presence of nano layers of clay on the fiber surfaces also reduced the contact surface area due to rough nano formation on the fiber surface as seen on the SEM pictures (*Figure 3c*). For the treated sample with nano clay in acidic and basic media, the condition of media had a little impact on the abrasion resistance.

Crease Recovery Angle (CRA)

The values of crease recovery angle of selected samples in warp and weft direction are given in *Table III*.

TABLE III. Changes of crease recovery angles of treated denim garments.

Samples	**Crease recovery angle (°) weft + warp**
Desized	250±4
Nc	237±3
Ac	236±2
D C N	245±1
D C A	246±1

The results characterized that the highest crease recovery angle was related to the desized sample with more wrinkle-resistant properties. Treatment of samples with cellulases reduced the fabric crease recovery angle. The differences between the value of crease recovery angle for treated samples with acid cellulases and neutral cellulases were not significant. It can be considered that enzymatic treatment reduced the wrinkle resistance through hydrolysis of cellulosic fibers. The crease recovery angle of treated sample with clay was higher than enzyme-treated samples but was lower than the desized sample. This is due to the presence of clay on the fiber surface, with no chemical influences on the cellulosic fibers similar to enzymatic treatment; and thus, clay improved wrinkle resistance of denim garment (cotton). Overall, it can be also considered that nano washing with clay, similar to enzymatic treatment, reduced the wrinkle resistance and acidic or neutral conditions were not an effective factor.

Thermal Analysis

Figure 4 shows TG, DTG and DTA curves of selected samples. *Figure 4* (TG curve) indicates that the desized sample (and treated denim with enzymes) was thermally analyzed at a higher rate at 400ºC and lost a great mass at higher temperatures up to 700ºC. Samples treated with nano clay indicated stability against heat and lost less mass. Also the decomposition rate of samples treated with nano clay was lower than that of the desized one, and these samples had more residue mass at 400ºC and lower temperatures. This is due to loaded clay on the fiber surfaces of treated the sample. Also the mineral structure of the clay involved aluminum and silicon, which caused better thermal properties on the treated denim.

DTG (differential thermo gravimetric) curves of the samples indicate that samples treated with nano clay had higher peaks in comparison to the desized one (and treated denim with enzymes) (*Table III* shows the peak values of DTG curve). Thus the desized sample treated with nano clay had a higher thermal stability than the desized one (untreated with clay), and also left more residual mass. Overall, based on SEM pictures and thermal behavior of the sample treated with clay, nano clay loaded on fibers changed the flammability properties of treated sample with more residual ashes than untreated one. This is due to presence of clay on fiber surfaces that had not burned and remained after burning.

DTA (Differential Thermal Analysis) curves exhibit the exothermic and endothermic effects of thermal decomposition of samples (*Figure 4-c*). The desized sample treated with nano clay, had an endothermic event over the temperature ranging from 400 to 600°C, whose intensity was greater at 400°C and was sharper. The desized sample (and treated denim with enzymes) had an exothermic event low in intensity over the temperature range, 400 to 700°C (*Table IV*). Therefore, regarding the endothermic nature of thermal decomposition at the considered temperature range, the sample treated with nano clay showed higher stability because of loaded clay on the fibers.

Table IV shows the limited oxygen index (LOI) values and burning times of selected samples. The desized sample treated with nano clay and the desized sample (and treated denim with enzymes) had the highest and lowest LOI values, respectively. Therefore, considering the results from TGA and LOI values, the sample treated with nano clay became resistant against heat and flame. This can be due to the presence of nano clay particles on the denim garment surface. Based on the SEM images (*Figure 2 and Figure 3*), the particles were well distributed on the surface of fibers. The burning times of samples, shown in *Table IV*, indicate the resistance of treated samples against flame in comparison to the untreated desized one with clay. Overall, the presence of clay (with mineral structure) on fiber surfaces delayed the burning of treated denim.

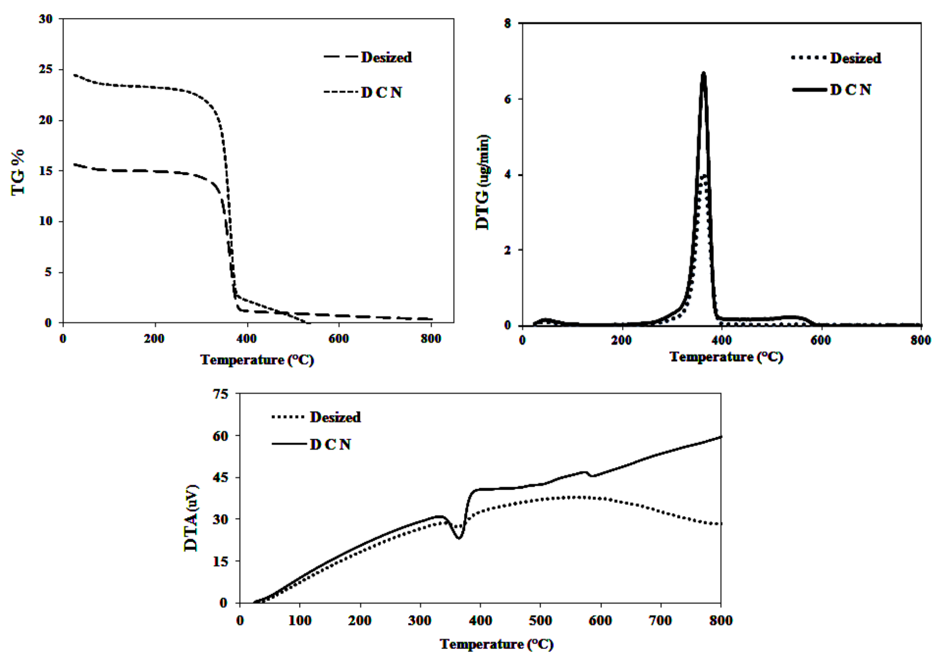

FIGURE 4. TG, DTG and DTA curves of selected denim garments

TABLE IV. DTG, DTA and LOY values of selected denim garments.

Properties	***DTG***		***DTA***			***LOI***	***Burning***
sample	maximum (ug/min)	Temperature (°C)	Maximum (uV)	Temperature (°C)	kind of event	(%)	(time/s)
Desized /(Nc)/(Ac)	401	361	27.43	361	Exotherm	20.2	16
D C N	670	364	23.12	366	Endotherm	24.9	23

XRD pattern

Figure 5 shows the XRD patterns of clay, the desized sample, and the sample treated with nano clay. The desized sample has a definite pattern and when loaded with mineral clay, created peaks at specific angles. Comparing the XRD patterns of the samples and clay, it can be proposed that those treated samples with nano clay indicated different peaks from the desized one at 60-80º, confirming the presence of nano clay on their surface. With regard to the XRD pattern of clay(*Figure 5-a*) at 60-80º, it can be seen that clay particles (layers of nano clay) settled on the fibers surface and penetrated onto the fibers layers of treated sample and distributed more appropriately as shown by SEM pictures (*Figure 3*).

Color Fastness

The changes in fastness and staining of the samples on the accompanying cotton, wool, and polyester fabrics for treated and untreated samples with clay are shown in *Table V*. The samples treated with cellulases or nano clay showed an obvious improvement in washing and rubbing fastness compared to the desized sample. This is due to discoloration of enzymes or clay that caused lower staining in after treatment (home washing). Although treated samples with nano clay had slightly higher fastness properties than the enzymatic treated sample, because of more discoloration and absorbency of clay in denim nano washing.

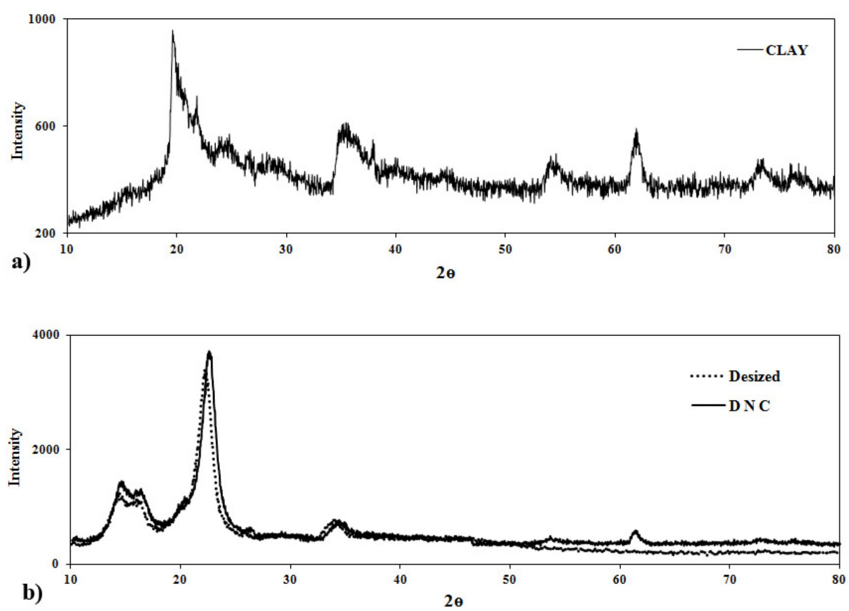

FIGURE 5. XRD patterns of clay (a) and selected denim garments (b).

TABLE V. Color fastness of the treated and untreated denim garments.

Properties	Washing fastness					Rubbing fastness		
Samples	**ISO A05**	**ΔE***	**staining cotton**	**staining polyester**	**staining wool**	**AATCC**	**ΔE***	**staining cotton**
Desized	3	3.7	3-4	4-5	4-5	2	6.7	1-2
Nc	4	1.4	4-5	5	5	3-4	1.9	3
Ac	4	1.8	4-5	5	5	3-4	1.8	3
D C N	4-5	0.4	5	5	5	3-4	1.4	3-4
D C A	4-5	0.9	5	5	5	3-4	1.6	3-4

*color difference with reference sample

The sample treated with cellulases and nano clay had an obvious improvement in washing fastness and staining from 3-4 to 4-5 and in rubbing fastness and staining from 1-2 to 3-4. Also nano clay caused an improvement in the color staining and those samples retained their original color staining grades because of better absorbency of clay in nano washing. When nano clay is used as a dye adsorbent, a higher discoloration is expected than that of cellulases in the denim washing process and yields higher wash fastness. Also, the nano clay showed no enhancement in rubbing fastness compared to enzymatic process case. However, it is very interesting that the treated samples with nano clay showed an obvious improvement in color staining in washing and rubbing fastness, compared with the other samples. Then nano clay discolored denim surface during the nano washing and improved the fastness properties of indigo on denim.

Antimicrobial Properties

Figure 6 shows the decrease in the number of colonies present in the desized denim (untreated with clay) sample treated with enzymes and nano clay, after being placed adjacent to Gram-negative and Gram-positive bacteria. Based on the *Figure 6*, the untreated sample with clay (desized denim and sample treated with cellulases) resulted in an uncountable increase in the number of bacteria colonies. Those samples had no antimicrobial substances and thereby provided an appropriate condition for bacteria growth and resulted in an increase in the number of microbe colonies. Samples treated with nano clay in acidic or basic media show antibacterial activity. As the results in SEM pictures of treated denim with nano clay demonstrate that nano clay settled on the surface of treated fibers. This could attach to the cellular surface of a microbe and decrease its permeability and the cationic reactions of clay with the anions in the cell wall could result in microbe death [24].

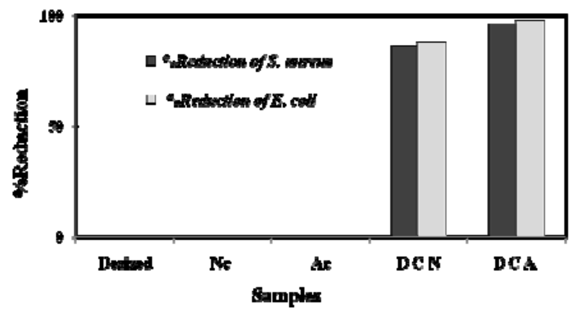

FIGURE 6. Antibacterial activity of treated denim with cellulase/clay.

CONCLUSION

In this study, nano clay was applied to produce old-look denim in order to reduce use of chemical or biochemical agents. The process of denim stonewashing with nano clay and conventional enzymes was carried out and some features of each resultant fabric are compared. The colorimetric results showed the possibility of obtaining washed denim without enzymes, and desized denim was successfully washed using nano clay. The color fastness properties of the washed denim confirmed the garment discoloration by nano clay (based on absorbency of clay). Desirable handle, air permeability, wrinkle resistance, and abrasion resistance properties were obtained on the nano clay treated garment. Overall, the used-look appearance of denim garment with enhanced thermal properties and antibacterial activity was produced.

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