Synthesis and application of Silica Nanoparticles on Cotton to impart Superhydrophobicity

S. M. Landage, S. G. Kulkarni, & D. P. Ubarhande.
D.K.T.E. Society's, Textile & Engineering Institute,
Ichalkaranji, Maharashtra, India.

Abstract

In this study the cotton fabric was treated with the silica nanoparticles and commercially available water repellent agent. The silica nanoparticles were synthesized by Stober method. The characterization of silica nanoparticles on the surface of cotton fabric was done by using scanning electron microscope (SEM). In this the properties of cotton fabric treated with only water repellent agent was compared with fabric finished with combination of silica nanoparticles and water repellent agent. It was observed that the cotton fabric treated only with water repellent agent showed the water repellency rating of 90 at 35gpl concentration of water repellent agent, while the rating of 90 was observed at 15 gpl of water repellent agent concentration when the fabric was treated with the combination of silica nanoparticles and water repellent agent.

"1. Introduction"

Superhydrophobic surfaces exist widely in nature. The lotus effect refers to the very high water repellence exhibited by the leaves of the lotus flower. Due to the invention of scanning electron microscopy today scientists becomes well known about the ability to repel the water results from superhydrophobicity, due to the combination of micrometer-scale hills and valleys and nanometer-scale waxy bumps, in combination with the reduced adhesion between surfaces and particles. The leaves of lotus have epidermal cells on their rough surface covered with wax crystals. The wax crystals provide a hydrophobic layer and the double-size structure gives the surface high roughness. [1, 2, 3, 4]

It is well established that the water wettability of materials is governed by both the chemical composition and the geometrical microstructure of the surface. Traditional textile wet processing treatments do indeed rely fundamentally upon complete wetting out of a textile structure to achieve satisfactory performance. However, the complexities introduced through the heterogeneous nature of the fiber surfaces, the nature of the fiber composition and the actual construction of the textile material create difficulties in attempting to predict the exact wettability of a particular textile material. For many applications the ability of a finished fabric to exhibit water repellency is essential and potential applications of highly water repellent textile materials include rainwear, upholstery, protective clothing, sportswear, and automobile interior fabrics. [5, 6]

Recent research indicates that such applications may benefit from a new generation of water repellent materials that make use of the "lotus effect" to provide ultrahydrophobic textile materials. Ultrahydrophobic surfaces are typically termed as the surfaces that show a water contact angle greater than 150° with very low contact angle hysteresis. In the case of textile materials, the level of hydrophobicity is often determined by measuring the static water contact angle only, since it is difficult to measure the contact angle hysteresis on a textile fabric because of the high levels of roughness inherent in textile structures. Reduced contact area between the substrate and the liquid and vice versa for hydrophilic substrates. [7, 8]

Rapidly emerging nanotechnology offers new and improved ways of imparting a range of functional performance properties to cotton rich fabrics. Now a day's fact is that textile industry is the first manufacturing industry to come up with finished products that are enhanced through nanotechnology-based functional finishing. Textile industry is the only major manufacturing industry that markets a range of end products with a nanotechnology label attached to them. [9]

"2. Experimental"

2.1. Materials.

2.1.1. Chemicals. Tetraethyl orthosilicate [Si $(OC_2H_5)_4$ (TEOS)] procured from Tritech Catalyst & Intermediate Pvt. Ltd. (Raigad), ethanol, ammonia solution (Laboratory Reagents) were used for the synthesis of silica nanoparticles. The distilled water was used for the synthesis of silica nanoparticles. The commercially available water repellent agent TUBIGUARD 270 L procured from CHT India Pvt. Ltd.

2.1.2. Fabric. Type – Cotton fabric, Weave – Plain**,** Warp Count – 22.72^S**,** Weft Count – 31.09^S**,** EPI X PPI – 74 X 61**,** GSM – 122.

2.2 Characterization.

The surface morphology of cotton fabric treated with silica nanoparticles and combination of silica nanoparticles & water repellent agent was recorded on scanning electron microscope (SEM) (JSM-6360 JEOL/EO). The water repellency and hydrostatic head pressure properties of treated fabrics were measured according to AATCC 22, ISO 4920 & ISO 811, AATCC 127 test methods respectively. The air permeability and tearing strength properties of treated fabrics were measured according to ASTM B 737 & IS 6359:1971SP-15 respectively.

2.3 Synthesis of Silica Nanoparticles.

The silica nanoparticles were synthesized by the alkaline hydrolysis of the tetraethyl orthosilicate followed by the dehydration, condensation reaction. [10, 11]

The mixture of 0.2 mol tetraethyl orthosilicate and 2.5 mol ethanol was prepared, then it was mixed with the mixture of 2.0 mol distilled water, 2.5 mol ethanol and 0.05 mol ammonia solution. The synthesis was carried out for 3 hours at 30^0C.

2.4 Application of Silica Nanoparticles & the Water Repellent Agent on cotton fabric.

The previously desized, scoured & bleached cotton fabric was padded with silica sol. The padded fabric samples were then dried at 80^0C to maintain residual moisture content 8 – 10%. The dried fabric samples were cured at 160^0C for 3 min. Then these fabric samples were again padded with the water repellent agent with varying concentration from 15gpl to 40gpl. The padded fabric samples were then dried at 80^0C and cured at 160^0C for 3 min. Table 1 shows the composition of chemicals for the synthesis of silica nanoparticles & the table 2 shows the composition of water repellent agent and silica nanoparticles for water repellent finish as follow.

"Table 1. Composition of Chemicals for the Synthesis of Silica Nanoparticles"

Sr. No.	TEOS (Mol)	Ethanol (Mol)	Water (Mol)	Ethanol (Mol)	Ammonium hydroxide (Mol)
1	0.2	2.5	2.0	2.5	0.05

"Table 2. Composition of water repellent agent and silica nanoparticles for water repellent finish"

Sr. No.	TEOS (Mol)	Ethanol (Mol)	Water (Mol)	Ethanol (Mol)	Ammonium hydroxide (Mol)	Water Repellent Agent (gpl)
1	0.2	2.5	2.0	2.5	0.05	15
2	0.2	2.5	2.0	2.5	0.05	20
3	0.2	2.5	2.0	2.5	0.05	25
4	0.2	2.5	2.0	2.5	0.05	30
5	0.2	2.5	2.0	2.5	0.05	35
6	0.2	2.5	2.0	2.5	0.05	40

"3. Results and Discussion"

3.1 Synthesis of Silica Nanoparticles.

Silica nanoparticles were prepared using Stober method including the hydrolysis of TEOS and the condensation of the hydrolyzed silica species in the presence of an ammonia catalyst. The reactions were as follows.

(1) **Hydrolysis**

$$Si\text{-}[OC_2H_5]_4 + 4\,H_2O \longrightarrow Si\text{-}(OH)_4 + 4\,C_2H_5OH$$

(2) **Alcohol condensation**

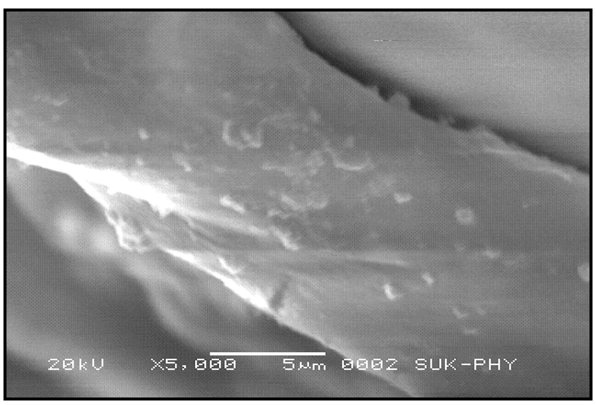
$$Si\text{-}(OH)_4 + Si\text{-}[OC_2H_5]_4 \longrightarrow\ \equiv Si\text{-}o\text{-}Si \equiv + 4\,C_2H_5OH$$

(3) **Water condensation**

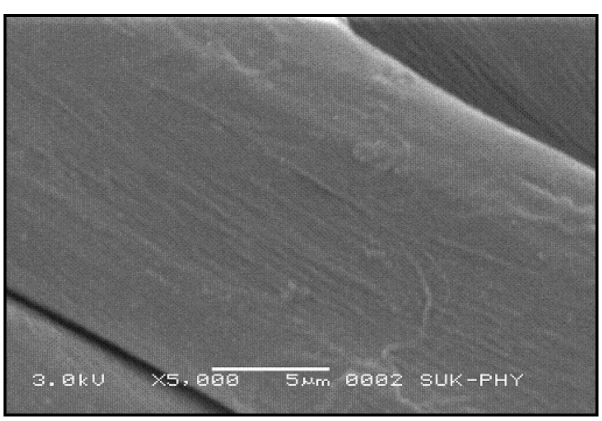
$$Si\text{-}(OH)_4 + Si\text{-}(OH)_4 \longrightarrow\ \equiv Si\text{-}o\text{-}Si \equiv + 4\,H_2O.$$

3.2 Characterization

The surface morphology was characterized by Scanning Electron Microscope (SEM). It was observed that, the cotton fabric treated with silica nanoparticles shows the scaly appearance on the surface, which made the surface rougher & enhance the water repellency. Also the scanning electron micrograph shows that change of the surface geometry of the cotton fabric. Figure 1 shows, the SEM image of cotton fabric treated with silica nanoparticles & figure 2 shows the SEM image of cotton fabric treated with both silica nanoparticles and water repellent agent (35gpl). The figure 2 shows the water repellent agent forms an oily layer on the silica nanoparticles just like lotus leaves. Here silica nanoparticles act as an epidermal cells and water repellent agent as waxy bumps which results in superhydrophobicity on cotton fabric.



"Figure 1. SEM image of cotton fabric treated with silica nanoparticles".

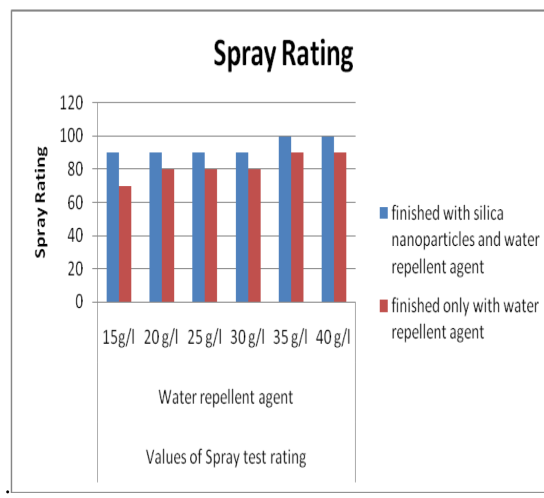


"Figure 2. SEM image of cotton fabric treated with both silica nanoparticles and water repellent agent (35gpl)".

3.3 Effect of Concentration of Water Repellent Agent on Water Repellency Rating- Spray Rating.

"Table 3. Effect of concentration of water repellent agent on Water Repellency Rating- Spray Rating"

	Values of Spray test rating					
	Water repellent agent					
	15 g/l	20 g/l	25 g/l	30 g/l	35 g/l	40 g/l
Finished with silica nanoparticles and water repellent agent	90	90	90	90	100	100
Finished only with water repellent agent	70	80	80	80	90	90



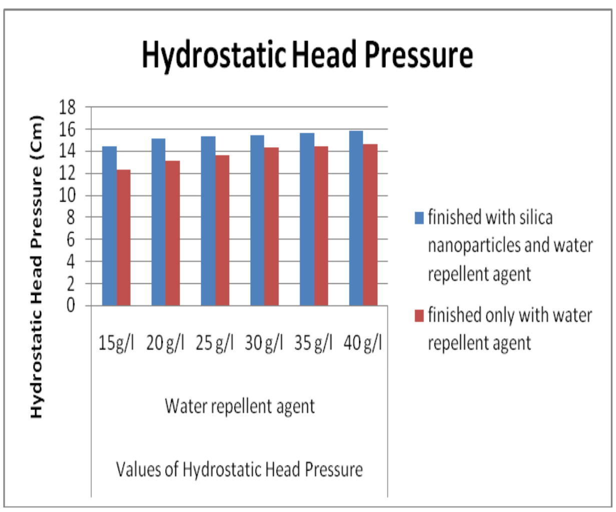
"Figure 3. Effect of concentration of water repellent agent on water repellency rating- spray rating"

From the above Table 3 and Figure 3 it is observed that, as the concentration of water repellent agent increases from 15 gpl to 40 gpl the fabric finished with only water repellent agent shows the spray rating of 70 at 15 gpl concentration and spray rating of 90 at 35 gpl concentration of water repellent agent, while the fabric finished with combination of silica nanoparticles and water repellent agent shows the spray rating of 90 at 15 gpl concentration and spray rating of 100 at 35 gpl concentration of water repellent agent.

3.4 Effect of Concentration of Water Repellent Agent on Hydrostatic Head Pressure.

"Table 4. Effect of concentration of water repellent agent on hydrostatic head pressure"

	Values of Hydrostatic Head Pressure(Cm)					
	Water repellent agent					
	15 g/l	20 g/l	25 g/l	30 g/l	35 g/l	40 g/l
Finished with silica nanoparticles and water repellent agent	14.50	15.16	15.33	15.50	15.66	15.83
Finished only with water repellent agent	12.33	13.16	13.66	14.33	14.50	14.66



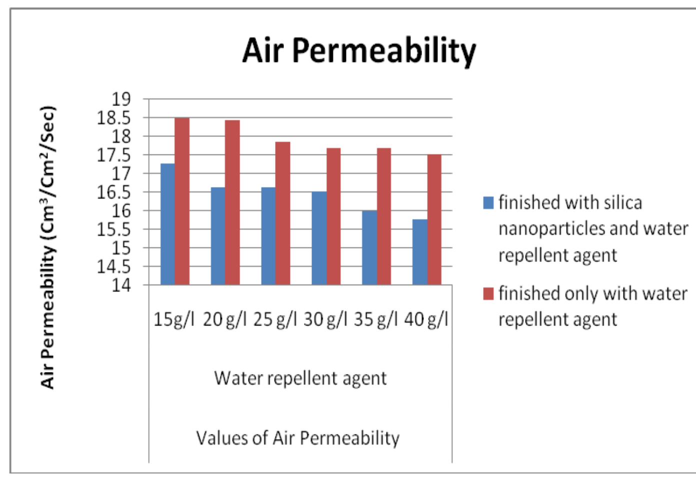
"Figure 4. Effect of concentration of water repellent agent on hydrostatic head pressure"

The Table 4 and Figure 4 shows that, the hydrostatic head pressure for the fabric treated with combination of silica nanoparticles and water repellent agent and the fabric treated with only water repellent agent. The fabric finished with only water repellent agent shows the increase in hydrostatic head pressure from 12.33 to 14.66 for water repellent agent concentration of 15 gpl to 40 gpl respectively. The fabric finished with combination of silica nanoparticles and water repellent agent shows an increase in hydrostatic head pressure from 14.50 to 15.83 for water repellent agent concentration of 15 gpl to 40 gpl respectively. This may be because of silica nanoparticles helps to resist the drop of water penetrating inside fabric structure.

3.5 Effect of Concentration of Water Repellent Agent on Air Permeability.

"Table 5. Effect of concentration of water repellent agent on air permeability"

	Values of Air Permeability ($Cm^3/Cm^2/Sec$)					
	Water repellent agent					
	15 g/l	20 g/l	25 g/l	30 g/l	35 g/l	40 g/l
Finished with silica nanoparticles and water repellent agent	17.29	16.65	16.64	16.54	16.01	15.77
Finished only with water repellent agent	18.51	18.45	17.87	17.70	17.69	17.52



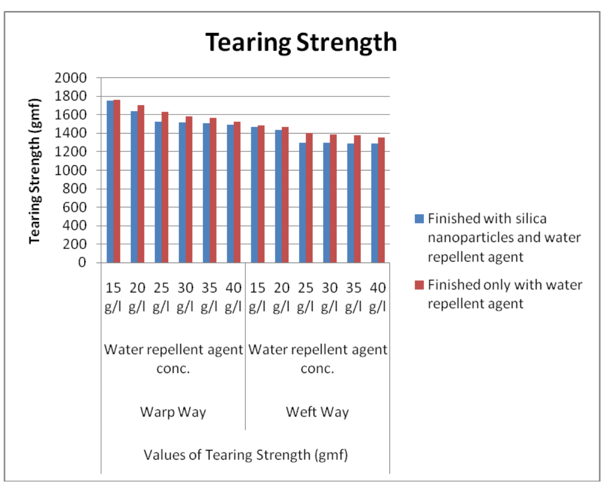
"Figure 5 . Effect of concentration of water repellent agent on air permeability" .

From the Table 5 and Figure 5, it is observed that, the fabric finished with only water repellent agent shows the decrease in air permeability from 18.51 to 17.52 for the concentration of 15 gpl to 40 gpl of water repellent agent respectively, while the fabric finished with combination of silica nanoparticles and water repellent agent shows decrease in air permeability from 17.29 to 15.77 for the concentration of 15 gpl to 40 gpl of water repellent agent respectively. This may be because; as concentration goes on increasing the film is going to become continuous, which causes decrease in air transmission rate. & also the silica nanoparticles help in filling the interstices between fibres.

3.6 Effect of Concentration of Water Repellent Agent on Tearing Strength

"Table 6. Effect of concentration of water repellent agent on tearing strength"

	Values of Tearing Strength (gmf)											
	Warp Way						Weft Way					
	Water repellent agent conc.						Water repellent agent conc.					
	15 g/l	20 g/l	25 g/l	30 g/l	35 g/l	40 g/l	15 g/l	20 g/l	25 g/l	30 g/l	35 g/l	40 g/l
Finished with silica nanoparticles and water repellent agent	1753.6	1644.8	1523.2	1516.8	1510.4	1491.2	1472.0	1440.0	1299.2	1299.2	1292.8	1286.4
Finished only with water repellent agent	1760.0	1702.4	1632.0	1587.2	1568.0	1529.6	1484.8	1465.6	1408.0	1388.8	1376.0	1356.8



"Figure 6 . Effect of concentration of water repellent agent on tearing strength"

The above Table 6 and Figure 6 shows the tearing strength in both warp and weft way for the fabric treated with combination of silica nanoparticles and water repellent agent and the fabric treated with only water repellent agent. It is observed that there is decrease in tearing strength in warp direction from 1760 to 1529.6 for water repellent agent concentration of 15 gpl to 40 gpl respectively, while the fabric finished with combination of silica nanoparticles and water repellent agent shows the decrease in tearing strength in warp direction from 1753.6 to 1491.2 for water repellent agent concentration of 15 gpl to 40 gpl respectively. The fabric finished with only water repellent agent shows the decrease in tearing strength in weft direction from 1484.8 to 1356.8 for water repellent agent concentration of 15 gpl to 40 gpl respectively, while the fabric finished with combination of silica nanoparticles and water repellent agent shows the decrease in tearing strength in weft direction from 1472 to 1286.4 for water repellent agent concentration of 15 gpl to 40 gpl respectively. This indicates that increase in concentration of water repellent agent along with silica nanoparticles causes increase in the resistance for the slippage of fibers in both warp and weft direction.

"4. Conclusion"

In this study the silica nanoparticles were synthesized by using Stober method. The characterization of silica nanoparticles treated cotton fabric was done by using SEM. The superhydrophobicity was imparted to the cotton fabric by the combination of silica nanoparticles and water repellent agent. It was observed that the spray rating of 70 was observed in the fabric treated alone with the water repellent agent with concentration of 15gpl. But, the spray rating of 90 was observed, when the fabric was treated with the combination of silica nanoparticles and the same concentration of water repellent agent i.e. 15 gpl. This indicates that the silica nanoparticles help in imparting superhydrophobicity on the cotton textile material by making the surface rough. Also there was decreased in air permeability and increased in hydrostatic head pressure and decreased in tearing strength was observed as the concentration of water repellent agent increased.

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