

Adhesive less Silica Nanoparticle Coating on Nylon Woven Fabric and Its Characterization

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ABSTRACT

Environment-friendly functional woven fabric with light weight has higher market demand in this era. This paper is aimed to prepare and characterize super-hydrophobic nylon-6 woven fabric by using silica nanoparticles, coupling agent 3-aminopropyltriethoxysilane (APTES), and a long chain hydrophobic agent hexadecyltrimethoxysilan (HDTMS). Synthesize of silica nanoparticles is processed with a modified Stöber method resulting in a mono-dispersed particle whose diameter is 51-60 nm. In this experiment chemical bonds presenting over the surface silica nanoparticle are Si-CH₃ and Si-OH. Due to the reaction between the hydrolyzed APTES and the first layered surface, the Si-OH group is spectra onto the surface. The hydrolyzed HDTMS molecules created a bond to the surface by the formation of Si-O-Si bonds. As result, a long chain of organo-silane with low surface free energy is introduced onto the fabric surface. The hydrophobic coated surface appeared after spray coating with additional treatment without any adhesive. The super-hydrophobic nylon-6 woven fabric has been coated by spray method with static water contact angle 151.8°. Characterization manifests a good self-cleaning tendency and low permeability difference.

Keywords: Silica nanoparticles, Nylon-6 woven fabric, super-hydrophobic, coating, synthesis, Stöber method.

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I. INTRODUCTION

Consumer demand for a comfortable and healthy lifestyle at the same time in one certain product has created the concept of multi-functional textiles. Hydrophobicity, air permeation, soil release tendency, and mostly lightweight clothes, etc. are in high demand of the market, and in current decades the attraction raises of hydrophobic or super-hydrophobic fabrics. Hydrophobic surfaces are characterized by a water contact angle of 90° to 150° and for super-hydrophobic is greater than 150° [1]. "Lotus leaf" which constitutes the hydrophobic epicuticular wax (decrease surface wetting) associated with the micro or nano-scale stratified architectures has made the concept of ultra-hydrophobic or super-hydrophobic [2]. Proper micro or nanostructures to create surface roughness and materials with low surface energy in a combined form can produce a super-hydrophobic

[3]. The roughened surface on textile substrates are studied by using various nanoparticles (NPs) such as silica NPs, silver NPs, and copper oxide NPs, where hydrophobic modification of these nanoparticles has been developed by using fluorinated compounds because of their good performance properties [4][5][6]. Nylon 6 or polycaprolactam polymer has developed by Paul Schlack at IG Farben, that reproduce a semi-crystalline polyamide without violating the patent on its production and contains similar properties of nylon 6,6 and nylon 6 polymerization is an exceptional case in the comparison between condensation and addition polymers, rather forming a ring-opening polymerization[7]. High-performance technical textiles in total effective liquid repellence, self-cleaning, unidirectional liquid transport, or to create barrier coatings on fiber surfaces the surfacemments of super-hydrophobic textile is in demand. Plenty of novel approaches to lower the free energy of fiber surface, by applying wet-chemical finishes-silane chemistry, nano composite structures, or physically applied thin layers, which are the modern chemical developments. Alike other fields, textile researchers are also working to mimic the extreme water repellence of several plant and animal surfaces according to the understanding by Cassie and Baxter during the last years[8]. Although, these hydrophobic products has hazardous effects on human health as well are harmful for environment [9]. So, the research turns to the development of environmental-friendly hydrophobic agents which is essential for the textile industry. Consequently, some alternative hydrophobic active agents were suggested by researchers Zhu, Gao, Guo, and Yang[10].

In “Super-hydrophobic cotton fabrics prepared by sol–gel coating of TiO₂ and surface hydrophobization” - fibers coating with titanium sol to generate a dual-size surface roughness followed by hydrophobization with stearic acid, (1H,1H,2H,2H) perfluorodecyltrichlorosilane or their combination, hydrophilic cotton fabrics comes into super-hydrophobic. The incorporation of TiO₂ particles by titanium sol coating cause a dual-size surface roughness for enhancing the hydrophobicity and also result in good UV-shielding property[11]. Alexey V. Krasnoslobodtsev and Sergei N. Smirnov has researched on “Effect of Water on Silanization of Silica by Trimethoxysilanes” and water has a big influence on the mechanism of monolayer formation that obtained on a silica surface. Trimethoxysilane(TMS) in the absence of water formed sub monolayers with only one Siloxane bond that binding the functional tails with the surface of substrate and hydrolysis of the remaining methoxy groups on the initial immobilized silane layer by water and followed by another silanization yields enhanced surface density of silanes with improved lateral polymerization. The improved technique allows surface concentration of coumarin dye molecules of $2.7 \times 10^{14} \text{cm}^{-2}$, which is almost 1.3 times higher than what is possible without water treatment[12]. “Super-hydrophobic cotton fabrics prepared by one-step water-based sol–gel coating A simple one-step” has published by the author L. Xu, et al. and they studied super-hydrophobic coating method for cotton fabrics based on a modified silica hydrosol is presented in this study. The modified silica hydrosol was prepared by the co-hydrolysis or co-condensation of methyl trimethoxysilane and a non-fluoro compound, hexadecyltrimethoxysilane(HDTMS) via water-based sol–gel reaction and produced a super-hydrophobic cotton fabric with a water contact angle of 151.9[13]. Synthesis of mono-dispersed silica nanoparticles with high concentration by the Stober process, sol-gel science and technology and reached that silica sol with about 4wt% in concentration and with particle diameter about 10 nm was obtained by controlling the reaction conditions in the Stöber process. The particle concentration was increased up to 15 wt% without aggregation after removing the solvent under a reduced pressure[14]. Facile fabrication of multifunctional fabrics by using copper and silver nanoparticles for antibacterial, super-hydrophobic, conductive fabrics that aims to develop a multifunctional fabric for antibacterial, super-hydrophobic and conductive performance using a facile fabrication method had developed by H.R.Hong et al. Conductive metal particles, copper and silver, were used

as antibacterial agents and also to produce nano-scale roughness on the fabric surface. Fabrics proceed with Cu and Cu/Ag particles (with hydrophobic coating) displayed super-hydrophobic characteristics with the contact angle of 161° – 162° and the shedding angle of 7.0° – 7.8° . The produced fabric is considered as multifunctional fabric, as can be practically applied to self-cleaning smart clothing, which has reduced laundering need, without hygiene concerns[15]. Super-hydrophobic and ultraviolet protective nylon fabrics by modified nano-silica coating in 2016 and Silica nanoparticles (SiO_2) were synthesized by the sol-gel method then particles were applied on nylon knitted fabric by pad-dry-cure technique. The silica nanoparticles coating on fabric was modified by in situ deposition of zinc oxide (ZnO) and further hydrophobic modification was done by using sodium stearate (SS). Modified fabric showed super-hydrophobicity with a water contact angle of 151° and also excellent ultraviolet protection with an ultraviolet protection factor of 279.68 with retention of hydrophobic and UV protection properties up to 10 washing cycles[16].

More corresponding research work has been reviewed and studied their theory and mechanism as well. This research work is on improving hydrophobicity of Nylon-6 woven fabric with a coat of silica nanoparticle till super-hydrophobic, which will be synthesis by using Stöber method and surface roughness will increase by amino terminated silane. That will produce a fluorine free, eco- friendly and low cost process to make a hydrophilic (65° surface WCA[17]) nylon to super-hydrophobic.

II. EXPERIMENTAL

2.1 Materials

70D Nylon woven fabric, Tetraethoxyorthosilane (TEOS), 3-aminopropyltriethoxysilane (APTES) or KH-550, Hexa decyltrimethoxysilan (HDTMS), Ethanol, Toluene, Ammonia aqueous Solution (NH_4OH), all the chemicals used without any further treatment.

2.2 Synthesis of Silica Nanoparticles

“Stöber method” is an excellent process to prepare mono dispersed silica particles using sol-gel process [14], and silica particles with a diameter of about 100 nm to a few μm are easily prepared by this method[18]. Silica nanoparticles were prepared using the Stöber process (figure 1) and according to the reference [11], where the molar ratio of TEOS : EtOH: H_2O (25 wt% NH_4OH aq.) is 1 :126: 9. But some modified ratio of chemicals has also produced Silica nanoparticles, several chemical compositions has experimented. TEOS : EtOH : H_2O (25 wt% NH_4OH aq.) is 1 :63: 4.5, 2:63:4.5, 4.5:63:4.5 ,2:31.5: 4.5 ratios are took placed with different concentration rate ,where the particle size has great effect of concentration percentage[19]. TEOS and 50% of Ethanol in one beaker and NH_4OH with half of the Ethanol in another beaker has stirred in magnetic stirring for 10 minutes and then mixed in one beaker for more 4hours oscillation. The sonication machine has used for 30minutes and the solution has left at room temperature for 12hours to remove the solvent. Then an oven has used at 65°C for 3hours to the dry silica that appeared in powder form (figure 2)

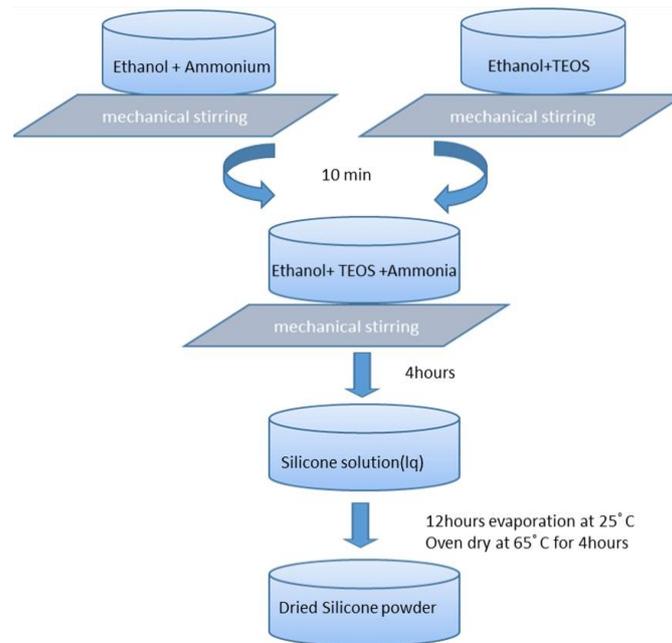


Figure 1: Silica particle formation process.

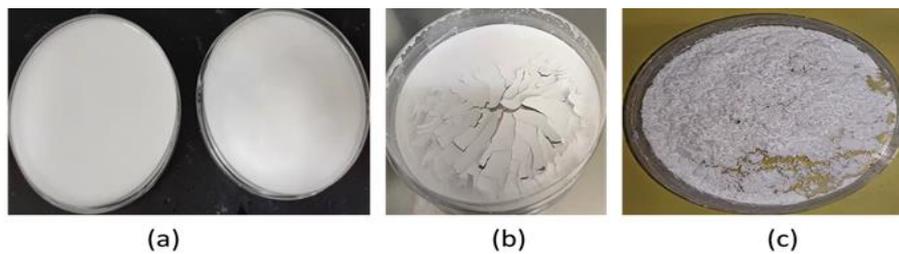


Figure 2 : (a) agitated milky white solution of silica, (b) evaporated dry Silica and (c) Oven dried silica powder.

2.3 Preparation of APTES-HDTMS chain extender coating solution

In this solution, toluene has used as a solvent along with KH-550 to disperse, which took 3hours of mechanical stirring to activate in the solution and then a minimal amount of HDTMS has addto in the solution and stirred it further 1hour.

2.4 Preparation of Super-hydrophobic Nylon Fabric

The brought nylon 6 woven fabric was washed with detergent for 10 minutes with normal water in a cyclic washing machine and dried at room temperature for 3hours. Application of silica solution and the chain extender coating solution completed by spray method , fabric has speeded evenly and spraying evenly on fabric assured very carefully in both side layer by layer. First layer of silica solution and last layer by APTES-HDTMS chain extender solution. After spraying fabric has transferred into the dryer for 10min at 85 °C and then cured at 130°C for 3min. Then the fabric was prepared for testing.

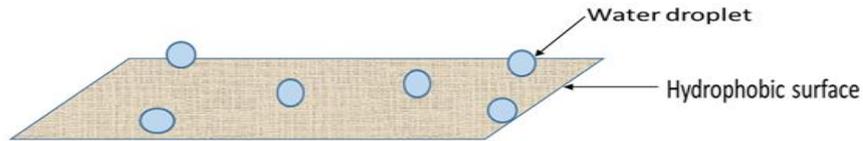


Figure-3: Designed super-hydrophobic surface of treated nylon-6 sample.

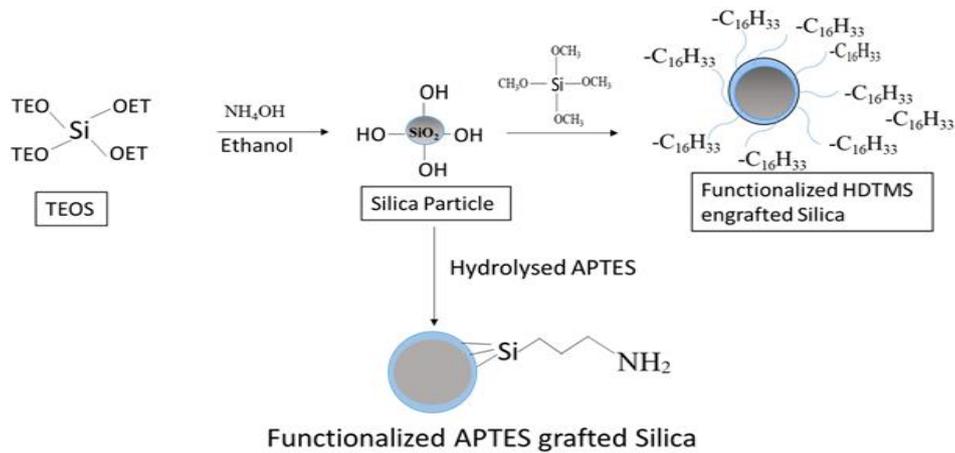


Figure 4 : Possible chemical mechanism through the treatment

2.5 Characterization

Ultra55 has used to test the scanning electron microscope (SEM), where the untreated and treated samples has tested several times after every development of the method and the treated samples microscopic photos are describing the coating presence in substrate. The Fourier transform infrared spectrometer (FTIR) test has used Nicolet-5700 with the minimum to maximum wavelengths. The static water contact angle has test by using JY-82B machine, water droplet was $5\mu\text{l}$. The water contact angle has focused on the sample's surface after 60seconds of falling the water droplet. Each sample has tested on five different positions and average data has considered as the final contact angle. Air permeability has tested by numerical air permeability tester YG461E, where the specimen size was 20cm^2 and an average result of three tests data of each sample has counted in final data. The durability to laundering has measured using washing conditions as per test method ISO 105 C01. A solution of 5g/L NaHCO_3 (sodium bicarbonate) non- ionic soap has used as washing liquor in which samples treated for 30 min at room temperature (34°C) for 15min . Then tap water used to rinsed and dried in an oven at 120°C for 15 min. The durability has studied till 15 washing cycles.

The anti-icing character of the nylon-6 fabric has evaluated by both static and dynamic tests. In the static test, some water droplets (≈ 0.1 mL) were first placed on the fabric surfaces and then kept at -18°C in a biochemical freezer for hard icing for 90min. The sample with fully frozen water droplets has placed on a 45° -slope plate at room condition (25°C and 50% relative humidity (RH) to test subsequent de-icing behavior within a very short time[20]. In the dynamic test, AATCC (American Association of Textile Chemists and Colorists) Test Method 22-2005 has used which is shown in the diagram below.

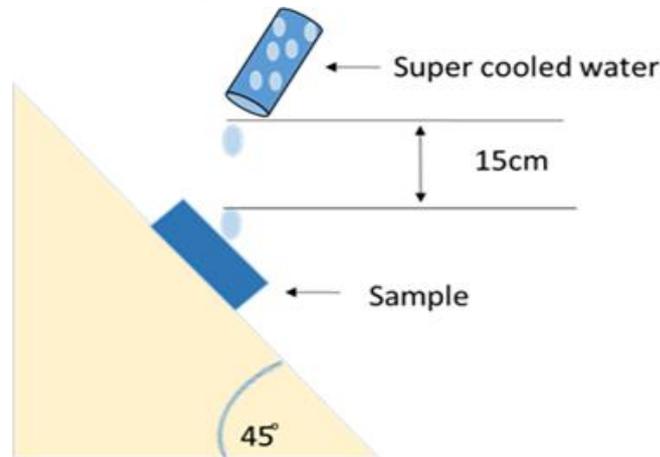


Figure 5: De-icing test in dynamic method

The sample was placed on a 45° -slope plate as shown in schematic diagram-2 and 50 mL super cooled water has sprayed onto the fabric surfaces from 15 cm height. Then immediately the deicing property has measured. The super cooled water was prepared by storing double distilled water in the freezer at temperature of -4°C for 2 hours.

Thickness of the untreated and treated sample has measured by the YG (B) 141D digital fabric thickness tester with a five averages for every sample.

III. RESULTS AND DISCUSSION

3.1 Surface Morphology of silica nanoparticles and super-hydrophobic nylon fabric

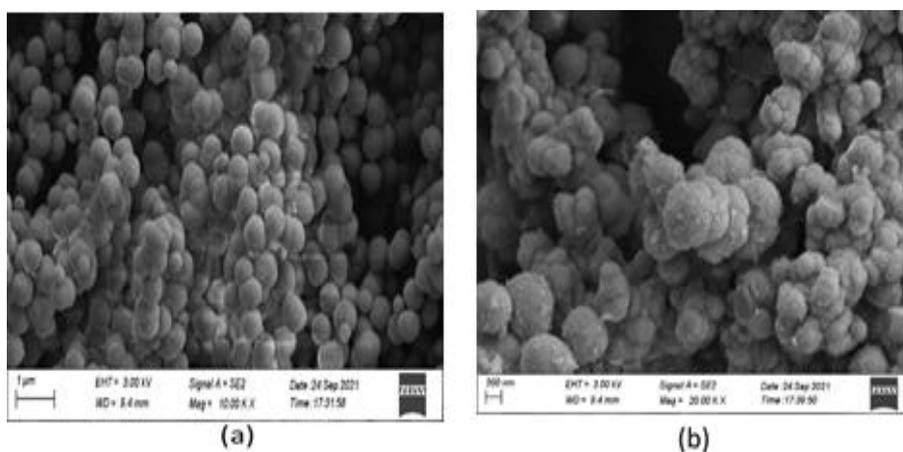


Figure 6: Morphological structure of Silica powder in (a) $1\mu\text{m}$ (b) 200 nm

Table 1: Particles information stands for Figure (b) from imageJ software

No	Area	Mean	Min	Max	Angle	Circ.	Solidity	Length
1	5.70E+01	1.00E+02	3.40E+01	1.35E+02	- 2.05E+00	2.28E-01	NaN	5.60E+01
2	5.60E+01	1.09E+02	6.30E+01	1.59E+02	0.00E+00	2.33E-01	NaN	5.50E+01
3	5.40E+01	6.36E+01	2.10E+01	8.77E+01	1.08E+00	2.42E-01	NaN	5.30E+01
4	5.50E+01	1.19E+02	5.17E+01	1.58E+02	- 8.58E+00	2.41E-01	NaN	5.36E+01
5	5.50E+01	1.12E+02	5.85E+01	1.57E+02	2.12E+00	2.37E-01	NaN	5.40E+01
6	5.80E+01	9.36E+01	7.00E+01	1.52E+02	1.01E+00	2.24E-01	NaN	5.70E+01
7	5.70E+01	7.91E+01	2.10E+01	9.70E+01	2.05E+00	2.28E-01	NaN	5.60E+01
8	5.10E+01	1.02E+02	8.30E+01	1.31E+02	0.00E+00	2.56E-01	NaN	5.00E+01
9	6.00E+01	1.12E+02	6.00E+01	1.42E+02	0.00E+00	2.17E-01	NaN	5.90E+01
10	5.00E+01	1.01E+02	5.75E+01	1.36E+02	- 8.30E+00	2.67E-01	NaN	4.85E+01

Figure-6 shows the Silica powder morphological structure, (a) and (b) structure has different lenses in 1µm and 200 nm where the particle presence is clearly showing its size, which are not uniform overall, but the size variation is closely insubstantial. The information chart from the imageJ software has evaluated the particle diameter which lies in between 5.10E+01 (51nm) to 6.00E+01 (60nm) where the area of the selected particles also varies in between 51nm to 60nm. The parameters in the chart are area and the mean, minimum and maximum of particle area, circle of area and the length of the diameter of the selected particle. Additionally, ImageJ software calculates solidity as the area of a particle divided by its convex hull area. The complement of the porosity is known as the term of solidity, according to the material science view, porosity plus solidity should be 1; $S = 1 - P$. As the porosity is not a number and it is not to be calculated so the result is not a number or NaN.

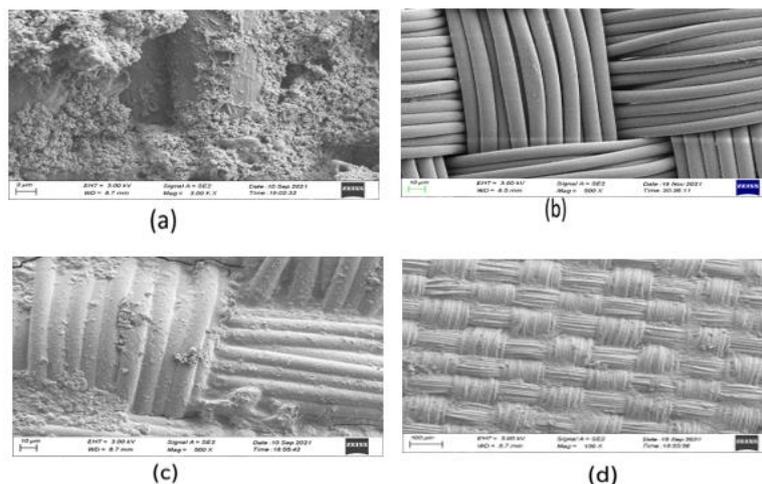


Figure 7: Morphological structure of (a) untreated nylon fabric. (b) Si-NP treated Nylon fabric, (c) & (d) final coated Nylon Fabric.

The SEM micrographs of pristine and treated nylon 6 woven fabrics are in figure 7. The results exhibited a rough surface and the presence of silica nanoparticles on the surface of the fabric. The high-magnification (inset) SEM image (Figure 7(b)) showed that the uniform silica nanoparticles were deposited throughout the fabric surface with average particle size. After modification of silica-coated fabric with HDTMS-APTES solution, the surface morphology becomes inhomogeneous with sticky particles. The change in morphology of HDTMS-APTES treated silica-coated fabric is clearly shown in Figure 7(c).

3.2 Composition of super-hydrophobic nylon fabric

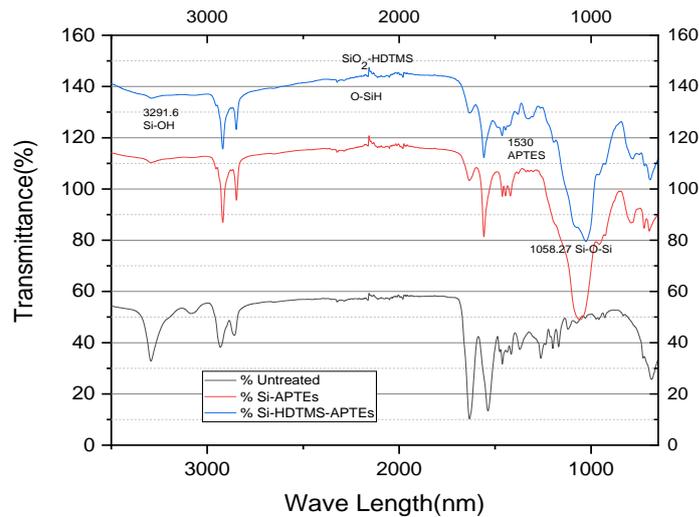


Figure 8: FTIR Spectra of treated nylon fabric with comparison wave lines of previous stages.

HDTMS with APTES has carried out and the possible reactions was investigated by FTIR (figure 8). Diminishing the characteristic absorption band of epoxide ring at 913 cm^{-1} , as well as increasing the hydroxyl and amine groups at 1530 cm^{-1} which are only appeared in final coated fabric, respectively, confirm the successful amine-modification and 2000-2500 cm^{-1} small sharp peak indicate the existing of HDMTS with SiO_2 . As it visible in spectrum of three line has clear peak point of Si-O-Si at 1058 cm^{-1} and hydroxyl stretching of Si-OH is appeared on final substrate at 3291.6 cm^{-1} . While the substrate is nylon-6, so it contains amide groups also which is in stretching of C-H at 2919 cm^{-1} , N-H bending at 1634 cm^{-1} and N-H stretching at 3200-3400 cm^{-1} with small peak. This spectra Figure-6 establish all components existence in the final coated substrate.

3.3. Water Contact Angles and Durability test

Water resistance increased through step by step in this process. The object turns into hydrophobic from hydrophilic by absorbing silica particles and shows 120°-124° contact angle from 62.6°-65°. Again the silica coated substrate encrypted with APTES and HDTMS. HDTMS is a hydrophobic modifier with SiO_2 functional group and C-H stretching long chain. Furthermore APTES created covalent attaching bond of organic oxides such as silica on the substrate with terminated -NH. It turns the water contact angle on nylon woven fabric which is finally reached to 151.8° with approximate error $\pm 2^\circ$ and it can be called highly hydrophobic or super-hydrophobic with subsided features (discussed in 3.5.1)

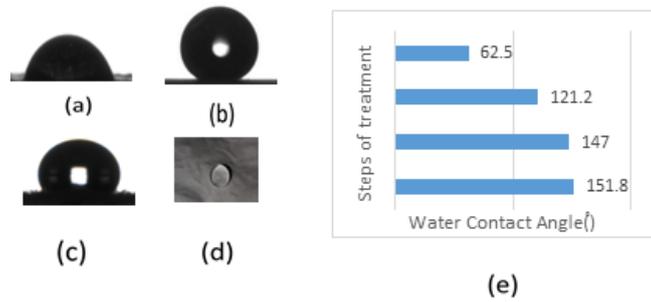


Figure 9: (a) Water contact angle of untreated fabric, (b) WCA of Si-treated fabric, (c) WCA of final sample, (d) water droplet on treated surface and (e) Diagram of WAC with treatment steps.

In regular life using purposes the substrate needs to pass through a harsh cycle and it's a large procedure to test the actual application cycle for a certain duration. An average amount of Na₂CO₃ laundry detergent has added in 100ml water to wash in a cyclic washing machine for 10min in in time cycle 1 to 15 and the results is shown in the Figure 10.

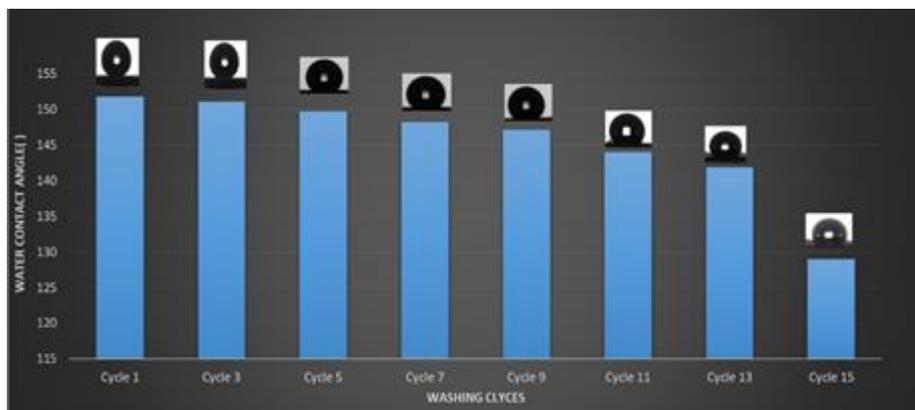


Figure 10: Hydrophobic durability to wash.

3.4. Air Permeability

Generally the air permeability of a fabric ground on its air porosity. The amount of porosity is proportional to the airflow rate of the fabric which influences the thermal comfort property of fabrics. The test analysis results show that variance is low on the air permeability values of the treated nylon-6woven fabrics at pressure 100 Pa/mmH₂O.

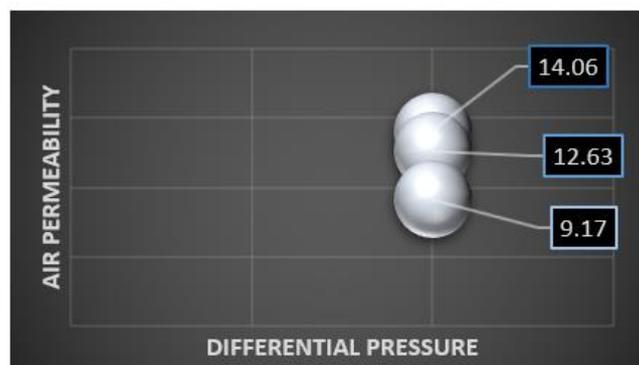


Figure 11 : Air permeability versus differential pressure graph

SL No.	Sample Type	Air Permeability (cm ³ /cm ² .s)	Nozzle Dia (m)	Differential Pressure (Pa/mmH ₂ O)	Time(s)
1	Untreated	14.06	1.2	100	2
2	Si-NP treated	12.63	1.2	100	3
3	0.5ml HDTMS treated final sample	9.15	1.2	100	3
4	0.8ml HDTMS treated final sample	9.17	1.2	100	2

Table 2: Air permeability test data chart.

The test data in figure-11 estimated that air permeability is comparable to the pressure level. On the comparison of four samples, the air permeability is higher in the untreated sample rather than the treated sample according to the test data. As the air permeability is related to the porous structure of the fabric, nylon-6 woven fabric has very low porosity and also is directly proportional to the percentage of porosity of the fabric so the permeability rate is very low. The highest pressure has been applied on the sample surface to ensure the minimum airflow through the surface. The air permeability was lower for treated samples with higher fabric thickness compare to the untreated fabric. The untreated sample and the final coated samples thickness has very minimal differences it's 10.83mm to 10.81mm on averages of five different spot checks. Handfeel is very soft and comfortable to easy drape. As the sample is very light with very low pore, it reveals a thermal effect with a bit better in the treated fabric.

3.5. Self-cleaning tendency of treated nylon fabric

3.5.1. Liquid repellence

In this test part, light red reactive dye solution has been used as a contaminant liquid for self-cleaning tests, as shown in Figure-11 when water droplets fall, we can clearly see the difference between the raw fabric and the super-hydrophobic fabric. The surface of the uncoated fabric is completely wetted and contaminated with dye and on the super-hydrophobic fabric, this dye solution took a place as a droplet topping and was easily removed itself without leaving any shade of the dye color. The untreated fabric has been completely immersed in tap water to compare the water-repellent characteristics of the super- hydrophobic fabric with it. As result, the untreated nylon fabric has sink in water with a complete wet surface, while the super- hydrophobic fabric floated on the water (Figure-11). This the test that support real life use of the coated fabrics as protection cloth against the contact of liquids. In additional test, salt water, coffee, milk, cola, tea, turmeric solution, and tomato ketchup. As shown in Figure-11 (a) and (b), the original fabric has wetted and contaminated by the liquids and the surface of the super-hydrophobic fabric has shown spherical droplets and zero contamination with no stain on the fabric surface. Figure. 11(a) and (b) show that when the droplets contact the original fabric, the fabric is completely penetrated. However, the droplets on the super-hydrophobic fabric are in a spherical form on top of the fabric. These results indicate that the super-hydrophobic fabric has excellent self-cleaning and antifouling properties that are suitable for use in daily life.



Figure 12 : Comparison of Cleaning tendency by using dye, salt-water, milk, coffee, tea, soil, turmeric and tomato solution (a) untreated sample,(b)treated sample and floating tendency of super-hydrophobic treated sample.

3.5.2. De-icing property analysis



Figure 12 : (a) Frozen water on the treated surface of the static test, (b) frozen water after 3s, (c) dynamic condition of de-icing test with super-cooled water.

Super-cooled water was poured on 45° inclined on the surface of APTES-HDTMS grafted Nylon woven fabric, and also on the untreated Nylon woven fabric. Figure represents the anti-icing and de-icing behaviours of the super-hydrophobic nylon-6 woven fabric. In a static condition, the initial water droplets were all frozen on the surfaces, when fabrics with the frozen ice-beads forming on the surfaces were exposed to a room condition (25°C and 50% RH) on the 45°-slope plate, the ice beads on all of the fabric surfaces did not slide off the surfaces but initially stuck to the fabrics. After 5 s the ice beads started to melt on the surface and sloped out at set angle. Testing under dynamic condition, super cooled water droplet impacts on a surface, it instantaneously freezes along with a recalescent stage. Due to the release of latent heat of the crystal freezing, only ~20% of the liquid droplet turns into ice and the rest works as ice-water with a jump of the temperature to 0°C. The evaporation and the resulting condensation occur during the freezing of the super cooled water. Ice formed and accumulated on the surfaces after spraying the super cooled water (50 mL) on the fabric samples angled at 45°. And the remaining water on the surfaces exposed to a room condition and respectively melt within a few seconds approximately 5s to 10 s has counted (figure12(b)). Another part of the test has resulted in untreated nylon fabric at a set angle turning wet with supercooled water. Therefore, the Cassie–Baxter state, as well as the high mobility of the molten droplet, are insured in the surface test along with the tests has shown in Figure 12(c). The results ensure the super-hydrophobic nylon-6 woven fabric has effective anti/de-icing properties even after the fast freezing of a deeply cooled water droplet.

3.6. Mechanism of Super-hydrophobic Nylon woven fabric

The super-hydrophobic nylon-6 coated woven fabric was achieved by surface modification of silica nanoparticles with APTES and HDTMs. As nanoparticles contain methyl ($-CH_3$) groups in modified silica nanoparticles, which provide hydrophobic surface property due to the presence of methyl groups along the surface. The chemical bonds presenting over the surface of silica nanoparticles are $Si-CH_3$ and $Si-OH$. Due to the hydrophobic surface property, silica nanoparticles cannot be stably dispersed in water, to generate silica nanoparticles in water dispersion. So, APTES was firstly followed by dispersing the mixture into toluene. The nanoparticles of first layer on the fabric surface was aggregated into solution. Due to the reaction between the hydrolyzed APTES and the first layered surface, $Si-OH$ group is spectre onto the surface [12][17] which is presented in FTIR data . The amine groups ($-NH_2$) on the surface of each bond stabilize the dispersion of the individual groups in toluene. Subsequently, HDTMS was added into the APTES dispersion. The hydrolyzed HDTMS molecules create a bond on the surface by formation of $Si-O-Si$ bonds [13]. As a result, long-chain of organo - silane with lower surface free energy was introduced onto the surface, an aqueous coating solution for super-hydrophobic fabric coatings appeared. By applying the as-prepared aqueous coating solution onto fabrics, the $Si-OH$ groups along with the surfaces bond with the fabric surfaces and the $-NH_2$ groups which will further enhance the adhesion of surface bond onto the fabrics. Therefore, the bond of nanoparticles can be effectively attached onto the fabrics, enhancing the roughness of the coated fabric surface [21] [22]. Meanwhile, HDTMS molecules with hydrophobic long carbon chains have been introduced onto the surface bond, lower surface free energy can be introduced to the fabrics after coating.

IV. Conclusion

The silica nanoparticles has synthesised with very nearly uniform size of diameter, the nanoparticles aggregated into solution and the reaction took place between the hydrolysed APTES and the $Si-OH$ groups of silica collated surface. The nanoparticle surface and $-NH_2$ groups stabilize the dispersion of the individual groups in toluene. HDTMS also dispersed in the solution and hydrolysed HDTMS molecules formed the $Si-O-Si$ bond to the surface. The resultant long-chain polymer of organo-silane with low surface free energy introduced onto surface that produced the super-hydrophobic nylon-6 woven fabric with a water contact angle 151.8° . Moreover, the treated nylon-6 woven fabric has super-hydrophobic stability and functionality for self-cleaning with a long duration of use, without an application of adhesive material. This method is simple, rapid, environmentally friendly and universally applicable and can be applied to endow other substrates with high hydrophobicity. Accordingly, the developed method shows good prospects for super- hydrophobic applications.

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