Short Communication:

Silane treated jute fabric: a promising natural material for oil absorption during oil spillage in water bodies

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Abstract

The study investigates the oil absorbing property of silane treated jute fabric. The surface of the jute fabric was modified by silane coupling agent for making it both oleophilic (oil attracting) and hydrophobic (water repellent). Application area is focused towards separation of oil from oil/water mixture during oil spillage. Diesel oil was used for the study. Triethoxyvinylsilane was used as silane coupling agent for modifying the surface of the fabric. The treated fabric was characterized by FTIR spectroscopy and its oil absorption as well as water repellent property was investigated. The reusability of the treated fabric for oil absorption was also studied.

The results revealed that the silane treatment of the jute fabric made it both oleophilic (oil attracting) and hydrophobic (water repelling). Its oil absorbency increases by two fold and its water absorbency became nil by the treatment process. Its reusability was also found to be good, having the potential to be used for three subsequent cycle. It is expected that the findings of the work along with further optimization will help in developing a natural and biodegradable oil absorbing material for use during oil spillage in water bodies.

Keywords: Jute fabric, Silane treated, Oil absorbing material, Oil spillage.

Introduction

Oil spillage and leakage accidents are frequent problems nowadays due to the increased use and transportation of oils all over the world. During spillage, oil seeps gradually to the nearby water bodies and causes a big concern to our water bodies and ecosystem as a whole.

Traditionally, a lot of strategy has been employed for combating oil spillage problems. Recently the use of sorbent material comes out as the most effective solution to extract out oil from the spillage area. Natural organic materials such as wood chips, saw dust, sugarcane bagasse and cotton have been used because of their biodegradable nature. However, these sorbents techniques become lame in economic and operational effectiveness. The sorbents made of synthetic materials like polyurethane or polyether and nylon have ecological compulsion as they are non-biodegradable in nature.[2]

Thus, there arises the need to find an alternative biodegradable and cost effective material having good oil absorbing property for the purpose. One such naturally occurring lignocellulosic fiber abundantly available in India at cheaper rate is jute. Jute is a lignocellulosic fiber composed of α–cellulose, hemicellulose, lignin, pectin and waxes. The former two compounds are hydrophilic and latter ones are hydrophobic. In other words, the cellulose and hemicelluloses being more hygroscopic than lignin are mainly responsible for moisture uptake.[1,4] Jute shows a high moisture regain of about 12-13% under standard conditions of temperature and humidity.

Different methods such as alkali treatment, silane treatment, acetylation and fatty acid modification are available in the literature for making the jute fabric hydrophobic and oil attracting. All these methods remove the free hydroxyl group on the surface of the jute fabric by forming siloxane linkage, acetyl linkages, ester linkages etc. thus making the jute fabric water repellent. Na Lv et al[2] prepared hydrophobic jute fiber via sol gel method to adsorb oil. Teli et al[5] enhanced the oleophilicity of jute fabric by treating it with fatty acid. It was found that the nonwoven jute grafted with fatty acid exhibited better sorption capacity than unmodified fabric for crude oil. Teli et al[4] also disclosed another method to prepare hydrophobic jute by acetylation method. It was observed that the oil absorption capacity of acetylated jute was higher than that of synthetic oil sorbents such as polypropylene fiber.

All of these studies showed that the jute fiber after surface modification has the potential to be used as oil absorbing material during oil-spillage. However, when oil spills on the water bodies, then it becomes very difficult to separate oil from water surface. Research works / literature on its application for oil water separation is still limited. This area needs to be explored for expanding its application for removal and recovery of oil spills on water surfaces. For using it as oil absorbing material, it has to be made both oleophilic (oil attracting) and hydrophobic (water repellent) by modifying its surface.

In our earlier study, we have prepared hydrophobic jute by using silane coupling agent. The moisture regain of the jute fabric decreased significantly by 48.2%. Water contact angle of the treated jute fabric determined was 111^{o} after silane treatment. The mechanism of the silanization technique is given in fig. 1. The method is eco-friendly and cost-effective thus providing an attractive method for improving the surface hydrophobicity of the jute fabric.[1]

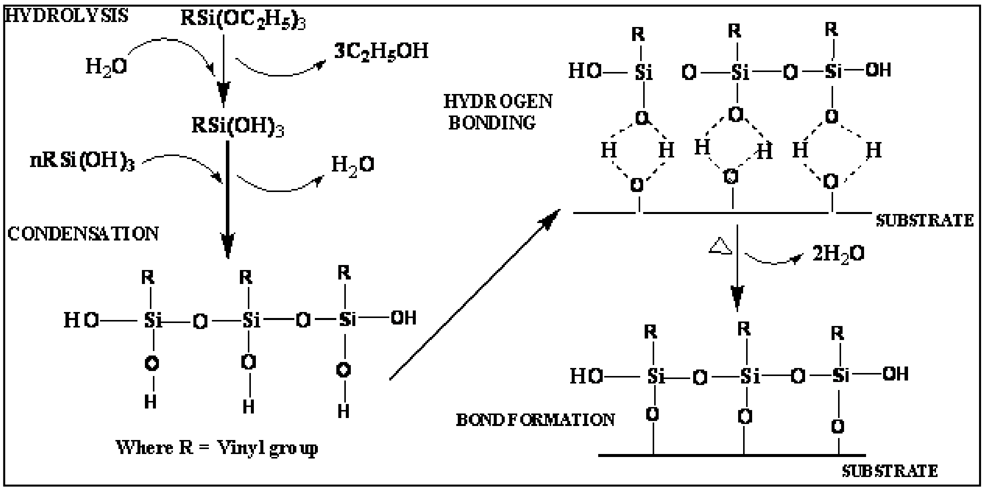

Fig. 1: Mechanism of silanization reaction

In the present work, using the same silane coupling agent and technique, surface modification of the jute fabric was carried out and the efficacy of the treated fabric towards removal and recovery of oil spills in water bodies was investigated. Diesel oil was used for the study.

Material and Methods

Raw Material: Hessain jute fabric (GSM: 243 g/m^2 at 65%RH and 27°C) was procured from Himanshu Jute fab, New Delhi (Fig. 2). It was used in raw form without any pretreatment. Triethoxyvinylsilane was procured from Sigma Aldrich. Acetone and hydrochloric acid were procured from SD Fine Chem Ltd, Mumbai. All the chemicals used were of analytical grade. The oil used for the experiment was light diesel oil with a density of 0.82 g/cm^3.

Fig. 2: Knitting pattern of jute fabric

Method for Silanization of Jute Fabric: Triethoxyvinylsilane (15wt % of fabric) was used for surface modification of jute. The silane was first hydrolyzed in acetone/ water solution (80/20 v/v) for 30 mins with continuous stirring. The pH of the solution was adjusted in the range of 3.5 to 4 with the addition of conc HCl. Pre-dried jute fabrics were then immersed in the treatment solution for 2 hrs at ambient temperature. After the treatment, the fabric was taken out and dried at room temperature for 1hr followed by oven drying at 110 ± 2°C till constant weight was obtained. The treated fabric was then used for the analysis.

Characterization of the Treated Jute Fabric

FTIR Analysis: Fourier transform infrared spectroscopy (FTIR) spectra of untreated and treated jute fabric was recorded in a FTIR spectrophotometer (Nicolet Corporation USA). The fabric was dried in an oven at 105± 2°C prior to use. The dried fabric piece was then analyzed in an attenuated total reflectance (ATR) detector over a range of 400 to 4000cm^{-1} at a resolution of 4cm^{-1}/min.

Oil Absorption Capacity: Evaluation of oil absorption capacity of the treated jute fabric was performed as follows: A fixed quantity of diesel oil (50g) was suspended in water in a beaker. The treated fabric (approx. 1g) was added into the beaker and left unpurturbed for the specified time period. After the time period, the fabric was removed and held in a sieving net to drain off the excess amount of oil for 10 min. The drained fabric was then reweighed to determine the oil absorptivity. This was repeated at different times (1, 5, 10 and 15 mins) to get maximum absorption. The oil absorption capacity of the fabric (expressed as g of oil absorbed / g of fabric) was calculated using equation:

$$\text{Oil absorption capacity} = (S_{st} - S_o) / S_o = S_s/S_o$$

where S_o = initial dry fabric weight (g), S_{st} = weight of oil absorbed sample (g) after 10 min gravimetric dripping and $S_s = (S_{st} – S_o)$ – net oil absorbed (g).

Water Repellent Property: The water repellent property of the treated jute fabric was evaluated manually by putting a colored water droplet on the surface of fabric. The shape of the droplet and the time taken by the droplet to collapse on the surface of the fabric were observed manually. The water repellency was also observed by sinking and floating behavior of the fabric in a beaker filled with water.

Reusability of the Oil Absorbed Sample: The reusability of the oil absorbed fabric was determined as follows: In a beaker half filled with water, suspend approx 50g diesel oil. The treated fabric was added into it and allowed to remain unperturbed for 5min. After 5 mins, the oil soaked fabric was squeezed using a roller to remove oil before it was weighed. The squeezed fabric was again used in the absorption process as mentioned above. The efficiency of the fabric reusability was determined by calculating the oil absorption capacity of the fabric after repeated sorption cycle.[4]

Results and Discussion

FTIR Analysis: The FTIR analysis of the treated jute fabric clearly indicates that silanization has taken place at the surface of the jute fabric (silanization mechanism shown in fig. 1). The treated jute fabric showed the presence of Si-O-Si peak (at 1032cm^{-1}), Si-O-C peak (at 1205cm^{-1}) and Si-O peak (at 777cm^{-1}) (Fig. 3). This confirms the chemical reaction between hydrolyzed silane and the hydroxyl groups of the jute fabric forming Si-O-C linkages creating polysiloxane network.

Oil Absorption Capacity: Fig. 4 shows that the oil absorption capacity of the jute fabric after silane treatment increased significantly from 1.1 in case of untreated fabric to 2.4 in case of treated fabric. A two fold increase in oil absorption was observed after the treatment process. The increase in oil absorption capacity can be attributed to the adsorption of diesel oil molecules at the hydrophobic reactive sites in addition to diffusion of oil into the pores or hollow lumen of the fabric.[3]

It was also observed that the oil absorption capacity of the fabric was time dependent. On increasing the contact time from 1min to 5min, the oil absorption capacity of the treated fabric increases from 1.6 to 2.4, after which it reached equilibrium. This may be due to the adsorption of diesel oil on the surface of the fabric first, before the oil starts to penetrate the inner microscopic voids until equilibrium time is reached.

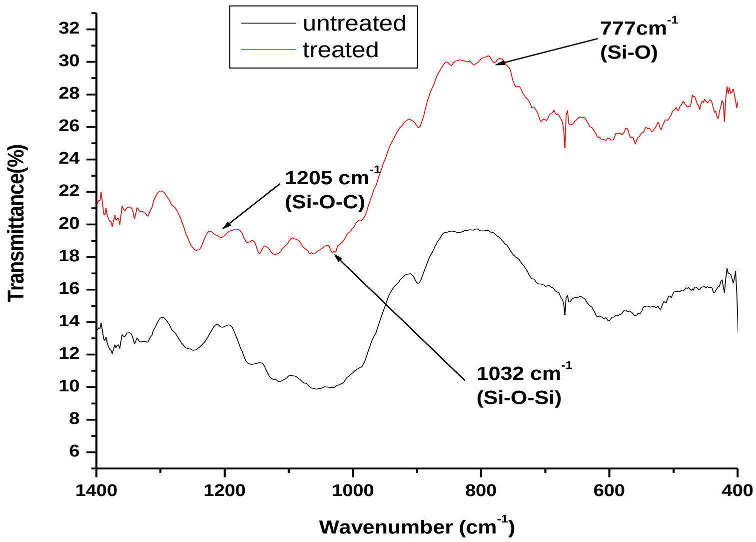

Fig. 3: FTIR spectra of untreated and treated jute fabric

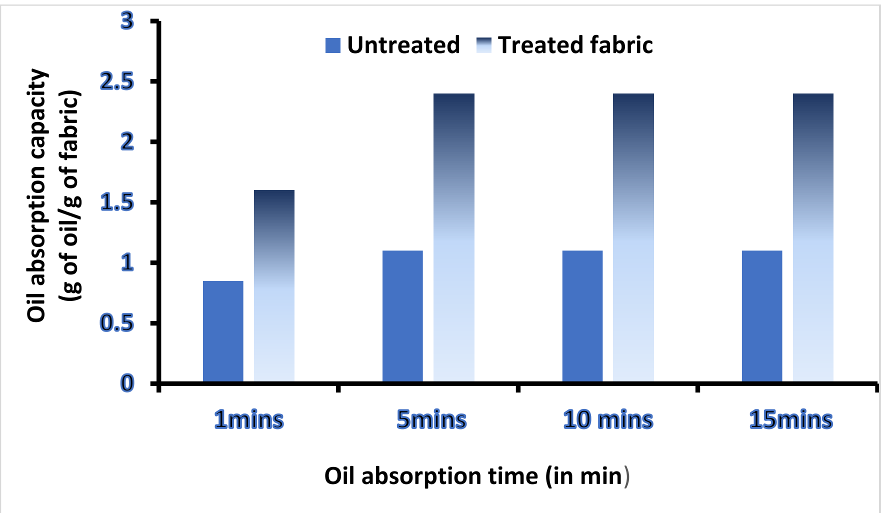

Fig. 4: Oil absorption capacity of untreated vs treated jute fabric

Water Repellency: The water repellency behavior of the treated fabric was observed manually by dropping a colored water droplet on the surface of the untreated vs treated fabric (Fig. 5). In case of untreated fabric, the water droplet loosens its shape and gets absorbed within 30 sec whereas in case of treated fabric, the droplet remains spherical up to 6 hours. After 6 hours, it gradually loses its spherical shape and starts collapsing. This clearly indicates that the inherent hydrophilicity of the jute fabric was reduced by silane treatment. This may be due to the fact that the OH group's of the jute fabric was blocked by the silane molecules limiting its affinity towards water.

The water repellency behavior of the treated fabric was also investigated by putting a $5cm^2$ fabric on a beaker half filled with water. The sinking and floating behavior of the untreated vs treated fabric were observed. In case of untreated fabric, the fabric sinks to the bottom as soon as it was put into the beaker. The treated fabric however remains floating on the surface of the water even after 30mins (Fig. 6).

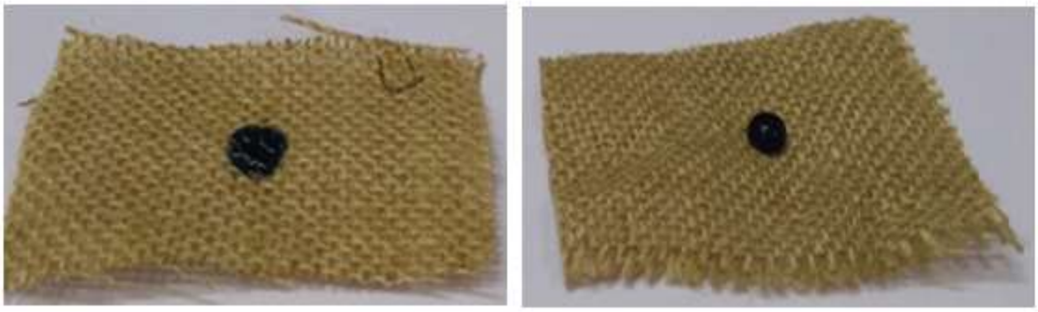

Fig. 5: Digital photographs of colored water droplets captured on the surface of (a) untreated jute fabric after 30s and (b) treated jute fabric after 6hrs.

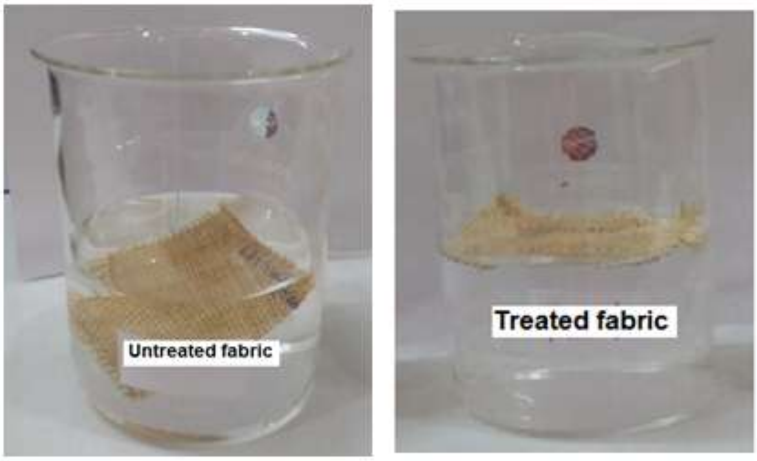

Fig. 6: Water repellency behavior of untreated/ treated jute fabric

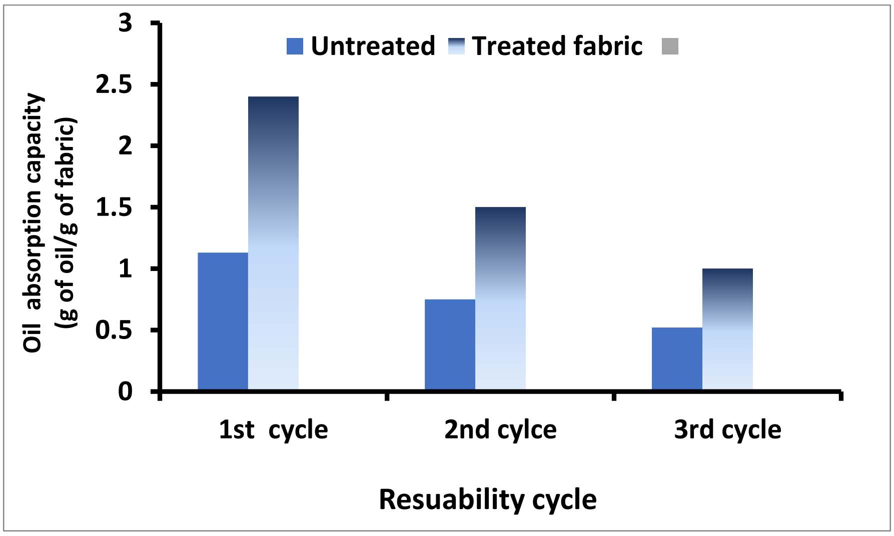

Fig. 7: Reusability study of untreated vs treated jute fabric

Reusability of Oil Absorbed Sample: It can be seen from fig. 7 that the treated fabric can be reused upto a maximum of three cycles. In the first cycle, the oil absorption capacity was 2.4 which decreases to 1.5 and 1.0 in the subsequent cycle. Although its oil absorption capacity decreased in the subsequent cycle, still better absorption was observed when compared to untreated one. The decrease in oil absorption may occur due to collapsing of lumen during the squeezing and masking of silane group in jute fabric by residual oil layer.

Conclusion

Silane treated jute fabric has shown the promising ability to be used as oil absorbing material during oil spillage in land surface as well as in water bodies. Silane treatment increased the oil absorption capacity of the fabric by two fold and its zero water absorption property gives it an additional edge to be used in separation of oil from oil/water mixture. Its oil absorption property can be further enhanced by properly manuevering the physical design of the material. Its reusability is also found to be good although a declining trend was observed with subsequent cycle.

Moreover, the product developing method and process is simple. The entire process involves minimal uses of chemical and low cost raw material, thus gives an opportunity to develop an ecofriendly, biodegradable and low cost oil absorbing material.

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