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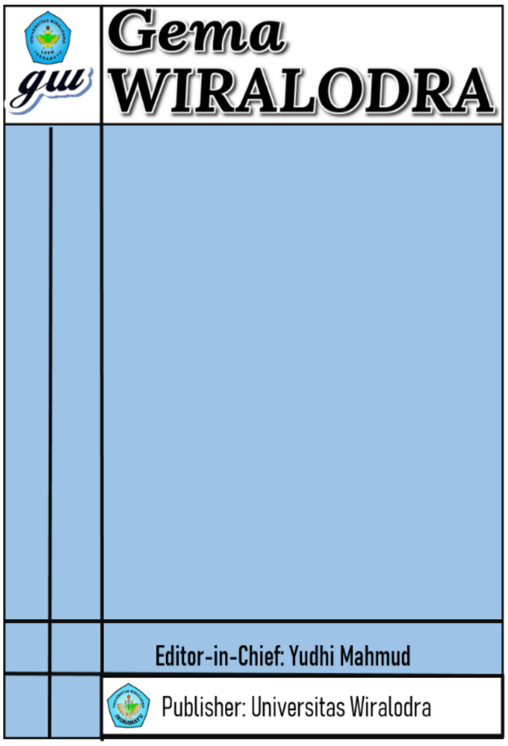

Analysis of Silica-Hexadecyltrimethoxysilane Nanosol Hybrids through optimization of Silica Nanosol Concentration and determining fabric types on Hydrophobicity

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Original Article

Analysis of Silica-Hexadecyltrimethoxysilane Nanosol Hybrids through optimization of Silica Nanosol Concentration and determining fabric types on Hydrophobicity

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Abstract

An analysis of the silica nanosol-hexadecyltrimethoxysilane hybrid has been carried out through optimizing the concentration of silica nanosol and determining the type of fabric regarding hydrophobicity. This research began with the synthesis of silica nanosol via the sol-gel method, where TEOS as a precursor was dissolved in a mixture of ethanol-distilled water with a base catalyst with a contact time of 2 hours. The concentration of silica nanosol was varied by 0.025, 0.05, and 0.075 mol. The dip-coating method was used to coat the fabric with nanosol, with a tensile rate of 3 cm per second. Then the fabric was re-coated with silica nanosol in HDTMS solution (4% wt/wt ethanol) and dried in a 120°C oven for 10 minutes. This research tested calico, cotton and mori fabrics. A Canon DSLR camera with a Thamron 100mm lens was used to measure the contact angle of the fabric surface. ImageJ software processes images to obtain contact angle values on the fabric surface. The fabric was then characterized using Fourier Transform Infrared Spectroscopy (FTIR) and Scanning Electron Microscope (SEM) and the silica nanosol was characterized using a Transmission Electron Microscope (TEM). The optimum concentration of silica-hdtms nanosol was obtained at a concentration of 0.075 mol with surface contact angles of cotton, mori and calico fabrics of 134, 132 and 135°. The flow speed of water with a slope of 100 on cotton, mori, and calico fabric produces flow speeds of 3.3, 6, and 5 m/s.

Keywords: optimization, hybrid, nanosol, silica, hydrophobic

1. Introduction

Nowadays, research related to hydrophobic materials has attracted the attention of researchers from both the academic and industrial worlds. This interest is motivated by the self-cleaning phenomenon that we can find in nature. When water drips on the surface of a lotus leaf (usually called a lotus leaf), the water becomes dots that roll, carrying pollutants or dust that stick to the leaf's surface. This phenomenon is known as the “Lotus Effect”. The surface of the lotus leaf is superhydrophobic because it can produce a high surface water contact angle (>150°) (Yang et al., 2008).

The rapid development of nanotechnology and the textile industry has given rise to the phenomenon that market demand for textile products is starting to shift from conventional textiles to multifunctional textiles, namely textiles that have new functional added value, one of which is hydrophobic, which provides water-repellent and self-cleaning properties. Natural textiles, generally made from cellulose (cotton) and protein (silk), are considered to be more susceptible to microbial attack than synthetic fibers because of their porous structure and the constituent polymers, which are hydrophilic, so they easily absorb moisture (Ye et al., 2005). Cotton fabric provides ideal conditions for the growth of microorganisms because of its large surface area and good adhesion and water retention properties. As a result, microorganisms easily grow on these clothes. Apart from being used as a basic material for making clothes, fabric is also used in various fields, including the health sector. So, the hydrophobic properties of the fabric indirectly also provide antibacterial properties to the surface of the fabric.

A good hydrophobic fabric has criteria such as being safe for the environment and skin, easy to clean, having good resistance to repeated washing, being mechanically strong, and not reducing the feeling of comfort when worn. However, in its application, hydrophobic fabric with good resistance and contact angle without reducing comfort is an opposing property. This is influenced by many factors, such as the availability of materials or additives that are safe for the environment and skin and form hydrophobic fabrics with good mechanical resistance without reducing the comfort or flexibility of the fabric. So, the current challenge for researchers is to determine the optimum conditions for hydrophobic fabric without reducing the hydrophobicity of the fabric, its resistance to the environment, and still providing comfort in its application to the fabric when used.

Hydrophobic fabric surface preparation has been widely carried out using fluorocarbon compounds, which are known to be compounds with low surface energy. Hue et al. (2008) conducted a study of hydrophobic thin films through a coating process using the compound PFTDS (perfluorodecyltrichlorosilane). This preparation produces a water contact angle of 168°. Meanwhile, Hayn et al. (2010) used a nylon-cotton blend fabric coated with a fluorosilane (FS) compound to produce a water contact angle of 148°. Chengyu et al. (2012) found that coating hydrophobic cotton fabric with the same hydrophobic compound produces a contact angle of 155 ± 2°. All of these preparations use TEOS as a coupling agent on the fabric surface.

The use of fluorinated compounds, which are usually used as hydrophobic agents, is now starting to be abandoned because of the negative impacts such as pollution caused by quite high toxicity and bioaccumulation in living creatures, and the cost used is also relatively more expensive (Prusty, 2009). This has caused research related to hydrophobic surface preparation to shift to the use of non-florous compounds, which are more environmentally friendly.

Alkylsilane-group compounds are known to have low surface energy. Some examples of non-fluoroalkylsilane compounds that are often used as hydrophobic agents include trimethylchlorosilane (TMCS), octadecyltrichlorosilane (ODTCS), cetyltrimethoxysilane (CTMS), and hexadecyltrimethoxysilane (HDTMS) (Gao and McCharty, 2006). HDTMS is a compound derived from silane, which has an alkoxide group and a long alkyl chain with 16 carbon atoms. This compound has the ability to reduce the surface energy of a material. A decrease in surface energy will result in the surface of the material having a larger contact angle (Shateri-Khalilabad & Yazdanshenas, 2013), so that the compound has the potential to act as an inductor for the hydrophobicity of a material. HDTMS is usually combined with coupling agent compounds to produce long-lasting hydrophobic materials. The combination of a hydrophobic agent with a coupling agent compound will cause the orientation of the non-polar groups towards the surface so that hydrophobicity can increase.

Organosilane compounds are examples of coupling agent compounds that are efficient for increasing adhesion in various material coating processes. The trialkoxysilane group, RiSi (OR)3, which easily undergoes hydrolysis reactions, will become a bridge between organic and inorganic materials through Si-O-Si (siloxane) bonds, so that film adhesion increases. The silica network on the substrate surface will provide Si-OH groups, which can react further with hydrophobic agents such as alkylsilane to produce hydrophobic characters. Modification of the silica-based compound -HDTMS on the surface of the fabric material will provide low surface energy, thereby increasing the hydrophobicity of the fabric.

To produce fabric that has hydrophobic capabilities, many methods have been used in terms of technical coatings, such as electrochemical deposition, layer by layer, phase inversion, gel sol, and so on. Meanwhile, other modifications involve the use of chemical compositions or hydrophobic agents such as organic-inorganic compounds or mixtures thereof.

The sol-gel method is known as one of the most commonly used coating methods because the preparation is quite simple and does not require special treatment, so it has the potential to be applied on a large or industrial scale. This process involves two main reactions, namely hydrolysis and polycondensation. The use of TEOS cannot be separated from the easy process of forming silica sol-gel and providing optimum flexibility compared to other compounds such as titanium, which tends to produce a stiff material and reduces the transparency of the coated material.

Cotton, calico, and mori fabrics are types of fabrics that are composed of cellulose fibers on their surface. Cellulose is an organic compound with the molecular formula ($C_6H_{10}O_5$), so the fabric has a hydrophilic surface. Fabric surface engineering needs to be done so the fabric surface becomes hydrophobic. The microstructure topography and chemical properties on the fabric surface are engineered using the sol-gel method.

In this proposal, the method used is the sol-gel method, and the coating is carried out using a dipping technique. At the preparation stage, the SiO_2 sol is expected to form long O-Si-O chains so that when the fabric is dyed on the sol, all the hydrophilic groups of the fabric will interact to form new layers. Thus, the silane group from HDTMS can bind well to long O-Si-O chains. The bonds formed are expected to increase the hydrophobicity of the fabric. Therefore, it is necessary to study the variations in silica concentration used to obtain the optimum water contact angle. Concentration variations are carried out by testing several concentration values of silica (Pereiz et al., 2023).

2. Method

Instrumentation

The equipment used in the research is in the form of preparation tools and analysis tools. Preparation equipment includes laboratory glassware, a stopwatch, a magnetic stirrer, a sonicator, and an oven. Analysis tools include Scanning Electron Microscopy (SEM), TEM, a digital SLR camera, and Image-J software.

Materials

The materials used in this research are: Tetraethyorthosilicate (TEOS), ammonium hydroxide (NH_4OH), aquades, ethanol 98% (Sigma-Aldrich), Hexadecyltrimethoxysilane (HDTMS) (Sigma-Aldrich), detergent, cotton cloth, mori cloth, and calico cloth.

Fabric Preparation

Before the fabric coating process is carried out, all fabric types are first cut to a size of 4 x 1 cm. Each cloth was ultrasonicated in a 1% w/w detergent solution and distilled water successively for 10 minutes. Immediately after washing, the fabric is dried in an oven at 80°C for 20 minutes.

Making Silica Sol

A study of the effect of SiO_2 nanosol concentration on fabric was carried out by Strober using the sol-gel method. The TEOS sol concentrations studied were 0.025, 0.050, and 0.075 mol. In the preparation of silica nanoparticles, first, a solution of 25 mL of 98% ethanol, 1 mL of ammonium hydroxide, 3.6 mL of distilled water, and a volume of TEOS according to each concentration variation is prepared. TEOS and distilled water were dissolved in ethanol and stirred with a stirrer for 2 hours at room temperature, while NH_4OH was added dropwise.

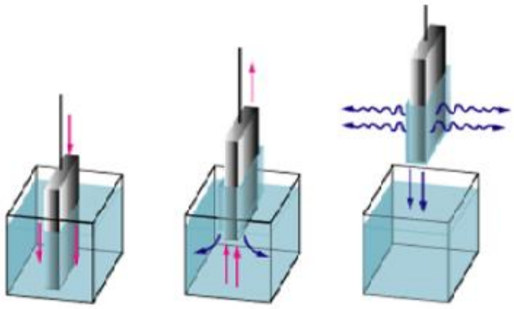
Fabric Coating on Silica Nanosol

The fabric coating process is carried out using the dip-coating method, which uses simple manual tools. The fabric is clamped and tied with a thread; the principle works like a molen tool. After the SiO_2 nanosol was formed, each type of cloth was soaked in silica sol for 10 minutes. After that, pulling is carried out at a pulling speed of 3 cm/minute. This process is presented in Figure III.1. The fabric coated with silica nanoparticles was dried in an oven at

80°C for 30 minutes. Cloth that has been dried and coated with silica nanoparticles is stored in a desiccator or dry place.

Figure 1

Stages of the dip coating process: immersion of the substrate into the coating solution, formation of a wet layer by pulling the substrate, and gelation of the layer through evaporation of the solvent



SiO_2-HDTMS Hybrid Film Coating

The fabrics that had been coated with SiO2 nanoparticles were then soaked in HDTMS sol (which had been dissolved in 4% wt/wt ethanol) for 10 minutes. Fabric coating is done in the same way as before. The fabric coated with SiO2-HDTMS nanoparticles was dried in an oven at 110°C for 10 minutes.

Characterization of the Hydrophobic Layer

Water contact angle measurements refer to the method used by Yeong et al. (2012). This measurement was carried out by taking images of water droplets on the surface of the hybrid film using a digital SLR camera and analyzing them using the B-Spline snake approach developed by Stalder et al. (2006). At each measurement, approximately 5 µL of water was dropped on the film surface at three different spots. This aims to determine the probability of the resulting contact angle distribution. The calculated water contact angle value is the average of three measurements. The water contact angle between 90-150° shows hydrophobic properties. Meanwhile, superhydrophobic properties are indicated by a water contact angle of >150°. Three images were also taken of each water drop with different image ISOs to obtain image quality suitable for processing in contact angle measurements.Measurement of silica nanoparticles. Identification of the average size of silica nanoparticles as a coupling agent was carried out using images from SEM analysis. The value of the size of the silica nanoparticles was obtained by measuring each particle in the image produced and processed using Image J software. This analysis was carried out at the sol concentration that provided the best water contact angle.Characterization of Silica–HDTMS nanoparticle hybrid coating on fabric surface. This identification is carried out to determine the hybrid film layer that adheres to the surface using images resulting from TEM analysis. Measurements were carried out at magnifications of 50, 2000, and 20,000 times. This measurement was carried out only on cotton fabric with the highest contact angle value of the silica sol concentration used.Test the water velocity against the slope. Measurement of water velocity at a slope of 10°. Video was taken of the water droplets on the surface of each cloth at a maximum height of 1 cm. The video was processed with Adobe Premiere software, and the water flow speed was converted to meters per second.

3. Results and Discussion

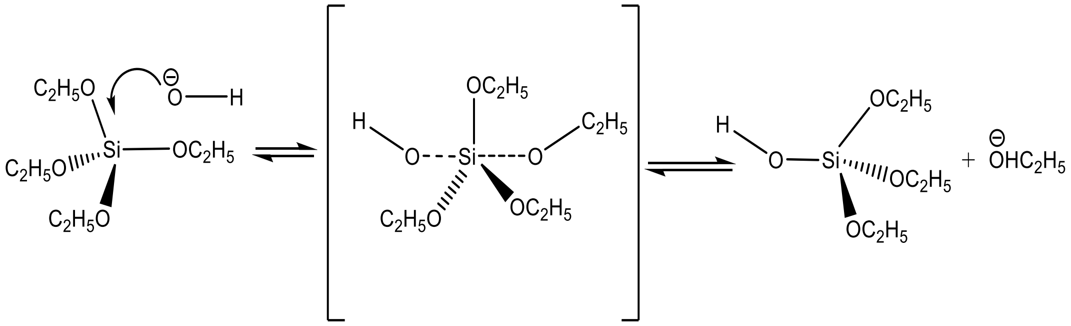
This research examines the manufacture of thin layers of silica-HDTMS nanoparticle hybrids on cotton, mori, and calico fabrics using the sol-gel technique, studies the effect of increasing variations in silica concentration used on the surface contact angle, observes the effect of the type of fabric used on the resulting fabric contact angle, and observes the flow rate of water droplets on a fabric surface with a slope of 10°. Please note that the coating process is carried out using the LbL (Layer by Layer) method, so the results of the analysis and discussion related to all these studies will be presented in this chapter. The results of the analysis in question include measuring the contact angle of water droplets produced from each variation of silica concentration used, namely 0.025, 0.050, and 0.075 mol, using software from the image. For each type of fabric used, characterization is carried out using techniques such as FTIR, SEM, and TEM analysis to determine the composition of the constituent groups, particle size, and surface topography.

Making a Thin Layer of Silica-HDTMS on Cotton Fabric

The silica-HDTMS hybrid film coating technique is carried out using the LbL method, where the fabric is first coated with silica nanoparticles, followed by HDTMS sol coating. Previously, making silica nanoparticle films on each type of fabric started with making silica sol first. This sol was made by dissolving TEOS in a mixture of ethanol and water and adding NH4OH in drops, covering, and stirring for 2 hours using a magnetic stirrer at room temperature. The reaction that occurs is hydrolysis, and this begins to take place when the precursor and base catalyst are mixed dropwise and stirred. Ethanol is used as a solvent, which functions to reduce the hydrolysis rate and condensation rate of tetraethoxyorthosilicate. The base catalyst is added in drops so that the silica sol formed can be controlled and agglomeration does not occur in the resulting sol. Because the hydrolysis reaction with a base catalyst takes place very quickly, Therefore, it is necessary to stir thoroughly before adding the base catalyst, NH_4OH.The study of variations in silica concentration was carried out at respective concentrations of 0.025, 0.050, and 0.075 mol. The mechanism of the TEOS hydrolysis reaction in making silica sol is estimated by the reaction shown in Figure 2.

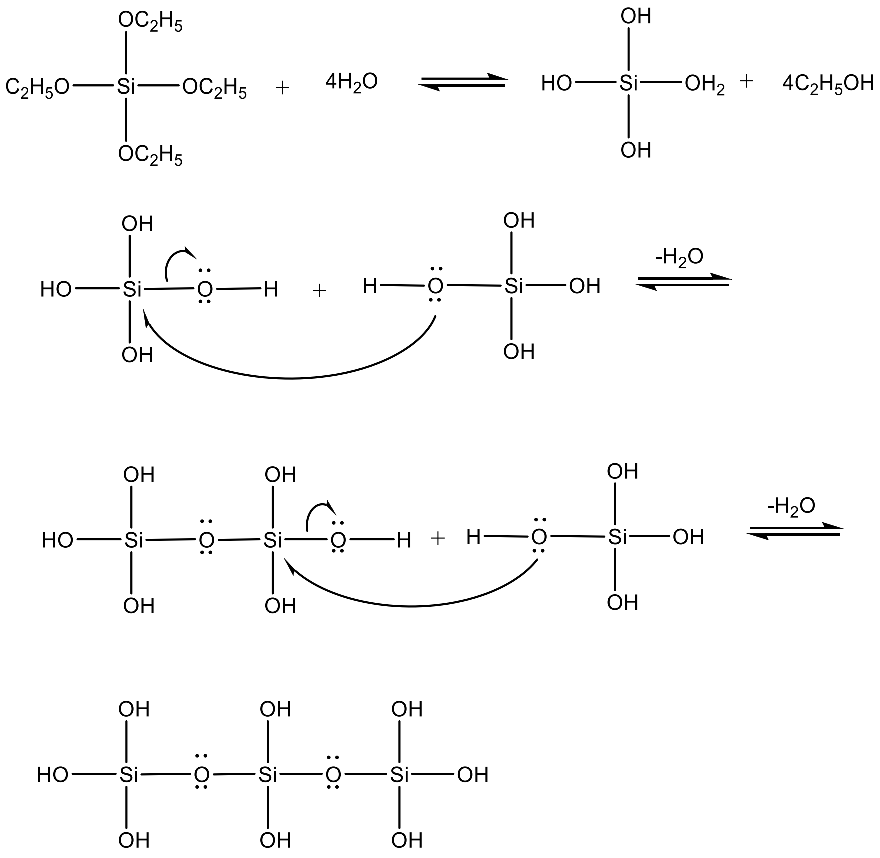
Figure 2

TEOS hydrolysis reaction mechanism



This hydrolysis reaction takes place very quickly. The initial stage of the reaction is that the central silica atom will be attacked by the hydroxyl group. The inclusion of the hydroxyl group will form an intermediate in the form of Si with a pentacoordinate shape. The pentacoordinate form of Si is unstable, so the ethoxy group with a larger size will be released more easily. Based on the reaction mechanism above, 1 molecule of TEOS will react with 4 molecules of water, and if total hydrolysis occurs, 1 molecule of silanol $(SiOH)_4$ and 4 molecules of ethanol will be formed, as shown by the reaction equation.

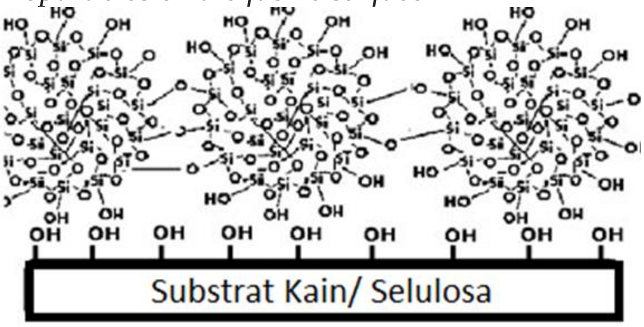
Figure 3
Reaction mechanism for the formation of O-Si-O polymer from SiO₄



The –OH group in the silanol species is the active group in silica. The silanol species that are formed when allowed to stand will undergo a condensation reaction (Figure 3) to form O-Si-O polymer (siloxane) by releasing water. Fabric coating on silica sol is carried out using the dip coating method or dipping technique. The cloth was soaked in the silica nanosol solution for 10 minutes before pulling. This aims to ensure that the interaction, or nanosol silica, can be maximally absorbed into the fabric fibers. In this way, the –OH groups from cellulose can interact evenly on all fabric surfaces and increase the hydrophobicity of the fabric. Withdrawing and immersion are carried out manually at a speed of 3 cm per minute. This aims to ensure that the film is coated on the surface of the fabric more evenly and that during withdrawal, evaporation or condensation of the alcohol on the sole can be controlled. The fabric that has been coated with silica sol is then oven at 80°C for 30 minutes. Drying at this temperature aims to remove residual ethanol solvent from the fabric.

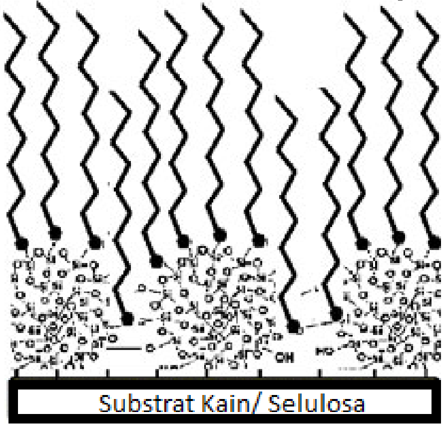
Cellulose, as the main ingredient in cotton, mori, and calico fabrics, provides hydraulic properties. The –OH groups from microfibril networks and fibers on the surface of the fabric are expected to interact with long-chain siloxane bonds. So, the silica nanosol coating on the surface of the fabric reduces hydrophilic groups and acts as a coupling agent for HDTMS. In this way, the surface of the fabric becomes more hydrophobic, increasing its hydrophobicity. The scheme for forming a silica film layer on fabric is shown in Figure 4.

Figure 4
Interaction of silica nanoparticles on the fabric surface



Each type of fabric has been coated with silica nanoparticles at each concentration, followed by a second coating by immersing the fabric coated with silica nanoparticles in HDTMS dissolved in ethanol at a ratio of 3% volume per volume. Dissolving HDTMS in ethanol causes the 3 methoxy groups attached to the central Si atom to be substituted into silanol $(SiOH)_3$. Similar to the silica nanoparticle coating treatment, the aim of immersion is to provide maximum activity or interaction of the siloxane chains, which act as coupling agents. It is expected that long chain siloxanes, which have hydrophilic groups, form bonds with the hydrophilic groups of HDTMS, which are dissolved in ethanol, namely $–Si(OH)_3$. The long chain of C16 atoms as hydrophobic micelles will be directed towards the surface of the fabric so that the hydrophobicity of the fabric increases. After the coating process, drying is carried out at a temperature of 110° for 5 minutes, which aims to make the film coating or the interaction of the hydroxyl groups of the siloxane chains with the hydroxyl groups of the silanol stronger and to remove any remaining water or alcohol content on the fabric. An illustration of the interaction of the resulting hybrid film on the fabric surface is presented in Figure 5.

Figure 5
Scheme of coating the substrate that has been coated with alkylsilane



In the next sub-chapter, we will study the contact angle analysis resulting from variations in silica concentration and the type of fabric coated, as well as other characterizations such as FTIR, SEM, TEM, and surface flow rate tests.

Effect of Variations in Silicate Mole Concentration on Fabric Characteristics

The hydrophobicity of a surface is influenced by two factors, namely chemical composition and surface morphology. The composition of the material that makes up the hybrid film is one of the factors that influences the properties of the hybrid material. Studies on optimizing the chemical composition of hybrid layers need to be carried out to obtain layers with the best hydrophobicity. The contact angle of the hydrophobic layer was calculated at varying silica moles of 0.025, 0.050, and 0.075 with fixed HDTMS moles. The study of variations in silica moles: HDTMS was carried out using the LbL technique. Table 1 shows photos of water droplets (5 µL) on the hydrophobic layer on various variations of silica moles and each type of fabric.

Table 1

Water contact angle at varying silica concentrations

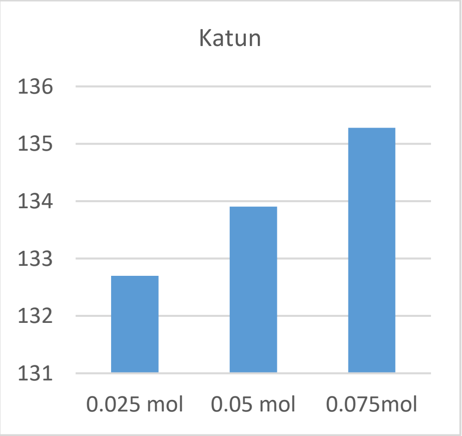
Fabric Type	Average angle (°) in each silica concentration		
	0.025 mol	0.050 mol	0.075 mol
Cotton	132.7	133.9	135.8
Mori	125.9	130.6	133.9
Calico	133.4	134.5	136.2

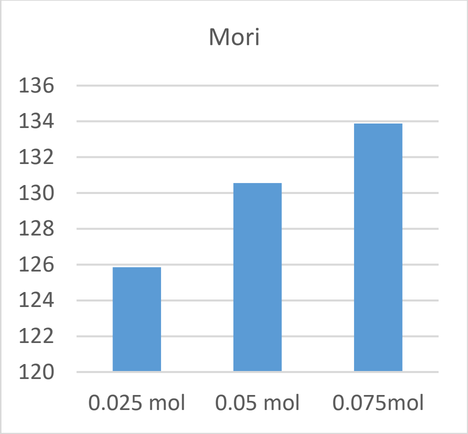
Based on the data in Table 1, increasing the mole ratio increased the water contact angle value in the hydrophobic layer. The contact angle of water droplets hitting the fabric surface increases the contact angle value along with the increase in silica moles. The higher the contact angle value, the hydrophobicity of the fabric increases.

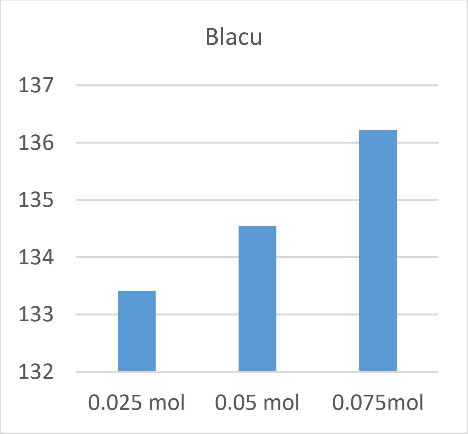
An increase in the water contact angle indicates an increase in silica nanoparticles covering the surface layer of the fabric. Thus, the hydroxyl groups of cellulose fibers decrease with the increase in silica nanoparticles. The bonding interactions between the –OH groups of cellulose and silica particles are thought to be hydrogen bonds. This increase in contact angle is also predicted to increase the size of the silica nanoparticles as the mole ratio of silica used increases. As is known, the silica concentration in the sol-gel process is one of the parameters that influences the size of the silica nanoparticles produced.

Figure 6

Histogram of water contact angle measurement results for each type of fabric on a variety of silica soles







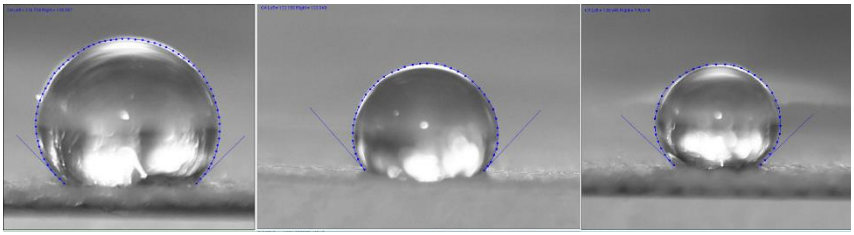
The resulting contact angle is the average of images processed on three water spots on one surface of each type of fabric. Because contact angle measurements are carried out using analog software, the error bars produced at this contact angle are quite large. Apart from that, the use of a lens or camera also affects the resulting image. The more you can focus on the magnification without breaking the image pixels, the easier it will be to measure contact angles using the Image-J software. Thus, based on Table 1, the best concentration of silica nanosol used as a thin first layer to produce the best contact is a silica sol concentration of 0.075 mol. The average contact angles for each type of cotton, mori, and calico fabric are 135.8, 133.9, and 136.2°, respectively. Thus, each type of fabric in the concentration was characterized by the surface of the fabric layers using a set of FTIR, SEM, and water flow tests. The discussion of this study is carried out in the next sub-chapter.

Influence of Fabric Type on Hydrophobicity

This sub-chapter aims to determine the effect of fabric type on the resulting contact angle. The three types of fabric used are cotton, mori, and calico. Calico cloth is the lowest quality cloth compared to mori cloth and cotton cloth. Calico cloth is also the basic cloth for making mori cloth. Therefore, the content of other compounds such as wax, oil, or other impurities in fabric fibers is greater than in other types of fabric. This is what causes the water absorption on the surface of calico fabric to tend to be longer and slower than other fabrics. Based on the comparison of fabric types to the contact angle produced at the optimum silica concentration of 0.075 mol, it was found that calico fabric has a contact angle greater than cotton and mori, namely 135.8, 133.9, and 136.2°, respectively. Figure 7 is a comparison of the contact angles for each fabric.

Figure 7

Comparison of contact angles for each type of cotton fabric (start), mori (middle), and calico (finish).



Test The Water Flow Rate

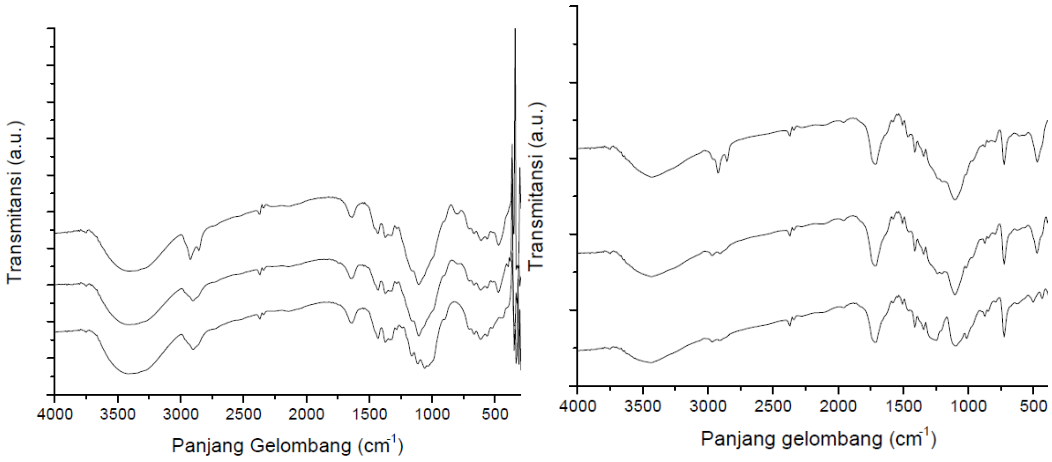
The water speed test was conducted at a fabric surface slope 10°. This was done to know the speed of water flow as well as a slope standard to determine the self-cleaning activity of hydrophobic materials against water droplets. Water droplets are dropped at a maximum height of 1 cm, to reduce the influence of gravity on the resulting flow rate. This assessment was carried out on each type of fabric coated with a silica nanoparticle-HDTMS hybrid with a silica mole ratio of 0.075. Each type of fabric is tested, and images are recorded. The resulting video is processed and edited to obtain an estimate of the water flow rate on the surface of each type of fabric. The speed of water flow in each cotton, mori, and calico fabric is 3.3, 5, and 6 meters per second, respectively.

FTIR Analysis of Each Type of Fabric

Based on the study of variations in silica moles, FTIR characterization was carried out to identify the functional group content in the fabric both before preparation, coated with silica nanoparticles, and coated with silica nanoparticle-HDTMS hybrids. The working principle of FTIR is to analyze the infrared radiation absorbed by the sample, and some of it is passed (transmitted). The number of frequencies that pass through the sample is measured as transmittance. The resulting spectrum is the absorption and transmission of molecules, creating peaks from the groups contained in the sample.

Figure 8

FTIR spectra of cotton fabric (top), mori (middle) and calico (bottom) before preparation (a), after being coated with silica nanoparticles (b) and coated with silica nanoparticle-HDTMS hybrid (c)



Based on the results of FTIR analysis, it can be seen that each type of fabric, with the addition of a layer of silica nanoparticles (b), provides a wavelength shift at 1103cm$^{-1,}$ which is the vibration of SiO_2. Moreover, after coating the hydrophobic agent (c), it shows the emergence

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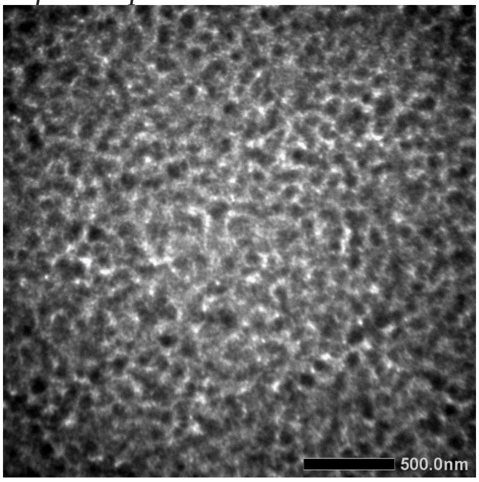
of new peaks at wavelengths of 2854 cm-1 and 2916 cm-1, which are the stretching and bending vibrations of the -CH group of the long alkyl chain (C16) of HDTMS.

TEM Surface Topography Characterization

This study aims to determine the estimated size of silica particles at a nanosol concentration of 0.075 mol. In brief, the working principle of TEM is that an electron beam illuminates the specimen and produces an image on a phosphor screen. At small magnification, the TEM image will have contrast due to electron absorption in the material due to the thickness and composition of the material. At high magnification, the resulting image will display clearer data on crystal structure analysis, etc.

Figure 9

TEM characterization results of silica particles



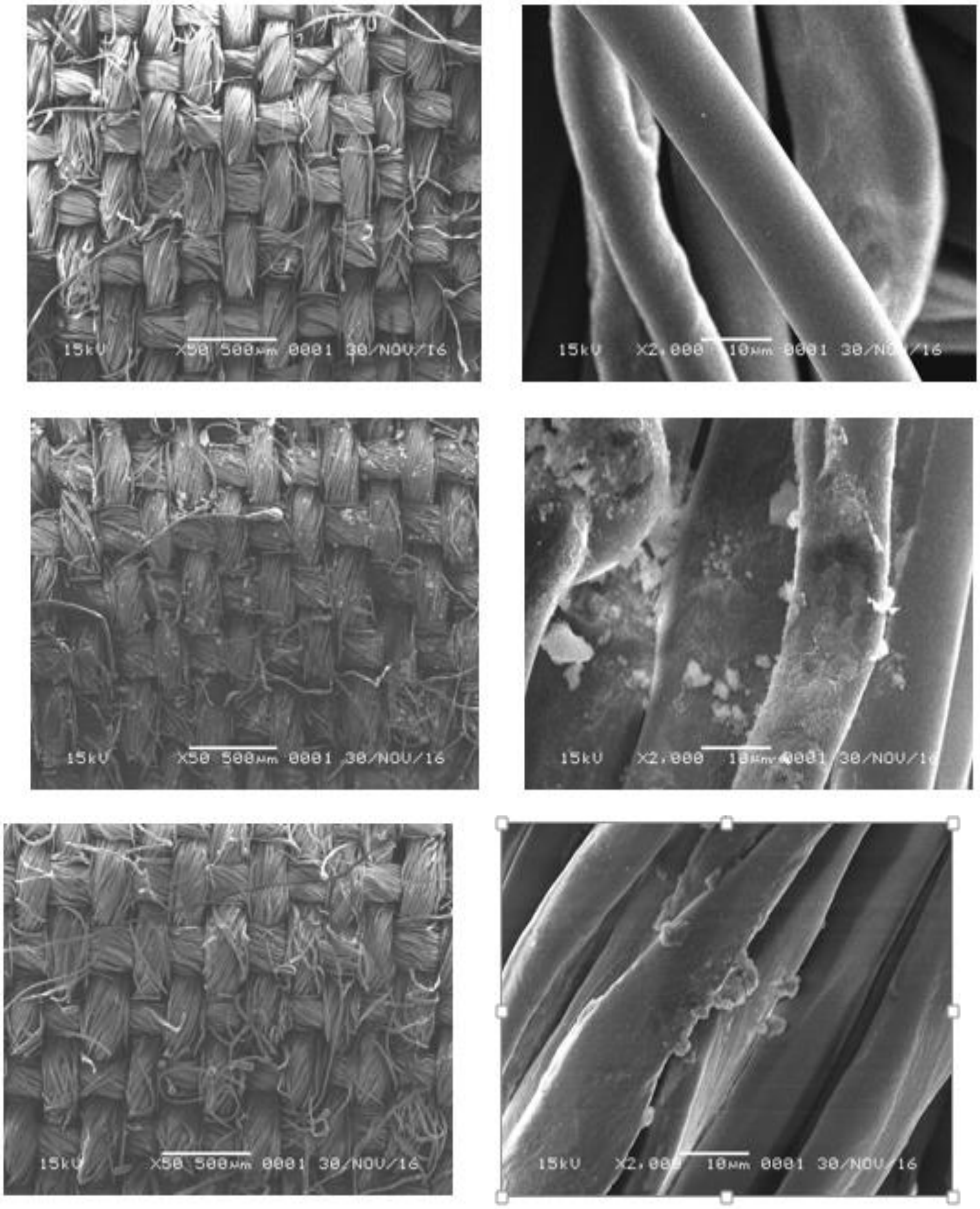
SEM characterization

This characterization aims to observe the film coated on the surface of the fabric. The difference between SEM and TEM is in the way the electrons fired by the electron gun hit the sample. In SEM analysis, the sample is not penetrated by electrons, so only the glow resulting from the collision of electrons with the sample is captured by the detector and processed. The requirement for SEM to produce sharp images is that the surface of the object must be electron-reflective or able to release secondary electrons when shot with an electron beam. Fabric is a non-metallic material; therefore, the fabric is first prepared by coating a thin layer of film on the surface of the fabric with gold palladium, which functions to reflect the electron beam and protect the surface layer so that it is not damaged. In this study, image analysis was carried out only on cotton fabric surface samples with magnifications of 50 and 2000X (times), as shown in Figure 10.

Based on the image below, both at 50- and 2000-times magnification, the cotton fabric before being coated with film (above) shows that the surface of the thread fibers is clean, and there are no particulates attached to the surface. Meanwhile, after coating the silica nanoparticle film (middle), on the surface of the fabric, you can see the silica nanoparticles coated on the thread fibers quite evenly. Silica particles at 50 times magnification show quite clearly that the silica nanoparticles have been successfully coated on the surface layer of the fabric; this indirectly influences the increase in the hydrophobicity of the fabric. At 2000 times magnification, it becomes increasingly visible that the silica nanoparticles form small solids between the silica. The uneven distribution of particles is also influenced by the manual dip coating technique. So, when the fabric is pulled from the sol, some of the silanol (SiOH)4 sol experiences rapid evaporation and forms inter-silica agglomeration.

Figure 10

SEM results of cotton fabric with magnification of X50 (left) and X2000 (right), before preparation (top), coated with silica nanoparticles (middle) and coated with HDTMS (bottom)



At the coating stage of the fabric that has been coated with the silica-HDTMS hybrid film (c), there is a change in the surface morphology of the cotton fabric, becoming smoother when observed at an image magnification of 50 times. The previously quite visible solid silica particles in Figure IV.8 (b) appear to have decreased. This may be due to the influence of the HDTMS coating dissolved in ethanol. Silica particles not completely firmly bound to the water surface dissolve again in ethanol. Thus, it can be seen that when the HDTMS coating as a hydrophobic agent has been coated on the surface of the fabric supported at a magnification of 2000 times, the silica particles after the HDTMS coating change physically, and there is also some fairly even distribution on the surface of the fabric fibers.

4. Conclusion

The optimum concentration of silica nanosol to form silica-HDTMS nanoparticle hybrids with the best contact angle is 0.075 mol TEOS. With the optimum nanosol concentration, the average contact angle for cotton, mori, and calico fabrics was obtained at 135°; 133°; and 136°. Testing the speed of water flow at a slope of 10 degrees on each cotton, mori, and calico fabric is 3.3; 5; and 6 m/s.

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Declarations

Author Contribution :
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Author 2: Writing - Review & Editing, Formal analysis, and Methodology;
Author 3: Validation and Supervision.
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The authors declare no conflict of interest.

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