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Bentonite Nanoclay Assisted Hydrophilic Nylon Fabrics

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Authors' contributions

This work was carried out in collaboration between all authors. Author SBYA designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Authors SP and KMNS managed the analyses of the study. Authors SW and MCWS managed the literature searches. All authors read and approved the final manuscript.

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Original Research Article

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ABSTRACT

Aim: Biomimetic surface modifications have gained significant attention in fabric innovations. In this study, elephant mud bathing was mimicked to create a superior hydrophilic nylon fabric.
Place and Duration of Study: Sri Lanka Institute of Nanotechnology and The University of Moratuwa, Sri Lanka, June 2017- March 2018.
Methodology: Bentonite nanoclay (BNC) grafted on nylon using silane as a coupling agent. Fourier transform infrared spectrophotometry, electron microscopy, energy dispersive X-ray spectroscopy

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and thermogravimetric analysis confirmed the successful grafting of nanoclay on nylon while textile protocols proved the wettability.
Results: Infrared spectroscopy and elemental analysis confirmed the presence of organic chains and Si groups in bentonite nanoclay modified nylon fabrics. The accomplishment of the surface modification was quantitatively proved by thermogravimetric analysis. SEM images clearly show a thin layer of clay on nylon fibres after being treated with bentonite nanoclay. BNC coated nylon show superior wettability and dryability.
Conclusion: It is expected that this bio-inspired wettable nylon fabric may break the barrier of using nylon in various hydrophilic textile applications.

Keywords: Bentonite nanoclay; biomimetic; surface modifications; nylon.

1. INTRODUCTION

Moisture management is one of the key performance criteria in today's apparel industry [1]. However, high demand synthetic fabrics such as nylon lack in moisture management properties due to their hydrophobic nature. Nylon fabrics are excellent in mechanical, thermal, and chemical properties. Yet, nylon fabric is weak in certain properties such as anti-electrostatic property, lack of comfortable touch with human skin, and low moisture regain [2]. Hence, new chemistries for surface modifications in creating hydrophilic nylon fabrics to meet market needs have received much attention [3,4]. Nature always provides sustainable, cost-effective, and flexible alternatives for various problems of the eco system [5,6]. By mimicking nature's way of cooling elephant's body temperature using mud, bentonite nanoclay was identified as an ideal sustainable solution to develop a wettable nylon fabric. Bentonite nanoclay (BNC) exhibits high cation exchange capacity and high swelling capacity in relation to hydration [7]. The structure of bentonite is composed of a three-layer platelet with an octahedral aluminum hydroxyl sheet sandwiched between two layers of silicon-oxygen tetrahedral. The nano size space between adjacent platelets of BNC comprises of exchangeable cations, which draw water, and form a rigid network made up of water layers [8]. Hence, this nanospace is vital for BNC's incomparable hydrophilicity. In this study, a silane coupling agent couples BNC and nylon with the intention of increasing hydrophilic properties of nylon.

2. METHODOLOGY

Purified nylon was stirred in 2 mmoldm-3 of (3-Glycidyloxypropyl)trimethoxysilane solution for 1 hour. APTES modified fabric was padded and cured at 110°C and washed thoroughly. A dispersion of clay was obtained by dissolving 4 g of bentonite clay (Aldrich), in 100 ml of deionized water. BNC of 100 nm size was obtained by ball milling (FRITSCH PULVERISETTE 7-grinder). Then, the fabric was dipped in a dispersion of BNC for 1 hour. The dipped fabric was padded and cured at 110°C and washed thoroughly. BNC grafted and pristine nylon fabric samples were characterized by Fourier transform infrared spectrophotometry (FTIR), Scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDX). Thermogravimetric analysis (TGA) was carried out on an SDT Q600 thermoanalyser (TA Instrument, sample mass ~10 mg; heating rate 10°C/min; nitrogen flow). Wettability of fabric samples was measured using ASTM TS-018 protocol. A drop of distilled water was allowed to fall onto the fabric sample, and the time taken for the drop of water to get fully absorbed into the fabric was recorded. The absorptive capacity of the fabric was tested using ASTM D1117-80 protocol. Five samples (76 mm^2) of treated and pristine nylon were weighed and dipped in distilled water for 5 min and hung vertically for another 5 min to allow extra water to drip down. Finally, the fabrics were weighed again. The drying rate of the fabric was measured by exposing to 10 µL of water, while in contact with a heated plate set to 37°C (human body perspiring temperature). To check the stability of BNC coating on nylon, 20 washing cycles were performed at 50°C with non-ionic detergent Ultravon CN Ciba for 45 min (AATCC 61 (2A)).

3. RESULTS AND DISCUSSION

(3-Glycidyloxypropyl)trimethoxysilane was employed as a coupling agent and the methoxy groups first hydrolysis into hydroxyl, and react with hydroxyl groups on the surface of BNC, forming a stable Si–O–Si bond on drying. Epoxy silane containing a reactive epoxy group could

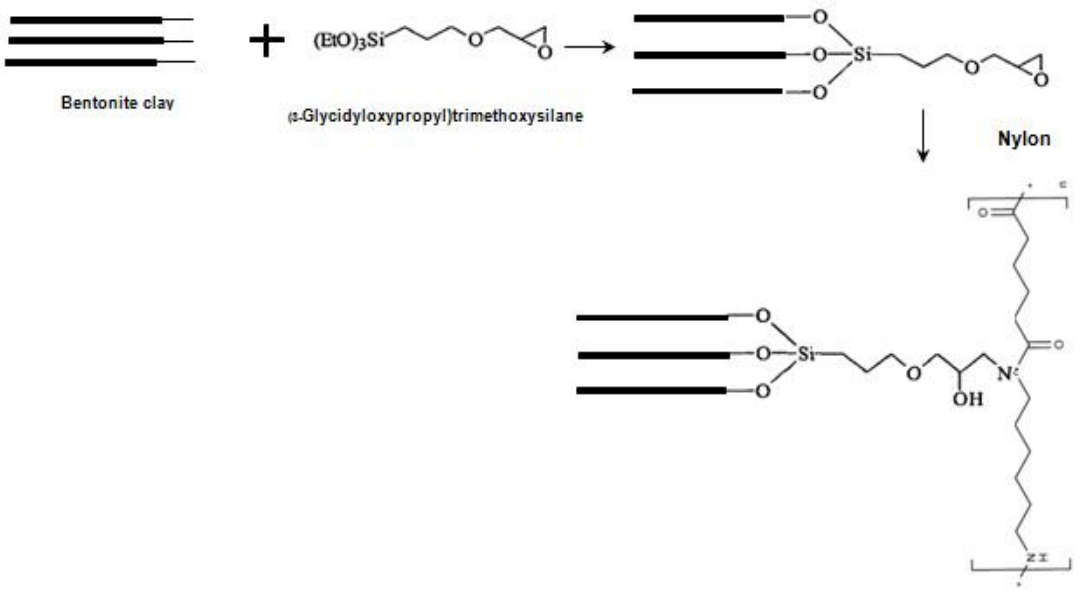

Fig. 1. The reaction process of silane functionalized BNC reacting with nylon fabrics

react with secondary amines in nylon fabric [9]. The reaction process is shown in Fig. 1. The presence of characteristic absorption bands in FTIR spectra of BNC grafted nylon proves a new bond formation between silane modified BNC and nylon fabric. Successfully grafted epoxy silane on BNC can be confirmed by a group of absorption bands in 3000–2800 cm^{-1} in spectrum E (Fig. 2). This absorption is attributed to the valence vibration (CH) of the propyl chain in epoxy silane. The absorption band in 1095-1075 cm^{-1} in spectrum B (Fig. 2.) shows the strong broad band which is attributed to valence vibration of Si–O–Si. The blue region in spectrum D (Fig. 2) shows a broad intense absorption band (above 3420 cm^{-1}) due to the vibrations of OH^- groups in water molecules of clay, participating in the formation of hydrogen bonds. In spectrum D (Fig. 2), intensive bands in approximately 1095-1075 cm^{-1} represent the asymmetric stretching of siloxane groups (Si–O–Si) [10]. Hence, FTIR spectra shows that nylon has been modified by clay successfully.

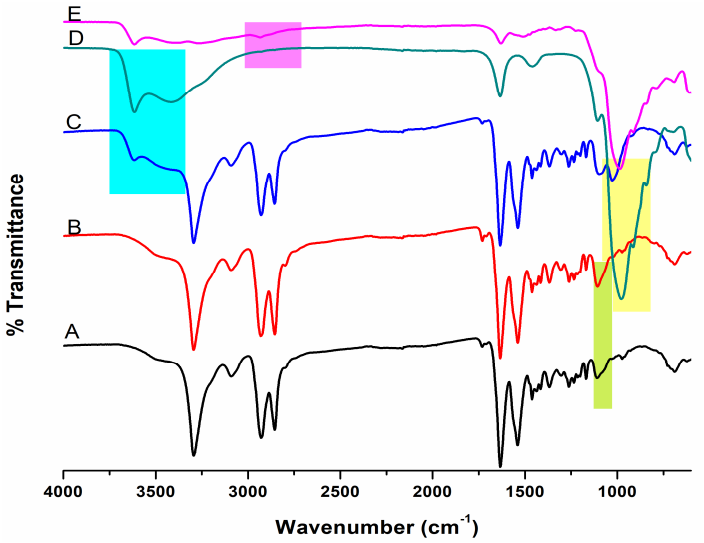

Fig. 2. FTIR spectra of (A) pristine nylon, (B) silane modified nylon, (C) BNC functionalized nylon (D) BNC and (E) epoxy modified BNC

SEM image of pristine nylon fabric (Fig. 3. A) indicates a smooth fibre surface after the purification. SEM images in Fig. 3. B and C clearly show a thin layer of BNC on nylon fibres after being treated with BNC. After the tenth washing cycle, the surface morphology (Fig. 3. D) is the same as the unwashed sample. BNC grafted nylon was proved further by EDX analysis (Fig. 4.) showing presence of significant amounts of silicon, aluminum, calcium, sodium, and magnesium elements.

The resulted thermograms show that pristine nylon fabric (Fig. 4. (B) Black) undergoes thermal degradation beginning at 452°C and with a total loss of mass of 98%. However, silane modified nylon (Fig. 4. (B) Green) undergoes the same degradation, with a lesser loss of mass of 97%. This is due to the organic and inorganic Si contents in (3-Glycidyloxypropyl) trimethoxysilane. BNC modified nylon fabric (Fig. 4. (B) Purple) undergoes the same degradation with even a lesser loss of mass of 94% compared to silane modified nylon fabric. The 6% residue remain is due to BNC bound to nylon fabric.

Excellent wettability, water absorptive capacity and drying rate of BNC grafted nylon (Table 1.) confirm the superior wettability of the nano modification due to instant diffusion of water into the nanospace and clinging of water with hydroxyl groups on the surface of BNC.

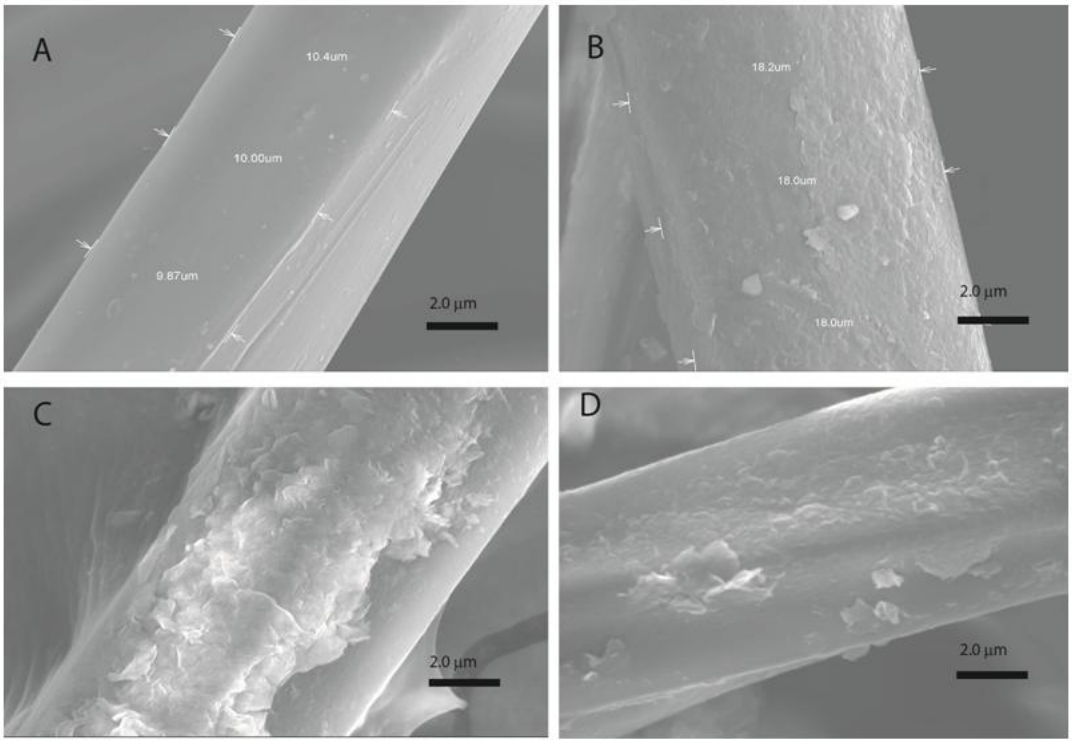

Fig. 3. SEM images of (A) pristine nylon, (B) (C) BNC modified nylon and (D) washed BNC grafted nylon

Table 1. Standard protocol test results for wettability

	Pristine nylon	BNC grafted nylon	10 times washed BNC grafted nylon
Wettability test (s)	30.20	0.00	0.00
Absorptive capacity (%)*	112	280	271
Drying rate (ml/h)**	0.07	0.10	0.10

**(B-A)/A*
***0.010/drying time*

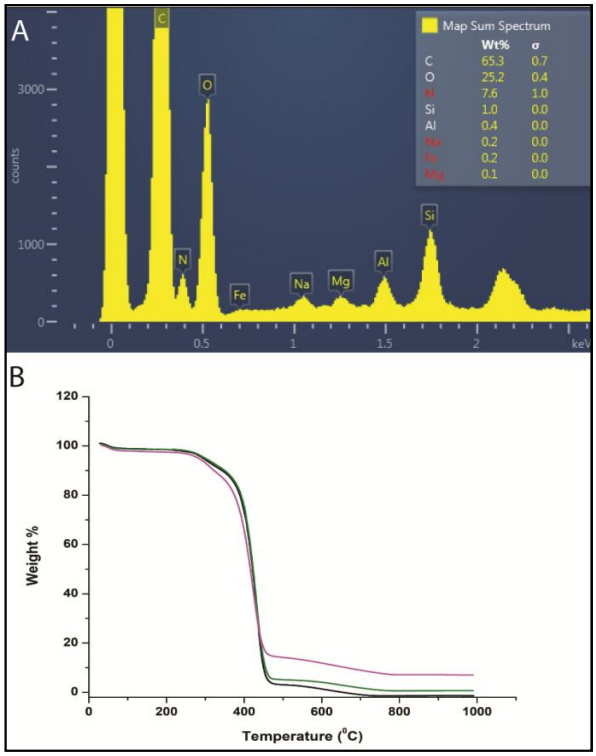

Fig. 4. (A) SEM-EDX spectrum of BNC functionalized nylon and (B) Thermograms for pristine nylon (Black), silane functionalized nylon (Green) and BNC grafted nylon (Purple)

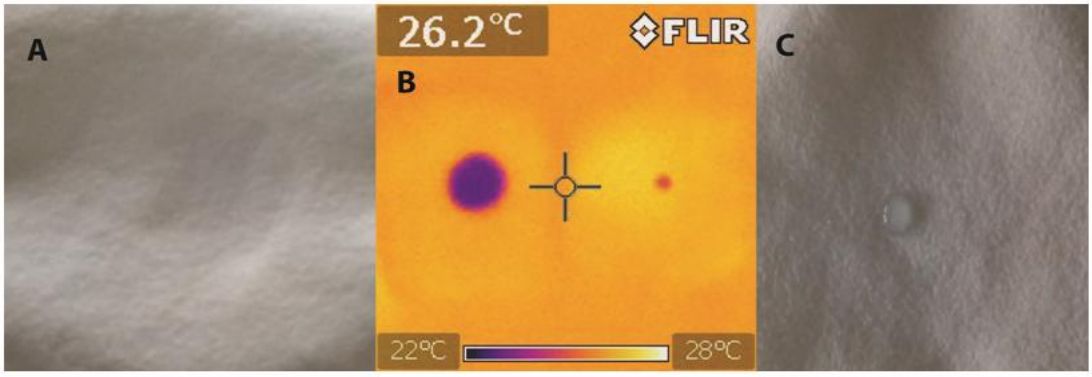

Fig. 5. Immediate view of a water drop fallen on (A) pristine nylon, (C) BNC functionalized nylon and (B) images (A) and (C) through IR camera

In Fig. 5. A drop of water was dropped on pristine and BNC grafted nylon to demonstrate the superior wettability of modified nylon. An Infra-red (IR) image (Fig. 5.B) was taken to clearly demonstrate the spreading of the water drop on BNC grafted nylon. The hydrophilic nature of BNC attracts water while its excellent swelling capacity enhances spreading of water promoting the superior wettability of BNC grafted fabric. The surface morphology and the wettability of 20 times washed BNC grafted nylon remained the same as the unwashed samples confirming the covalent bond between the fabric and the coating. In fact, the siloxane bond between (3-Glycidyloxypropyl) trimethoxysilane and BNC, and the amide bond between BNC and the nylon fabric, have given the best adhesion and washing resistance properties to the treated nylon fabric [11].

4. CONCLUSION

FTIR spectrum confirmed the covalent bond network in the (3-Glycidyloxypropyl) trimethoxysilane modified BNC coated nylon fabric. SEM images also show the occurrence of surface modification. BNC coated nylon showed superior wettability and dryability. The BNC coating on nylon, appears as a convenient green modification route to produce a wettable nylon, which can be used for many hydrophilic fabric applications apart from its excellent ability to substitute expensive natural fibre usage in clothing.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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