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บทความวิจัย

การปรับปรุงความคงทนของสีและสมบัติการป้องกันรังสียูวีของผ้าฝ้ายเคลือบนาโนไคโตซานและซิงค์ออกไซด์ย้อมคราม

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บทคัดย่อ

วัสดุโนนาโนไคโตซานและนาโนซิงค์ออกไซด์สามารถปรับปรุงความคงทนของสีและสมบัติการป้องกันรังสียูวีของสิ่งทอได้ งานวิจัยนี้ศึกษาผ้าฝ้ายเคลือบด้วยอนุภาคนาโนไคโตซานและนาโนซิงค์ออกไซด์ย้อมคราม ทดสอบสัณฐานวิทยาของผ้าฝ้ายที่เคลือบอนุภาคนาโนไคโตซานและนาโนซิงค์ออกไซด์ด้วยกล้องจุลทรรศน์อิเล็กตรอนแบบส่องกราด (SEM) และพิสูจน์เอกลักษณ์ด้วยเครื่องฟูเรียร์ทรานฟอร์มอินฟราเรดสเปกโตรโฟโตมิเตอร์ (FT-IR) ทดสอบสมบัติการป้องกันรังสียูวี และความคงทนของสีต่อแสง และความคงทนของสีต่อการซักล้างของผ้าฝ้ายที่เคลือบ ผลการวิจัยพบว่า ผ้าฝ้ายที่ไม่เคลือบด้วยอนุภาคนาโนไคโตซาน และนาโนซิงค์ออกไซด์มีผิวหน้าที่เรียบ ผ้าฝ้ายที่เคลือบจะปรากฏอนุภาคนาโนไคโตซาน และนาโนซิงค์ออกไซด์ที่ผิวหน้าซึ่งช่วยเพิ่มพื้นที่ผิวสัมผัสให้เส้นใยดูดซับโมเลกุลสีย้อมได้มากขึ้น ความคงทนต่อแสง และความคงทนต่อการซักล้างของผ้าฝ้ายที่เคลือบย้อมคราม เฉลี่ยอยู่ในระดับ 4–5 (ดีถึงดีมาก) และ 4 (ดี) ตามลำดับ ผ้าฝ้ายเคลือบนาโนไคโตซาน (0.3 และ 0.5 กรัม) : นาโนซิงค์ออกไซด์ (1, 2 และ 3 กรัม) ย้อมคราม ทดสอบความคงทนต่อการซักล้างจำนวน 10, 20 และ 30 ครั้ง พบว่าความคงทนอยู่ในระดับ 4 (ดี) และสามารถป้องกันรังสียูวีได้ดีเยี่ยมด้วยค่า UPF ในช่วง 51.61–60.31

คำสำคัญ: นาโนไคโตซาน นาโนซิงค์ออกไซด์ ผ้าฝ้าย คราม การป้องกันรังสียูวี

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Research Article

Color Fastness and UV Protection Improvement of Indigo Dyed Cotton Fabrics Coated with Nano Chitosan and Zinc Oxide

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Abstract

Nano chitosan and nano zinc oxide materials can improve the UV protection and color fastness properties in textiles. Cotton fabrics coated with nano chitosan and nano zinc oxide particles dyed with indigo were studied. The morphologies of coated cotton were characterized by using SEM and its surface was investigated using a FT-IR. UV protection, light fastness, and washing fastness properties of coated cotton were also investigated. The results reflected that cotton not coated with nano chitosan and zinc oxide had a smooth surface, while coated cotton fabrics had nano chitosan and zinc oxide particles on the surface, which is useful to increase the high surface area, allowing the fibers to absorb more dyed molecules. On average, light fastness and washing fastness properties of coated cotton dyed with indigo were 4–5 (good-very good) and 4 (good), respectively. Cotton coated with nano chitosan (0.3 and 0.5 grams) : zinc oxide (1, 2, and 3 grams), dyed with indigo and washed for 10, 20 and 30 times, shows good fastness and excellent UV protection with UPF values in the range of 51.61–60.31.

Keywords: Nano Chitosan, Nano Zinc Oxide, Cotton, Indigo, UV Protection

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1. Introduction

Indigo dyed fabric is a unique of color and aroma from indigo which is the popular product for foreigners, especially in Europe, Japan, as well as Thailand markets due to its anti-UV properties. However, indigo dyed fabric has disadvantages such as fading, resistant to mold, easily wrinkled and easily attached by dirt when it was worn for a long time. Adding innovation to indigo dyed fabrics is an interesting because it can improve fastness properties, UV resistance, anti-fungal and bacteria properties. Nanotechnology such as nano chitosan, nano zinc oxide, nano titanium dioxide and nano silver is an alternative way to improve the properties of the dyed fabrics. The nano material properties will increase the physical properties of fibers including anti-fungal and bacterial, waterproof, dirt, crease, UV resistance, fire resistance. Moreover, it can increase color fastness and tensile strength in textile [1]. Chitosan is a natural polymer obtained from chitin by eliminating of acetyl groups in a deacetylation reaction. It can be found in living organisms, especially in the insect wing structure, the outer shell of crustaceans, crabs, shells, squid and crayfish shells, cell walls of yeasts, fungi and microorganisms. The use of chitosan to coating on the fibers is an alternative way to increase the efficiency and to improve the color fastness of the fibers which will be developing of textile products in the future. In 2009 Giri Dev *et al*. [2] reported of improved wool coating chitosan and henna dye. They found that wool coated with chitosan increase washing fastness, sweat absorption and bacteria inhibition.

Ultraviolet (UV) radiation from the sun is one of the problems that directly affect humans' body. It is the main factor causing skin cancer cells. UVA (320–400 nm) and UVB (290–320 nm) rays are able to penetrate the skin and cause permanent skin damage, ageing, eye damage and melanoma and skin cancers [3]. UV protection materials as nano zinc oxide (ZnO) and titanium dioxide (TiO_2) particles are substances which can reflect UV light due to high surface area, translucent, clear and they can protect both of UVA and UVB. The two types of UV protection materials are commonly used in sunscreen and coated on the fabrics. TiO_2 is more effective in UVB and ZnO in the UVA range [4]. ZnO and TiO_2 can be utilized in textiles application.

Zinc oxide has more reasonable benefits than titanium dioxide such as lower cost, easier synthesis method, higher photocatalytic activity, more effective antimicrobial properties and less sensitivity to the synthesis conditions. The applications of nano zinc oxide on textiles are UV- blocking, self-cleaning, antibacterial properties [5]. Sudaporn Tangkawanit developed silk coated with nano zinc oxide and dyed natural dye. The results found that silk coated with nano zinc oxide can protected UV rays and has heat resistance higher than the uncoated silk. The increasing heat resistance may be the result of bonding between the silk and nano zinc oxide [6]. Cotton, silk and muslin fabrics coated with nano carbon and titanium dioxide ratios 0.01 : 0.49 (g), have UPF values for UV protection more than 50. The light and washing fastness of the dyeing have the average of 4–5 [7]. In 2017, Thi [8] developed the self-cleaning properties of cotton coated with ZnO using a microwave. It was found that the pH 6–7, 8–9 and 10–11 had the highest UPF value of 222.52, 162.68 and 202.57, respectively. Self-cleaning properties of cotton coated ZnO under UV irradiation for 15 hours can get the highest elimination coffee stains at 90% moisture. Moreover cotton coated with chitosan 0.5-0.75% (w/w) using butane tetracarboxylic acid and arcrofix NEC crosslink agents showed the highest antibacterial property [9]. Yadav *et al*. [1] reported that cotton coated with 2% nano zinc oxide using acrylic binder, coated cotton could resists 75% of UV radiation, high air permeability, comfortable to wear, durable to wash, abrasion and antibacterial properties higher than non-coated fabrics. In 2010, Li *et al*. [10] reported that zinc oxide can inhibit bacteria with the mechanism causing by photocatalytic processes. When zinc oxide absorbed light energy (3.37 eV), the electrons were stimulated from the valence band to the conduction band, resulting in the absence of an electrons at the valence band called holes (h^+). Hole can interact to hydroxide ion (OH^-) on the surface of zinc oxide, forming a free radical of hydroxyl, super oxide, anions and free radicals of peroxides, which was a strong oxidizing agent that can destroy the internal structure of bacteria, causing bacteria to die. Shaheen [11] prepared zinc oxide nanoparticles using Hexamethyltriethylene tetramine (HMTETA) found that zinc oxide nanoparticles regularly on the cotton surface and the fabric had antibacterial properties and high UV rays protection. Farouk *et al*. [12] reported zinc oxide-chitosan nanoparticles composite for the decoration of textiles with antibacterial properties on cotton and cotton/polyester by using chitosan molecular weight equal to 1.36×10^5, 2.2×10^5 and 3.0×10^5 Da and using nano zinc oxide with an average particle size of 40 nm (different molecular weight) can resist both Gram-positive (*Micrococcus lutus*) and Gram-negative (*Escherichia coli*) bacteria. Antibacterial ability increases when molecular weight of chitosan decreases. Rejendran and Sivalingam [13] improved cotton fabric coated with chitosan and zinc oxide composite prepared by using hydrothermal method. It was found that improved cotton fabric has high heat resistance and antibacterial properties. The mechanism for inhibiting bacteria of chitosan is caused by the reaction between the positively charged of chitosan and the negative charge on the bacterial wall, causing inhibition of cell metabolism or inhibiting the activity of mRNA and stopping bacterial growth. Therefore, the use of nano materials to improve the properties of cotton and dyed with natural indigo is an interesting.

The most common indigo is indigo blue or indigo cream which is insoluble in water. Therefore, before dyeing the indigo blue had to be changed to indigo white, which is soluble in alkaline conditions, pH 10.5–11.5, at temperature 27–30 degrees celsius. Water, ashes and *Bacillus alkaliphylus* bacteria, chemical reducing agents or natural reducing agents such as reducing sugar from fruits can be used to convert indigo blue to indigo white. Reducing agent, the most commonly used for the indigo dyeing industry, is sodium dithionite ($Na_2S_2O_4$) and sodium hydroxide which are reducing the indigo dye in a short time. But the results from the reaction caused sulfite and sulfate which can cause various problems to pollute the environment, endanger to producers and consumers because heavy metal oxides are carcinogenic cause [14]. As a result of this problem, many researchers have tried to study the use of natural reducing agents to replace chemicals.

Namely, natural reducing agents from fruits mainly contain glucose and fructose such as tamarind, star fruit, pineapple, watermelon and bananas. And disaccharide sugar as galactose, lactose and maltose are used as an eco-friendly reducing agent [15].

Therefore, this research focus on the study of cotton coated with nano chitosan and nano zinc oxide composite and indigo dyed. Physical properties of cotton coated with nano chitosan and nano zinc oxide composite as UV protection and color fastness property were investigated. Cotton innovation with UV protection, very good light fastness and washing fastness properties can promote the production, products and increase value added for community enterprise products, reduce global warming and safe for consumers. The route of nano zinc oxide and chitosan crosslinking through GPTMS coated on cotton fabric dyed with indigo was shown in Figure 1. Chitosan and zinc oxide nano composites in solution was applied as coating on cellulosic cotton fabrics using GPTMS as crossing agent chemically bound between ZnO through chitosan. The oxirane ring on the GPTMS and the amino group of chitosan chain could react with ZnO and the positive charge of ZnO also enable the establishment of bonding with OH group of chitosan which will enhance indigo dye adsorption and UV blocking properties. Chitosan is linked to the cellulose of cotton with hydrogen bonds through the hydroxyl group at acidic condition. The chitosan structure was protonated into a cationic amine group (NH_3^+) that can bind to the negative ion of indigo. The OH group of chitosan will be introduced by the formation of hydrogen bonding with indigo dyed.

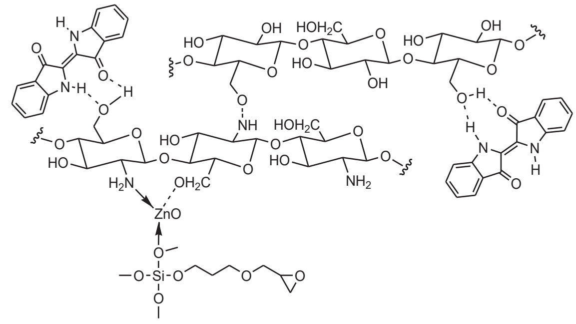

Figure 1: Proposed schematic mechanism of GPTMS-nano zinc oxide and chitosan coated on cotton fabric dyed with natural indigo.

2. Material and Methods

2.1 Cotton preparation

Cotton fabrics were cleaned by using nonionic detergent at room temperature for 24 hours. The cotton was washed and air-dried.

2.2 Chitosan preparation [16]

Shrimp shell was washed thoroughly and then dried. The protein was eliminated with 0.3 M sodium hydroxide solution at a ratio of 1 : 10% (w/v) at 80°C for 2 hours, rinsed with water until the neutral pH and dried at 50°C. Mineral was removed with 0.55 M hydrochloric acid solution at a ratio of 1:20% (w/ v) at room temperature for 24 hours, washed with DI water until neutralized pH and dried at 50°C. The chitin powder was boiled with 50% sodium hydroxide solution (w/v) at a ratio of 1:2% (w/v) at 120°C for 6 hours, washed with DI water until reaching a neutral pH, dried at 50°C. Chitosan product was characterized by using a Fourier Transform Infrared Spectrophotometer) Model 45321 Spectrum 2000 Perkin Elmer Company, USA.

2.3 Nano chitosan preparation process

Chitosan powder 100 mg was weighed, dissolved with 3% acetic acid 20 cm^3, added 0.5% sodium chloride 4 cm^3, blended with magnetic stirrer for 120 minutes at room temperature to give chitosan gel. Chitosan gel 5 cm^3 was pipetted, added 10 cm^3 linseed oil, shaked and added 4 cm^3 span 80, stirred with magnetic stirrer for 30 minutes at room temperature, slowly added acetone and stirred with a magnetic stirrer at room temperature overnight, then evaporated to remove acetone for 10 minutes at a temperature of 50°C, slowly added 4.86 cm^3 saturated glutaraldehyde in toluene (GST) at room temperature, stirred for 120 minutes at room temperature, centrifuged at 5000 rpm for 30 minutes. After that the mixture was left to dried at room temperature and ground into fine powder [12]. Nano chitosan product was characterized by using infrared spectroscopy techniques and morphology was also confirmed by the Scanning Electron Microscope (SEM).

2.4 Preparation of nano chitosan/nano zinc oxide and cotton fibers coated

Nano chitosan was dissolved in 1% (v/v) acetic acid for 2–3 hours, sonicated for 2 hours. Nano zinc oxide (NanoZnO, Infarmat Product Company # 30N-0801) was prepared by mixing GPTMS sol (110 mL) ((3-Glycidyloxypropyl) trimethoxysilane (GPTMS, 98%) from SIGMA-ALDRICH, Lot # STBF6130V). Then the mixture was sonicated for 2 hours. Cotton fibers were dipped into nano chitosan/nano zinc oxide solution, then heated at 130 degrees celsius for 30 minutes and washed with 40 degrees celsius water, and then air dried [12].

2.5 Preparation of indigo dyed

1 kilogram of indigo paste was mixed with 1 liter of warm (40°C) alkali wood pH 9 to 11. Tamarind 100 gram was mixed with 1 liter warm water at 40°C. The reaction was mixed together and continuous stirred for 5 minutes, then left at room temperature for 24 hours.

2.6 Cotton dyed with indigo

Cotton fabrics coated with nano chitosan/nano zinc oxide were soaked in deionized water for 1 hour, dyed with indigo for 5 minutes, and then allowed to be oxidized with oxygen in the air for 3–5 minutes, duplicated 5 times washed until neutral pH and air dried at room temperature.

2.7 Physical properties of cotton fabrics testing

The dyed cotton fabrics were measured the color strength by using the Chroma meter for the K/S, L*, a* and b* values. Morphology of cotton coated with nano chitosan and nano zinc oxide was analyzed by the scanning electron microscope (SEM), model JSM-6010LV, JEOL, USA. The light fastness was measured according to ISO 105-BO2: 1994 (E), washing fastness was measured according to TISI 121, Volume 3: 2009 Method A (1) (40°C, 30 minutes). The washing fastness of nano materials washed for 10, 20 and 30 times was carried out and the UV resistance was also confirmed by using the UV-visible spectrophotometer (UV), Lambda 35, Perkin Elemer Company, USA. The coated samples were characterized in the wavenumber range between 4000 and 400 cm^{-1} by using a Fourier Transform Infrared Spectrophotometer) Model 45321 Spectrum 2000, Perkin Elemer Company, USA.

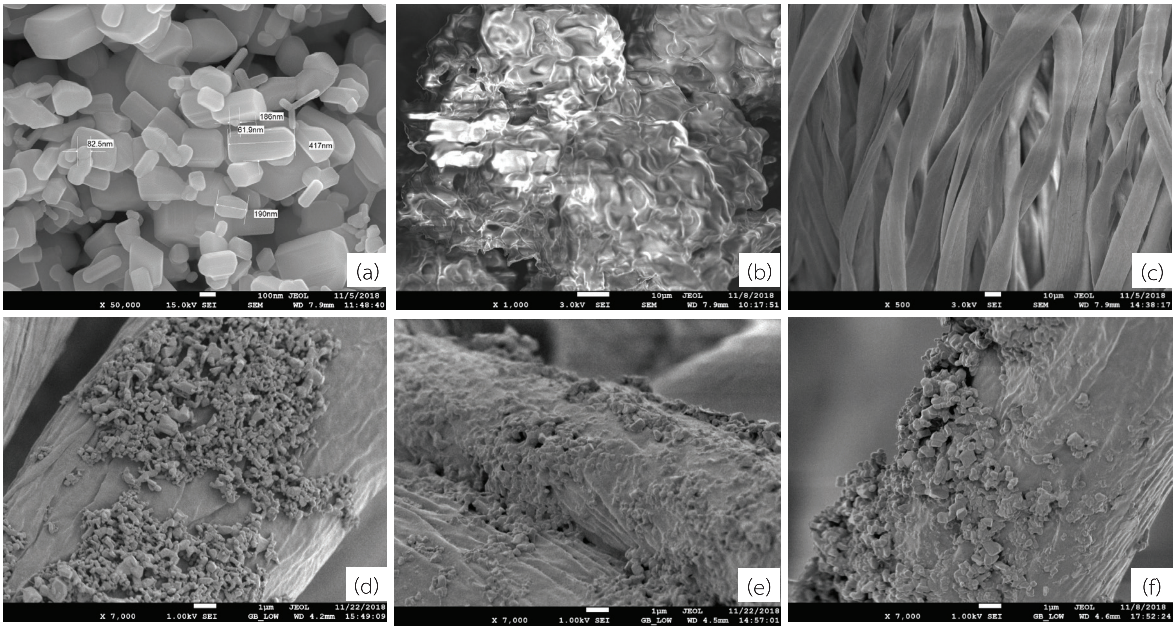

Figure 2: SEM photographs of (a) nano zinc oxide (b) nano chitosan (c) cotton coated with nano chitosan and nano zinc oxide at various ratio of (d) 0.1 : 3 g (e) 0.3 : 3 g and (f) 0.5 : 3 g.

3. Results and Discussion

3.1 Physical properties of coated cotton fabrics testing

Figure 2 shows SEM photographs of cotton coated with (a) nano zinc oxide (b) nano chitosan (c) nano chitosan and nano zinc oxide at various ratio of (d) 0.1 : 3 g (e) 0.3 : 3 g and (f) 0.5 : 3. It was shown that zinc oxide particles have an average size about 82.5–417 nm. Uncoated cotton has a smooth surface while the cotton coated with nano-chitosan and nano-zinc oxide reflected roughly the surface contained nano chitosan and nano zinc oxide particles, which is useful to increase the surface area, causing the fabrics to absorbed dye molecules. It can be improved durable to washing and better UV resistance properties. The FT-IR spectrum of uncoated cotton, cotton coated with nano zinc oxide, nano chitosan and nano chitosan and nano zinc oxide as shown in Figure 3. For cotton as shown in Figure 3, the characteristic peak of 3331 cm^{-1}, 2896 cm^{-1}, 1627 cm^{-1}, 1427 cm^{-1}, 1314 cm^{-1}, and 556 cm^{-1} were ascribed to the vibration of OH stretching, CH_2 stretching, OH bonding, C-H wagging, C-H bending and C-H stretching, respectively. The absorption peaks appeared at 1106, 1063 and 1029 cm^{-1} were attributed to C-O-C bridge [7]. The O-Zn-O vibration bands of cotton coated with nano chitosan and nano zinc oxide appeared at 661 cm^{-1} and the O-Zn-O oscillation strip appeared at 436 cm^{-1}, which confirmed that zinc oxide nanoparticles coated on cotton [17], [18] and the position of the NH_2 stretching of cotton coated with nano chitosan and nano zinc oxide nanoparticles appeared at position 2922 cm^{-1}, 2877 cm^{-1}, 2872 cm^{-1} and 2896 cm^{-1}, respectively [12] which confirmed that there are chitosan nanoparticles stuck on cotton.

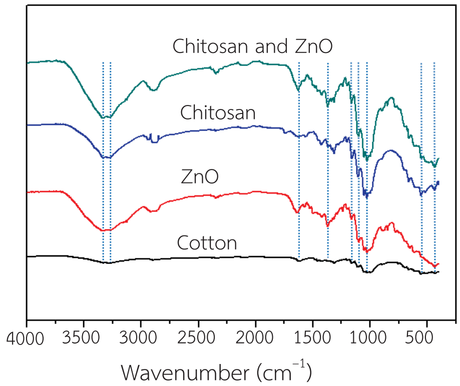

Figure 3: FT-IR spectra of uncoated cotton, cotton coated with nano zinc oxide, cotton coated with nano chitosan and cotton coated with nano chitosan and nano zinc oxide.

3.2 Color shade and color strength of cotton indigo dyed

Figure 4 shows color shades of cotton coated with nano chitosan : nano zinc oxide in various ratios (a) 0.5 : 1 g, (b) 0.5 : 2 g and (c) 0.5 : 3 g and indigo dyed. It was found that the color shades slightly decreased as the concentration of nano zinc oxide increased. Figure 5 shows the color strength of cotton coated with nano chitosan, nano zinc oxide, indigo dyed, washed for 10, 20 and 30 times. It was found that when the number of washing increased, the color strength (K/S) slightly decreased, corresponding to the washing fastness which will little decrease when the number of washing increases (Table 3), the L*, a* and b* values were also slightly change.

3.3 Durability of coated cotton dyed with indigo

Light fastness and washing fastness of cotton coated with nano chitosan, nano zinc oxide and indigo dyed revealed that light fastness and washing fastness properties were average at the

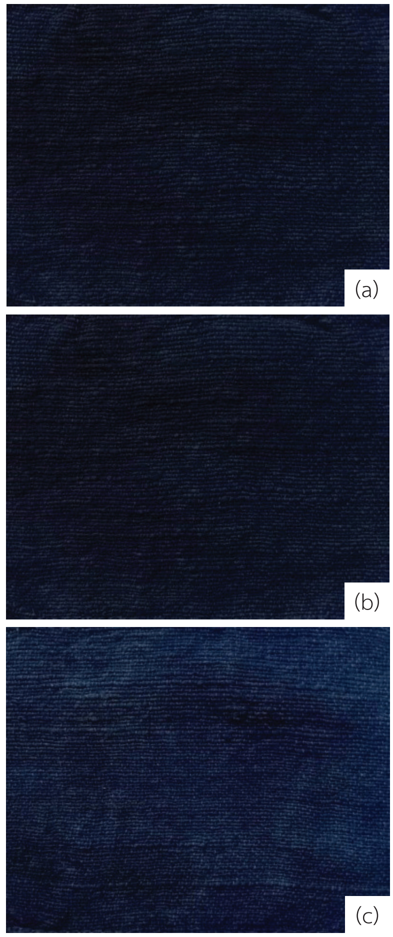

Figure 4: Color shades of cotton coated with nano chitosan : nano zinc oxide in various ratios (a) 0.5 : 1 g, (b) 0.5 : 2 g and (c) 0.5 : 3 g and indigo dyed.

level of 4–5 (good–very good), washability of washing for 10, 20 and 30 times reflected the fastness at an average level of 4–5 (good–very good) (Table 1). It can be implied that cotton coated with nano chitosan and nano zinc oxide improves fastness properties. Krishnaveni and Thambidurai [19] prepared nano chitosan and ZnO coated on cotton fabrics. They found that coated samples had various properties such as antibacterial,

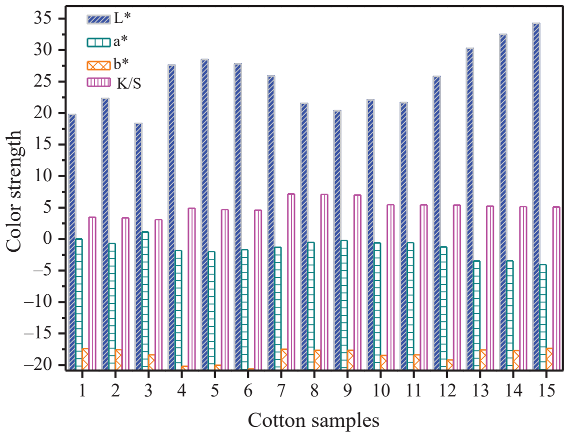

Figure 5: Color strength of cotton coated with nano chitosan and nano zinc oxide at various ratios, cotton fabrics (1=10 washed, 2=20 washed, 3=30 washed), cotton fabrics coated with nano zinc oxide 3 g (4=10 washed, 5=20 washed, 6=30 washed), cotton fabrics coated with nano chitosan 0.5 g (7=10 washed, 8=20 washed, 9=30 washed), cotton fabrics coated with nano chitosan 0.3 g and nano zinc oxide 3 g (10=10 washed,11=20 washed, 12=30 washed) and cotton fabrics coated with nano chitosan 0.5 g and nano zinc oxide 3 g (13=10 washed,14=20 washed, 15=30 washed) indigo dyed, washed for 10, 20 and 30 times.

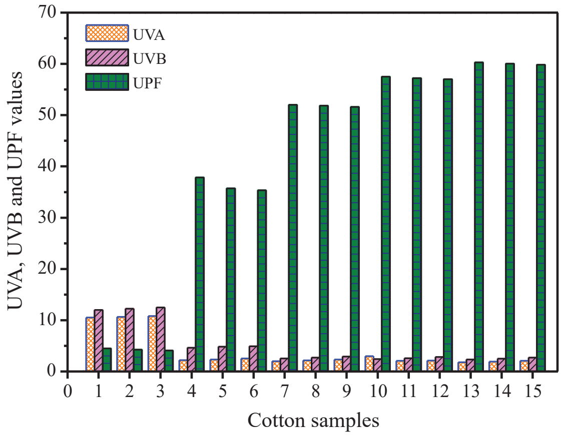

Figure 6: UPF values, UVA and UVB protection ability of uncoated cotton fabrics (1=10 washed, 2=20 washed, 3=30 washed), cotton fabrics coated with nano zinc oxide 3 g (4=10 washed, 5=20 washed, 6=30 washed), cotton fabrics coated with nano chitosan 0.5 g (7=10 washed, 8=20 washed, 9=30 washed), cotton fabrics coated with nano chitosan 0.3 g and nano zinc oxide 3 g (10=10 washed, 11=20 washed, 12=30 washed) and cotton fabrics coated with nano chitosan 0.5 g and nano zinc oxide 3 g (13=10 washed,14=20 washed, 15=30 washed) indigo dyed, washed for 10, 20 and 30 times.

odor reduction, increase of washing fastness. The chitosan nanoparticles coated on cotton were also better than chitosan because of higher surface area, allowing cotton to have better UV radiation protection ability. Due to a lot of surface area of the small nanoparticles structure, cotton fabrics can better reflect or prevent radiation. Cotton was improved by using cycl-cyclodextrin and chitosan found that chitosan can increase color adhesion [20]. Wool fibers coated with chitosan help to resist bacteria, absorb sweat, good color absorbed from henna and washed resistance [21]. Figure 6 shows the UPF values, UVA and UVB protection ability of cotton fabrics coated with nano chitosan and nano zinc oxide at different ratios, indigo dyed, washed for 10, 20 and 30 times. Cotton was coated with 0.5 g nano chitosan and nano zinc oxide in the various ratios of 1, 2 and 3 g indigo dyed, washed for 10, 20 and 30 times reflected the UPF value for UV protection in the range of 51.61–60.31 (excellent). UPF categories with relative transmittance and protection level as shown in Table 2. Comparison of UV protection of cotton coated with nano chitosan and zinc oxide at various methods is shown in Table 3. Coating methods such as microwave method, pad dry cure, immerse and cross link have an effect on UV protection properties [1], [8], [11], [17]–[19].

The excellent UV protection of finished cotton fabrics due to energy band of ZnO at room temperature is 3.37 eV and the ZnO on the cotton fabrics also has a good absorption effect on UVA and UVB [18]. The Ultraviolet Protection Factor (UPF) of treated samples is higher than untreated cotton fabric, which is increased proportionally to the increase of the concentration of nano chitosan and zinc oxide particles [17].

Table 1 Light fastness and washing fastness properties of cotton fabrics coated with nano chitosan and nano zinc oxide, indigo dyed, washed for 10, 20 and 30 times

Cotton Samples	Light Fastness	Washing Fastness			
		1 washed	10 washed	20 washed	30 washed
cotton	5	4-5	4-5	4	4
nano zinc oxide 1 g	5	5	5	4-5	4-5
nano zinc oxide 2 g	5	5	5	5	4-5
nano zinc oxide 3 g	5	5	5	5	4-5
nano chitosan 0.1 g	4-5	4-5	4-5	4-5	4
nano chitosan 0.3 g	4-5	4-5	4-5	4-5	4
nano chitosan 0.5 g	4-5	4-5	4-5	4-5	4
nano chitosan 0.1 g: 1 g nano zinc oxide	5	4-5	4-5	4-5	4
nano chitosan 0.1 g: 2 g nano zinc oxide	5	4-5	4-5	4	4
nano chitosan 0.1 g: 3 g nano zinc oxide	4-5	5	4-5	4	4
nano chitosan 0.3 g: 1 g nano zinc oxide	5	5	4-5	4	4
nano chitosan 0.3 g: 2 g nano zinc oxide	5	5	5	5	5
nano chitosan 0.3 g: 3 g nano zinc oxide	5	5	5	5	5
nano chitosan 0.5 g: 1 g nano zinc oxide	5	5	5	5	4-5
nano chitosan 0.5 g: 2 g nano zinc oxide	4-5	5	5	4-5	4
nano chitosan 0.5 g: 3 g nano zinc oxide	4-5	5	5	4-5	4

Table 2 UPF categories with relative transmittance and protection level

UPF range	Protection category	UVB transmittance (%)
<15	Insufficient protection (The amount of radiation that can be protected is less than 93.3%)	>6.7
15–24	Good protection (The amount of radiation that can be protected is between 93.3-95.9%)	6.7-4.2
25–39	Very good protection (The amount of radiation that can be protected is between 96.0-97.4%)	4.1-2.6
40–50, 50+	Excellent protection (The amount of radiation that can be protected is higher than 98%)	≤2.5

Ref: [22]

Table 3 Comparison of UV protection of cotton coated with nano chitosan and zinc oxide at various methods

Material coated	Methods	UV Protection level	References
ZnO	Microwave method	at pH 6–7, 8–9, 10–11, UPF value as 222.52 162.68 and 202.57, respectively. (Excellence)	[8]
ZnO/CMCS 0.25%	Pad dry cure	UPF value equal 30+ (Very good)	[19]
ZnO 2 g	Immerse	UPF value equal 22.8 (Good)	[11]
ZnO/CS 4 g	Pad dry cure	UPF equal 8.3 (low)	[17]
ZnO 2%	Acrylic binder and Pad dry cure	UV Protection 75%	[1]
PT-ZnO/CMCS-1% washed 30 cycles	Cross link	UPF equal 50+ (Excellence)	[18]
ZnO (1, 2 and 3 g) : CS (0.5 g) washed 30 cycles	Cross link	UPF value equal 41.14–105.07 (Excellence)	This work (2019)

4. Conclusions

Cotton coated with nano chitosan and nano zinc oxide refected that the particle sizes of nano chitosan and nano zinc oxide on the cotton surface are useful for increasing surface area, causing the fiber to absorb dye molecules and has improved better UV resistance properties. The color strength of cotton coated with nano chitosan and nano zinc indigo dyed, washed for 10, 20 and 30 times was investigated. The color strength (K/S) was slightly decreased, corresponding to the washing fastness will little decreases when the number of washing increases. Light fastness and washing fastness properties of coated cotton, nano chitosan and nano zinc oxide indigo dyed were in the average level of 4–5 (good–very good). When washed for 10, 20 and 30 times, it was found that the washing fastness properties were slightly changed, which the average of 4–5 (good–very good). Cotton coated with the ratios of 0.5 grams nano chitosan and 1, 2 and 3 grams of nano zinc oxide and indigo dyed, washed for 10, 20 and 30 times, shows that coated cotton still exhibited good durable to washing. The coated cotton can be improved its fastness properties and it becomes excellent sun protective clothing with an UPF values in the range of 51.61–60.31.

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