Chattopadhyay and Patel, J Textile Sci Eng 2015, 5:2
DOI: 10.4172/2165-8064.1000189

Journal of Textile Science & Engineering

ISSN: 2165-8064

Research Article Open Access

Studies on the Effect of Nano Zinc Treatment on Jute Fabric

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Abstract

In the present investigation in-house synthesized colloidal nano-zinc was applied on jute fabric by pad-dry-cure technique. The fabric samples treated with zinc nano-particles were tested for changes in absorbency, air permeability, water permeability, electrical resistivity, antibacterial activity and dye ability. These properties were compared to their untreated counterpart. The treatment with zinc nano sol improves the physical properties along with the dye ability of jute fiber with direct dye. The treatment also enhances the antimicrobial efficacy of jute fiber.

Keywords: Antimicrobial; Absorbency; Air and Water permeability; Dyeing, Jute; Zinc Nano-sol

Introduction

Incorporation of nano-sized particles in textile fiber can generate special properties or cause enhancement of existing properties. Nano-size particles of metal and metal oxides can be applied on textiles to impart antibacterial property as well as to improve various functional properties like water repellence, soil-resistance, anti-static, anti-infrared, flame-retardancy etc [1-6].

Nano surface coating is one of the approach to the production of highly active surfaces to have UV-blocking, antimicrobial and self-cleaning properties. Works reported that the self-cleaning property can be imparted by nano-TiO_2/nano-ZnO coating [7], while nano-Ag imparts antimicrobial property. Nano-particle coating may affect the other fabric properties like dyeing, absorbency, air permeability and strength. The ZnO nano-particles were also reported to improve the antistatic, friction resistance properties of textiles [8,9]. Earlier, our research group synthesized and characterized the zinc nano-particles using chemical reduction reaction and reported their effect on physical and antimicrobial properties of cotton [10] and effect of Cu and Ag Nano sol on natural textiles [11-13]. In this work, jute fabric was coated with the in-house synthesized zinc Nano-particles which was synthesized as reported elsewhere [10]. The mechanical property of these fabrics was evaluated in addition to the effect on absorbency, air permeability, water permeability, electrical resistivity, dye ability and antibacterial properties.

Materials

In house synthesized Zinc nano-sol was applied to jute fabric. Change in functional properties due to the treatment was evaluated by standard methods.

Fabric

Plan weaves jute fabric ends/inch-13, picks/inch-10 and weight-465.11 gm/m^2 was supplied by Institute of jute technology, Kolkata, India for the study.

Dyes and chemicals

Three commercial direct dyes, namely C.I. Direct Red 9 (D1), C.I. Direct Blue 67 (D2) and C.I. Direct Green 6 (D3), In-house synthesized and TSC capped metallic nano zinc-colloid were used in this study without further purification. Gram positive *Staphylococcus aureus* (Lab collection) was used for evaluation of antimicrobial property test as per ASTM E-2149 method.

Equipments

- Scanning electron microscope (SEM, Model JSM-5610 LV, Japan)
- X-ray fluorescence spectrometer (EDX 800 Simadzu, Japan)
- Laboratory Constant temperature shaking water bath (Alliance enterprise, India).
- Laboratory two bowl automatic padding mangles (EEC, India).
- Launder-ometer (Digi. wash, Paramount Scientific Instruments., India).
- Xenon arc Fadometer, (FDA-R, Atlas, U.S.A.).
- Spectrophotometer interphased with computer colour matching system; Spectra scan 5100 (RT) (Premier colour scan instrument), India.
- Air permeability test: Metefem, type-FF12/A, no: 8838_002, made in Hungary.
- Antibacterial test equipments: Incubator cum oven, Laminar air flow (Hexatec Instruments Pvt. Ltd. Mumbai: Model: HIPL-042), Autoclave Equitron (Sr.No. NC11GC-2824), Shaker Incubator and UV spectrophotometer.
- Electrical surface resistivity test: KEITHLEY-614 Electrometer MET/K/16B, USA.

Experimental methods

Preparation of textile fabrics for nano treatment

The jute fabric was first treated in a bath containing 5gpl non-ionic detergent (Lissapol N) and 2 gpl sodium carbonate for 30 minutes at 80°C temperature. Then the fabrics were washed thoroughly in running water, neutralized and again washed thoroughly in running water.

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Received February 03, 2015; **Accepted** March 23, 2015; **Published** April 25, 2015

Citation: Chattopadhyay DP, Patel BH (2015) Studies on the Effect of Nano Zinc Treatment on Jute Fabric. J Textile Sci Eng 5: 189. doi: 10.4172/2165-8064.1000189

Finally, the pH of fabrics was checked to neutral.

Coating of samples with zinc nano colloids by pad–dry–cure method

Nano-colloidal solutions were applied to jute fabric samples by soaking them in the dispersion for 10 min and then squeezed on an automatic two bowl padding mangle operated at 15 rpm with a pressure of 1.75 kg/cm^2 using 2-dip-2-nip padding sequence at 70% expression. The padded substrates were air dried and finally cured at 120 ˚C for 20 min in a preheated curing oven.

Testing and Analysis

Physical testing

Before physical testing the samples were dried and conditioned at 65± 2% RH and 27 ± 2°C temperature.

Determination of tensile properties :

2 cm×8 cm fabric samples were tested at 100 mm/min traversing speed for the determination of breaking load, breaking elongation, stress and strain. The test was performed as per B.S. 2576:1959

Determination of crease recovery angle: The test was performed as per AATCC test method 66-2003.

Determination of bending length: The stiffness in terms of bending length of nano treated and untreated samples were measured as per AATCC Test Method 115-2005 using prolific stiffness tester (India).

Determination of absorbency by Drop test method: Absorbency of nano treated and untreated fabric sample were evaluated using AATCC Test Method 79-2000. The test was conducted in a standard atmospheric condition. Before the test the samples were kept in standard atmosphere having a relative humidity of 65 ± 2% RH and 27 ± 2°C temperature. Five tests were conducted for each sample. An average of five readings was reported.

Evaluation of water permittivity: This test is conducted for determining the hydraulic conductivity (water permeability) of textiles materials in terms of permittivity under standard testing conditions in uncompressed state. It shows flow of water perpendicular to plane of fabric which is very important to assess for filtration and drainage purpose. Permittivity is an indicator of the quantity of water that can pass through a textile material in an isolated condition, by using ASTM D 4491 water permeability test method. Constant head method has been selected for this test.

Permittivity **Ψ** was calculated as follows

$$\boldsymbol{\Psi = QR_T/hAt}$$

Where

Ψ = Permittivity (S^{-1})

Q = Quantity of flow (mm^3)

h = Head of water on the specimen (mm)

A = Cross sectional area of test area specimen (mm^2)

t = Time for flow Q (S)

R_T = Temperature correlation factor determined using Equation (c)

$$\boldsymbol{R_{T=}U_t/U_{20t}}$$

Where: U_t = Water viscosity at test temperature millipoises.

U_{20t} = Water viscosity at 20°C millipoises.

Evaluation of air permeability: The air permeability of treated and untreated fabric samples were measured on Metefem air permeability tester. The testing was carried out as per ASTM D 737 test method. The result of the test measured in m^3/m^2/h to three significant digits.

Evaluation of antibacterial activity

Soil burial test (AATCC Test Method 30-2004): The samples exposed to the action of micro-organism in compost soil for 7 days, at the end of the period, the specimens were tested for the change in tensile strength measured as per B.S. 2576:1959 test method on Instrument Model-Lloyd, LRX. Samples of 2 cm×8 cm were tested at 100 mm/min traversing speed.

ASTM E-2149 test method: Antimicrobial activity was measured as per ASTM E-2149 test methods. Antimicrobial test for jute fabrics with and without nano zinc was carried out with gram-positive *Staphylococcus aureus* and gram-negative *Escherichia coli* bacterium. The percentage reduction in bacterial growth was calculated using following equation

$$\text{Percent Reduction in bacterial growth} = \frac{(B-A)}{B} \times 100$$

Where,

A is the optical density of the inoculated test culture containing the treated sample.

B is the optical density of the inoculated test culture containing the untreated sample.

Determination of electrical surface resistivity: The purpose of this test method was to determine the electrical surface resistivity of fabric. The test was carried out as per AATCC test method 76-2005. The specimen size of the treated and untreated fabric samples were used as electrodes and the electrical surface resistivity of fabric samples were measured on KEITHLEY-614 electrometer. The instrument directly showed the electrical resistivity (R) value of the fabric samples.

Dyeing of untreated and treated jute with direct dyes: All dyeing were carried out in laboratory dyeing machine at a liquor to material ratio of 20: 1, in the presence of 50 gpl of sodium chloride and 20 gpl of sodium bicarbonate using 2.0% dye on the weight of the sample. The sample was initially treated in the dye bath at 40°C for 10 min. The temperature was slowly raised to boil over 30 min (2°C/min) and the dyeing was continued at boil for further 45 min. Finally the samples were washed and dried in air. For comparison purpose, untreated jute was also dyed under the same condition.

Evaluation of dyed samples: The colour strength values (*K/S* value) of the samples were measured using Spectra Scan 5100 (RT) spectrophotometer (Premium Colourscan Instruments, India). All the dyed samples were also evaluated for fastness to light by ISO 105-BO2 (1990) and washing by ISO 105-CO6 (C2S) methods.

Results and Discussion

The treatment with nano-particles was performed using pad-dry-cure technique. The distributions of nano-particles on the surface of the fabric were observed using SEM and elementally analyzed using XRF technique.

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Characterization of zinc nano treated fabric

Figure 1 represents SEM photographs of jute fabrics, treated with zinc nano-particles. Deposition of zinc nano was done successfully using pad-dry-cure technique. Table 1 shows the amount of zinc on the fabric measured by XRF technique.

Effect of zinc nano treatment on physical properties

The effect of nano zinc treatment on the physical properties of jute is presented in Table 2. It is seen from the results that introduction of nano zinc particles into the structure of the fiber caused an improvement in the load bearing capacity of the fiber. Improvements in the bending length and crease recovery angle of treated fabrics were also observed. These may be due to the interference of zinc nano-particles with the polymer chain mobility. From the SEM microphotograph of nano zinc treated samples shown in Figure 1, it can be clearly seen that the zinc nano-particles are distributed on the surface of the treated samples, being distributed in polymer matrices nano-particles can carry load and increase the toughness and abrasion resistance of the polymer matrices and enhance tensile strength of treated fiber.

Effect of zinc nano treatment on fabric absorbency

The water absorbency of zinc nano treated and untreated fabric samples were presented in Table 3. From the results it is found that nano- zinc treatment caused a drop in water absorbency of the samples. The drop in absorbency was found to be 4.62% in case of treated jute compared to the untreated jute fabric. The nano-metal particles act as whiskers and resists immediate penetration of water droplets, which increased the time to get water molecules absorbed, inside the fabric structure.

Effect of zinc nano on water permeability of fabric

The results presented in Table 4 show that the water permeability of the treated samples was dropped after zinc-nano treatment since the nano-particles present in polymer matrix resists the flow of water through the fabric.

Effect of zinc nano on air permeability of fabric

The results presented in Table 5 were measured on Metefem for air permeability of zinc nano treated and untreated fabric samples. It shows that the air permeability through treated samples was reduced compared to untreated sample.

Effect of zinc nano on resistance against microbes

Antimicrobial activity on the fabric was measured by soil burial test and the results are shown in Table 6. It is clear that the zinc nano treatment was found to enhance the resistance of jute towards microbial attack when measured in terms of loss in breaking load due to soil burial

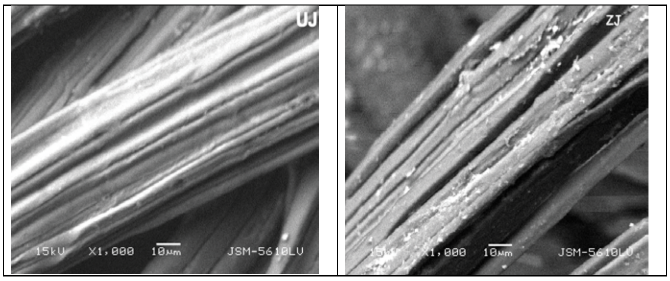

Figure 1: Scanning electron microphotographs of untreated jute (UJ) and jute treated with zinc nano sol (ZJ) fabric.

Sample	Amount of zinc, µg
Jute fabric	Nil
Jute fabric treated with zinc nano sol	0.15 µg

Table 1: Amount of zinc detected using XRF.

Sample	Breaking load (kgf)	Crease recovery angle °(deg)	Bending length (cm)
Jute (Control)	10.44	90	3.00
Jute treated with zinc nano sol	10.78 (+3.26)	101 (+12.22)	3.32 (+10.67)
Note: Values in the parenthesis indicate percentage change in physical properties.			

Table 2: Effect of zinc nano treatment on physical properties of jute.

Fabric sample	Time (sec)	
	Untreated	Treated with Ag nano
Jute	13	13.6

Table 3: Absorbency of zinc nano treated and untreated fabrics

Sample	Ψ-Water Permeability(S^{-1})
Untreated Jute sample	0.3726
Treated with zinc nano sol	0.3659

Table 4: Water permeability of fabric before and after the zinc-nano treatment.

Sample	Air permeability ($m^3/h/m^2$)
Untreated Jute sample	884.28
Treated with zinc nano sol	859.24

Table 5: Air permeability of jute fabric before and after zinc nano sol treatment.

Sample	Breaking load, kgf	
	Before soil burial	After soil burial
Untreated jute sample	10.44	5.02
Jute pretreated with zinc nano particles	10.92	9.86

Table 6: Effect of zinc nanoparticles on resistance against microbial attack.

Fabric sample	Reduction in bacterial growth (%)
Jute (Control)	Nil
Zinc nano treated Jute	73.12

Table 7: Anti-bacterial effect of zinc nano treated fabric

Fabric sample	Electrical surface resistivity (ohm Ω)
Jute (Control)	>200 x 10^9
Zinc nano treated Jute	>200 x 10^9

Table 8: Electrical surface resistivity of jute fabrics.

test. The breaking load of untreated control samples were reduced due to bacterial damage during soil burial test whereas zinc nano-particle treated sample resist the bacterial attack. The treated samples were also tested against gram-positive *Staphylococcus aureus* bacteria. Anti bacterial efficiency of zinc nano treated samples against the original fabric sample is reported in Table 7. It is found from the results that the zinc nano treated jute have more resistance against bacterial growth compared to its untreated counterpart. The enhancement in the resistance towards bacterial attack may be attributed to the certain degree of sterilizing effect of the metal atoms. It is possible that zinc nano particles may get attached to the surface of the microbe's cell membrane enter inside the cell and destroy their metabolic function.

Effect of zinc nano treatment on electrical surface resistivity

The Electrical surface resistivity of treated and untreated fabric

Sample	Colour strength (*K/S*)					
	C.I. Direct Red 9		**C.I. Direct Blue 67**		**C.I. Direct Green 6**	
	Control	Zinc nano treated	Control	Zinc nano treated	Control	Zinc nano treated
Jute	14.15	14.36	16.43	16.57	17.26	17.88

Table 9: Effect of zinc nano-particles on colour strength of fabrics dyed with direct dye.

Sample	Fastness to											
	Light						**Washing**					
	C.I. Direct Red 9		C.I. Direct Blue 67		C.I. Direct Green 6		C.I. Direct Red 9		C.I. Direct Blue 67		C.I. Direct Green 6	
	C	T	C	T	C	T	C	T	C	T	C	T
Jute	2-3	3	3-4	3-4	2-3	3	3	3-4	3	3-4	3	4
Note: C – Control sample, T – Sample treated with zinc nano sol.												

Table 10: Effect of zinc nanoparticles on fastness properties of samples dyed with direct dyes.

Pairs	Description	Reference Table	Mean	SD	t-value	p-value
1	Breaking load of jute (Control)	2	10.4400	.61500	-1.843	0.098
	Breaking load of jute treated with zinc nano sol	2	10.7800	.15492		
2	Crease recovery of jute (Control)	2	90.0000	2.19241	-18.517	0.000
	Crease recovery of jute treated with zinc nano sol	2	101.0000	1.50923		
3	Bending length of jute (Control)	2	3.0000	.40000	-1.829	0.101
	Bending length of jute treated with zinc nano sol	2	3.3200	.44920		
4	Absorbency of jute (Control)	3	13.0000	.50553	-2.491	0.034
	Absorbency of jute treated with zinc nano sol	3	13.6000	.55976		
5	Water permeability of jute (control)	4	.3720	.02658	0.611	0.556
	Water permeability of jute treated with zinc nano sol	4	.3650	.04767		
6	Air permeability of jute (Control)	5	884.2800	9.08195	8.492	0.000
	Air permeability of jute treated with zinc nano sol	5	859.2400	3.59605		
7	Breaking load of untreated jute (before soil burial)	6	10.4400	.61500	-2.478	0.035
	Breaking load of jute treated with zinc nano sol (before soil burial)	6	10.9200	.12293		
8	Breaking load of untreated jute (after soil burial)	6	5.0200	.35528	-43.700	0.000
	Breaking load of jute treated with zinc nano sol (after soil burial)	6	9.8600	.15055		
9	K/S of control jute dyed with C.I. Direct Red 9	9	14.1500	.17159	-2.973	0.016
	K/S of treated jute dyed with C.I. Direct Red 9	9	14.3600	.14298		
10	K/S of control jute dyed with C.I. Direct Blue 67	9	16.4300	.42960	-1.367	0.205
	K/S of treated jute dyed with C.I. Direct Blue 67	9	16.5700	.24967		
11	K/S of control jute dyed with C.I. Direct Green 6	9	17.2600	.45509	-4.439	0.002
	K/S of treated jute dyed with C.I. Direct Green 6	9	17.8800	.11353		
Note: p-value<=0.005, significant at 5% level of significance.						

Table 11: Mean comparison between different control groups with respect to their treatment group using paired t-test statistics.

samples was measured on KEITHLEY614-Electrometer and the results are given in Table 8. There was no significant change in surface resistivity of jute was observed due to the incorporation of zinc nano sol.

Effect of zinc nano treatment on dyeing behavior

The zinc nano sol treated jute fabric was dyed with three direct dyes and compared with the untreated samples. The *K/S* values of the nano zinc pretreated samples were found to be higher (Table 9) than the corresponding untreated samples. The maximum improvement in color strength was observed with direct green 6 dyes. The higher *K/S* values of nano-treated samples indicate that the presence of nano metal particles increased the dye affinity towards the material. The zinc nanoparticles in the fabric thus acted as mordant. The better coupling of the dye and fiber is also reflected in the improvement of the color fastness properties (Tables 10 and 11), which is a major drawback of most direct dyes. Above table indicates the pair wise mean comparison of data sets using paired t-test statistics, look in to the results, it can be concluded that pair numbers 2, 4, 6, 7, 8, 9, and 11 have significant difference because the calculated t-value is significant as p-value found to be less than 0.05 which means that there exist real differences between the mean values of the control and the mean values of the zinc nano sol treated samples for the corresponding properties which also include reduction in water absorbency.

Conclusions

Zinc nano-sol was successfully applied on jute fabric using pad-dry-cure technique. The treatment reduced the water permittivity and air permeability of jute fabric samples. After the treatment the fabric manifested better dye ability, higher fastness and enhanced bacterial resistance.

Acknowledgement

Authors are thankful to AICTE (RPS) for financial assistance to carry out this research work.

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