Environmental Technology & Innovation 28 (2022) 102849

Contents lists available at ScienceDirect

Environmental Technology & Innovation

journal homepage: www.elsevier.com/locate/eti

Surface innovation for fabrication of superhydrophobic sand grains with improved water holding capacity for various environmental applications

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A R T I C L E   I N F O

Article history:
Received 21 June 2022
Received in revised form 20 July 2022
Accepted 22 July 2022
Available online 2 August 2022

Keywords:
Sand grains
Nanoparticles coating
Superhydrophobic sand
Anti-droplet
Self-cleaning
Oil–water separation

A B S T R A C T

The extreme evaporative loss of water from topsoil complicates cultivation in arid areas, and artificial plastic mulches that imitate sand mulches may minimize such water losses. However, the application of such plastic mulches is limited by their high cost and non-biodegradability. In this study, we developed superhydrophobic sand grains to reduce evaporative water loss from soil. Sea sand (SS) was coated with silica sol, which was prepared by the hydrolysis of tetraethoxysilane (TEOS) under alkaline conditions, followed by treatment with perfluorodecyltrichlorosilane (FDTS). A facile step was optimized for fabricating hydrophobic sand grains with contact angle of 151° and rolling-off angle of 9.5° to confirm the hydrophobicity and anti-droplet properties of the modified sand grains. The sands modified with engineered nanomaterials have shown the enhanced water holding and storage efficiency, and they can be applied as an oil sorbent scaffold to absorb oil (chloroform) from water selectively due to their water repelling properties. The coated superhydrophobic sand grains displayed anti-droplet and self-cleaning features, and withheld water for extended periods of time, which could benefit agriculture in arid regions and various environmental applications.

1. Introduction

Water sources in arid and desert regions are extremely limited, complicating water supply to domestic, agricultural, and industrial sectors. Furthermore, water pollution in arid and desert regions is a significant, unacceptable, and irreversible threat (Heyns, 2009). Furthermore, a substantial amount of water supplied to soil/sand is lost due to evaporation and percolation (Gong et al., 2017). Layers impermeable to water have been studied to minimize water loss through evaporation and percolation. For example, plastic mulches have been used to wrap the soil surface to minimize percolation and evaporation. The plastic mulches have been commercially used for both small fruit crops and vegetables. They are used commercially for both vegetables and small fruit crops. However, the installation of plastic mulches is expensive, labor-intensive, and unsustainable due to plastic pollution (Salem et al., 2010; Guber et al., 2015). As an alternative,

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https://doi.org/10.1016/j.eti.2022.102849

Table 1
State-of-art discussion of previous research outputs by comparing the present study.

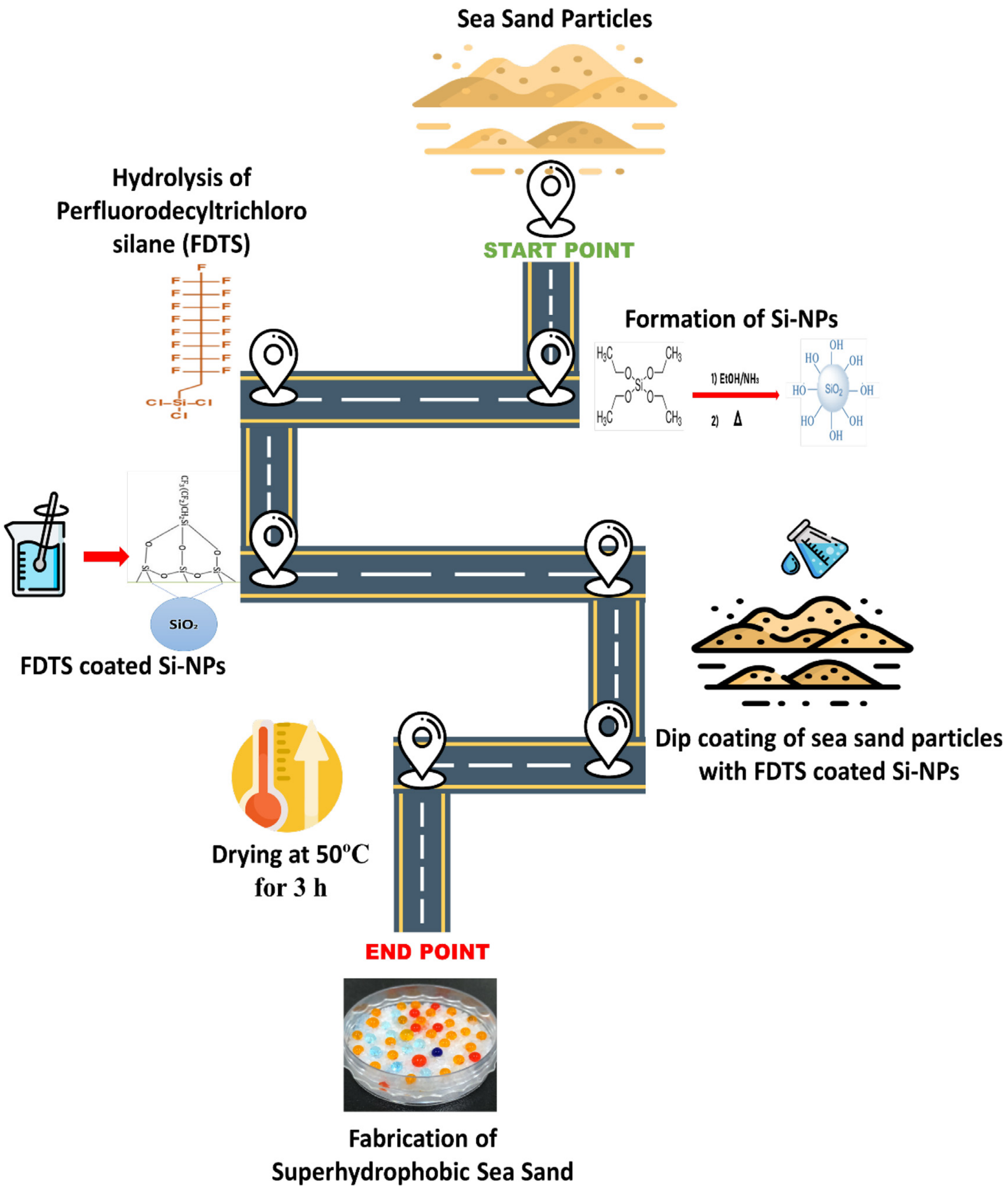
Sand type	Functionalization	Method of coating	Applications	Reference
Regular sand	Perfluorodecyltri-ethoxysilane coated with sand (PFDS-sand@SiO_2)	Silver mirror reaction and Copper mirror reaction	• Water storage • Water transportation	Chen et al. (2017)
Arid region sand	Sand coated with paraffin wax	Dip coating technique	• Water-use efficiency • Agricultural application	Gallo Jr. et al. (2022)
Common sand	Sand functionalized with Octadecyltrichlorosilane	Dip coating technique	• Oil–water separation	Men et al. (2016)
Sand grains	Sand grains loaded with polydimethylsiloxane (PDMS)	Chemical vapor deposition	• Oil–water separation	Mosayebi et al. (2020)
Sea sand and regular sand	Coating imparted from silica sol and Perfluo-rodecyltrichlorosilane (FDTS) solution	Dip coating technique	• Enhancement of water holding capacity • Environmental applications such as oil/water separation	This study

the use of engineered nanomaterials has been shown to improve water-usage efficiency in agricultural applications, as exemplified by "superhydrophobic sand", which is obtained by modification using nanomaterials, and can tackle the issue of desertification and enhance plant growth in arid environments (González-Peñaloza et al., 2013; Atta et al., 2019; Mitzel et al., 2016). Superhydrophobic sand also reduces diffusion of underground salts and affects plant growth (Atta et al., 2019; Mitzel et al., 2016). Therefore, harnessing the superhydrophobic characteristics of various nanomaterials is a key research area of global significance.

Recently, silica-based nanomaterials and silicon derivatives have attracted much attention owing to their exceptional adhesion to glass and sand surfaces (Leelamanie and Karube, 2009; Ogihara et al., 2012; Xu et al., 2014). Several organic silane-based derivatives have been explored for coating sand grains to generate hydrophobic surfaces (Xu et al., 2014; Men et al., 2016; Soni et al., 2021; Ray et al., 2020; Sinha Ray et al., 2019). Typically, in situ hydrolysis and condensation of alkoxide precursors with hydrophobic side functional groups, such as silsequioxanes and organosilanes, is practiced. However, the formation of hydrophobic coated surfaces is highly dependent on the organic substitution of organosilane, residual unreacted groups (both from the surface and silane), surface coverage, and surface distribution (Sah et al., 2004). In terms of the structure, long-chain fluorinated alkysilanes have been functionalized onto silica surfaces, thereby generating modified superhydrophobic sand surfaces (Oyola-Reynoso et al., 2016; Xiu et al., 2008). The superhydrophobic coating is usually produced using various materials and nanomaterials including nanocomposites. Typically, inorganic nanomaterials offer stable, large surface and mechanically robust areas on different substrates. Thus, the longevity of the material can be improved via covalent bonding or cross linking between the coating and substrate (Kausar, 2019). Additionally, superhydrophobic materials have been extensively utilized for effective oil/water separation (Mosayebi et al., 2020).

In other related works, dip coating techniques and chemical vapor deposition methods were applied to modify the surface of sand for various agricultural and environmental applications as demonstrated in Table 1. Interestingly, most studies have improved water storage and oil/water separation performance.

In this study, superhydrophobic sand surfaces with anti-wetting and self-cleaning properties were produced for various purposes, such as improved agricultural productivity and oil/water separation. The facile approach entails the hydrolysis of tetraethyl orthosilicate (TEOS) in ethanol to produce a silane sol, and subsequently, fluoroalkyl silane was hydrolyzed in ethanol to produce alkylsilanol. Fluoroalkyl silane was used to lower the surface energy of the coated silica nanoparticles. Sea sand (SS) grains were functionalized with silica nanoparticles (Si-NPs), followed by 1H,1H,2H,2H-perfluorooctyl-trichlorosilane (FDTS) to impart superhydrophobic characteristics, as illustrated in Scheme 1. To the best of our knowledge, the combination of TOES and FDTS has not been explored before, and this study presents and evaluates a novel approach for coating of sand grains in a single step to enhance water-use efficiency in agriculture. FDTS has the ability to lower the surface free energy. Reducing the surface free energy involves covalent grafting of long chain fluorocarbon or hydrocarbon molecules on solid substrates. Typically, longer molecular chains are more effective in reducing the surface free energy as illustrated by FDTS (Zhao et al., 2021). The average contact angle, rolling-off angle, and contact angle hysteresis were recorded to understand the dynamics of wetting resistance of the produced sea sand grains. The functionalized sea sand grains were impermeable to water, suppressing water loss through percolation or evaporation. Although superhydrophobic materials or filters are widely utilized for efficient oil/water separation (Mosayebi et al., 2020; Wang et al., 2021; Mosayebi et al., 2021), very few are energy conservative and inexpensive. Additionally, s similar approach was applied to modify regular sand (RS) using Si-NPs/FDTS to create a natural filter for oil/water separation. Our study demonstrates a simple and facile approach for generating superhydrophobic sand without the need for complicated facilities. The modified sand could potentially be applied to improve agricultural productivity under arid conditions.



Scheme 1. Roadmap of the chemical mechanism involved in modifying sea sand particles using silica nanoparticles (Si-NPs) coated with perfluorodecyltrichlorosilane (FDTS).

2. Materials and methods

2.1. Starting materials

SS grains of 15–20 mesh size were acquired from Daejung Chemicals, South Korea. The regular sand grains (RS) were acquired from Joomoonjin Silica Sand Co. Ltd. The particle grain size ranges from 0.1 to 1 mm with dry density of 1.64 g/cc. FDTS was obtained from Alfa Aesar. Ethanol was obtained from Daejung Chemicals (Seoul, South Korea). TEOS and ammonium hydroxide (reagent grade) were purchased from Sigma and Alfa Aesar, respectively, and were used without further purification.

2.2. Preparation of silica sol

TEOS was hydrolyzed under alkaline conditions using ammonia hydroxide in ethanol. Specifically, 5 mL of ammonium hydroxide was added to ethanol (100 mL) and stirred vigorously at 60 °C for 1 h. Then, 5 ml of TEOS was added to the solution and vigorously mixed for 6 h to generate a silica sol. Meanwhile, FDTS was added to ethanol (3%v/v) and vigorously mixed for 6 h to produce an alkylsilanol solution. Then the FDTS solution was added to the silica sol solution to produce the modified silica sol (Si/FDTS).

2.3. Sand grain coating

Initially, SS and RS was sonicated in Si/FDTS for 1 h to achieve a uniform coating. The coated SS (SS-Si/FDTS) and RS (RS-Si/FDTS) samples were filtered and then dried for 12 h initially and then treated in hot air oven at 50 °C for 3 h to remove extra moisture in them. Scheme 1 shows a roadmap of the anti-droplet SS coating process.

2.4. Characterization

Images and slow-motion videos were captured using a high-quality mobile camera. The average water contact angle was evaluated using a Phoenix 300 Plus instrument (Surface & Electro Optics Co., Ltd., Korea). Initially, the Si-NP particles were subjected to nanoparticle analysis to evaluate their size and size distribution using a Zetasizer Nano (ZS, UK). In this study, three samples were analyzed under the same conditions in. The morphologies of the unmodified and functionalized sand particles were imaged using a field-emission scanning electron microscope (FE-SEM; 200 FEG Quanta, FEI company). In addition, elemental mapping was performed using an energy-dispersive X-ray spectroscopy (EDS) detector equipped with FE-SEM. Fourier transform infrared spectroscopy (FTIR) was performed to confirm the presence of various organic functional groups in the functionalized sand particles. Elemental identification was performed using X-ray photoelectron spectroscopy (XPS) (Thermo Fisher Scientific, K-Alpha, USA).

2.5. Analysis of contact angle hysteresis (CAH)

The hydrophobicity and wetting phenomena of the functionalized SS grains were evaluated using sessile drop methodology. Herein, the contact angle hysteresis (CAH) was determined to understand the dynamics of the wetting tendency. The maximum advancing contact angle (Θ_A) was recorded for a small droplet (1 μL/s) over 30 frames with 1 s intervals. Subsequently, the minimum receding contact angle (Θ_R) was recorded by gently absorbing a droplet at 1 μL/s. Finally, the CAH was determined according to Eq. (1) (Guo et al., 2018; Ray et al., 2021b,a):

$$CAH = \Theta_A - \Theta_R \quad (1)$$

3. Results and discussion

3.1. Particle size distribution of Si-NPs

The silica particle size was successfully recorded using a Zetasizer Nano device following the working principle of dynamic light scattering (DLS) technique. DLS was used to evaluate the particle size of the prepared nanomaterials. The mean hydrodynamic diameter of the nano-silica particles was found to be 131.7 nm, as shown in Fig. 1(a). Furthermore, the polydispersity index (PDI), which indicates the average uniformity of nanoparticle dispersion (Clayton et al., 2016; Shajari et al., 2020), was 0.109. Typically, PDI values > 0.8 indicate lower stability for a nano-delivery/drug delivery/colloidal system. A uniform and smooth distribution was confirmed based on the SEM images shown in Fig. 1(b–c).

3.2. Elemental composition of modified sea sand grains

FTIR spectra confirmed the presence of the desired functional groups. Fig. 2(a) shows the FTIR spectrum of the coated silica (Si-NPs/FDTS), indicating the stretching vibration of Si–O–Si at 1096 cm^{-1} (Zhang et al., 2018) as well as the Si–OH stretching at 880 cm^{-1} and 3200–3600 cm^{-1}. The peak at 1199 cm^{-1} corresponds to C–F functional groups. The presence of Si–O and C–F functional groups indicate the attachment of the hydrophobic FDTS tail to the surface of silica nanoparticles (Tudu et al., 2020).

The elemental composition of the unmodified and modified sea sand particles was characterized using XPS spectroscopy. As indicated in Fig. 2(b-c), the scanning spectra of the unmodified SS particles contain three prominent peaks at 103, 284.5, and 531.5 eV, which correspond to Si2p, C1s, and O1s, respectively. The results indicate the presence of Si, C, and O and confirm that the primary component of sand is silica (SiO_2) in the form of quartz. After successful treatment with FDTS-coated Si-NPs, the modified SS particles (SS-Si/FDTS) gave rise to five intense peaks at 104, 292.5, 284.5, 533.5, and 688 eV, which are associated with Si2p, C1s, C1s, O1s, and F1s respectively, confirming the presence of Si, C, O, and F. Additionally, Fig. S1, high resolution XPS spectra for each element demonstrates: (a) unmodified sea sand (SS) for F1s, C1s and Si2p peaks and (c) modified SS (SS-Si/FDTS) F1s, O1s, C1s and Si2p.

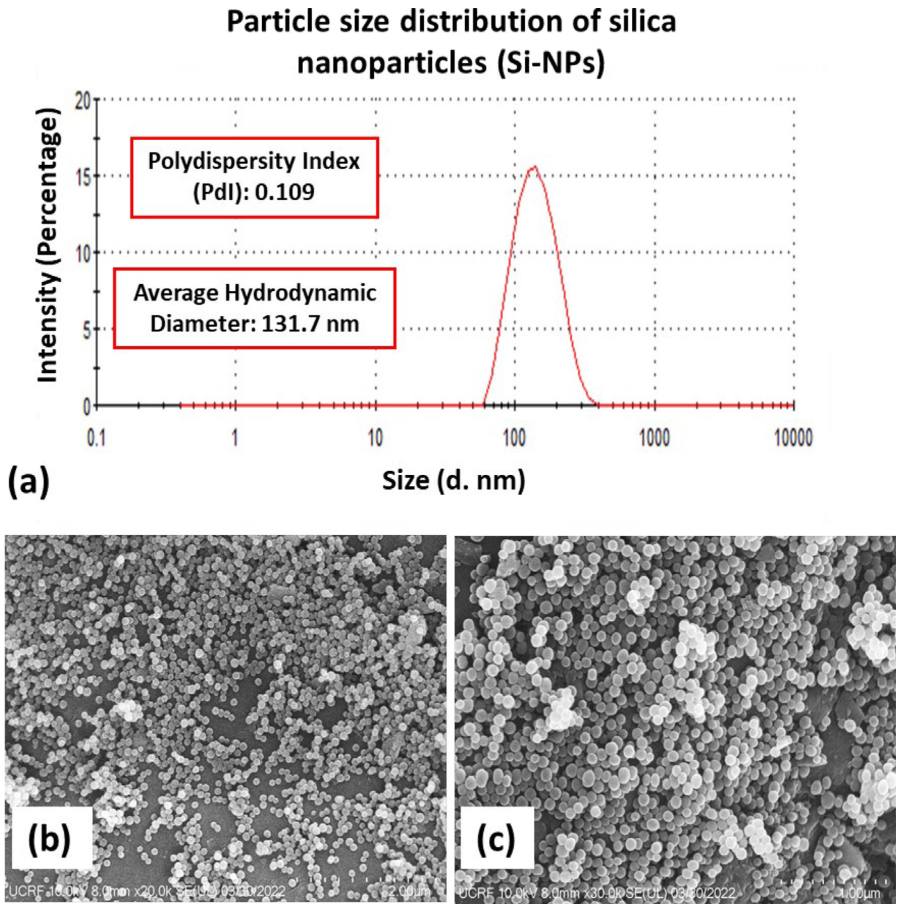


Fig. 1. (a) Particle size distribution of silica nanoparticles (Si-NPs), (b–c) SEM images of prepared Si-NPs.

3.3. Morphological study

The SEM images in Fig. 3(a) show that the majority of the unmodified SS grains are angular or subangular with sizes ranging between 750 and 1000 μm. After modification with Si-NPs/FDTS, the SS was coated with the nanoparticles to form SS-Si/FDTS, as confirmed by the SEM images in Fig. 3(b). The silica nanoparticles were mostly spherical with diameters in the range of 100 to 150 nm, as supported by the DLS results in Fig. 1.

The successful modification of SS with Si-NP/FDTS was further confirmed by EDS analysis. The EDS spectra in Fig. 4(a–b) show that the unmodified sand grains consist mostly of Si and O, corresponding to the composition of quartz. In the case of SS-Si/FDTS, Si and O mapping indicated that the entire SS grain surface was covered by Si-NPs. The consistent distribution of Si, F, and C confirms successful surface modification with Si-NPs/FDTS, as shown in Fig. 4(b, d). EDS elemental mapping indicated a stable dispersion representing C and F signals from the –CF3, –CF2, and –CH3 moieties in hydrolyzed FTDS.

3.4. Wetting tendency of modified sea sand grains

The superhydrophobic surfaces of the coated sand grains were evaluated based on the average water contact angle and rolling-off angle, as shown in Fig. 5(a). The unmodified sand grains readily absorbed water, giving a water contact angle of 0° because the polar oxygen atoms in silica form hydrogen bonds with water molecules (Tschapek et al., 1983). Coating the sand with Si-NPs/FDTS rendered the surface superhydrophobic, and a mean contact angle of 151° was obtained Subsequently, to evaluate the self-cleaning nature of the modified sand, the rolling-off angle was measured. SS-Si/FDTS showed a rolling-off angle of 9.5°, whereas the value for unmodified SS could not be determined because the water droplet was readily absorbed. Thus, the outcomes agree with those of previous studies in which water droplets immediately rolled off nanostructured surfaces, which lowered the surface energy by forming nanoscale air pockets (Ray et al., 2021a; Roach et al., 2008).

Typically, the maximum contact angle is referred to as the advancing contact angle of a material, whereas the smallest contact angle is known as the receding contact angle (Deng et al., 2022). The difference between the advancing and

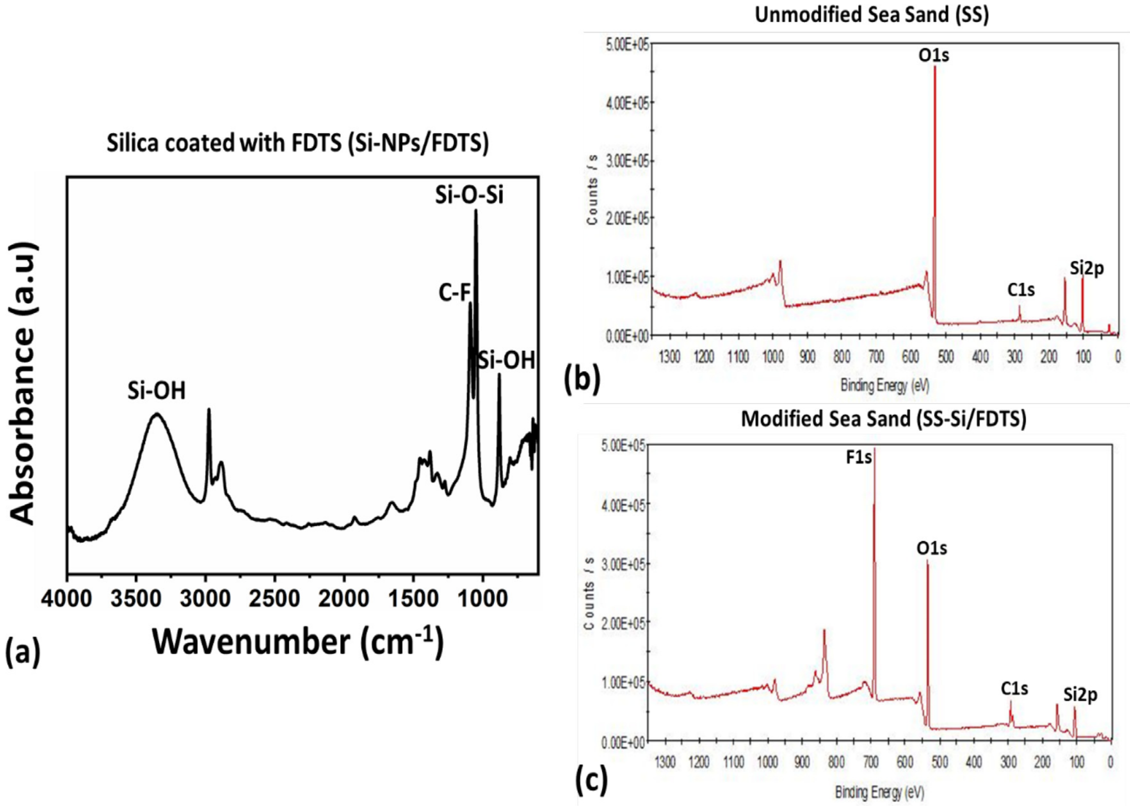


Fig. 2. Elemental composition: (a) FTIR spectrum of coated silica (Si-NPs/FDTS); XPS spectra of (b) unmodified sea sand (SS) and (c) modified SS (SS-Si/FDTS).

receding contact angles indicates contact angle hysteresis. Recent studies have demonstrated that the key sources of contact angle hysteresis are heterogeneity, surface roughness, and metastable surface states (Wang et al., 2020; Li, 1996). In general, a superhydrophobic surface is non-adhesive and demonstrates extremely low water contact angle hysteresis (Zhu and Dai, 2019). A similar phenomenon can be observed in Fig. 5(b), where the contact angle hysteresis was measured for unmodified and modified SS. The modified SS showed an extremely low contact angle hysteresis value (11°), indicative of non-sticky and slippery surfaces. Furthermore, it is directly correlated with the rolling-off angle. Superhydrophobic SS with a minimum contact angle hysteresis possesses a self-cleaning tendency, whereby water droplets can readily slide off it. However, the contact angle hysteresis of unmodified SS, which absorbs water droplets, could not be readily determined.

3.5. Water holding capacity of modified sea sand grains

Toward addressing the concern of water loss in arid regions, the water-holding capacity of unmodified SS and SS-Si/FDTS was thoroughly investigated. As shown in Fig. 6(a), 3 mL of dyed water was immediately absorbed by the unmodified sand (left), whereas the colored water formed a stable water marble on the SS-Si/FDTS sand pit. This result indicates that superhydrophobic sand is impermeable to water, and can thus potentially be utilized to reduce water loss from open water sources or stores in deserts and arid regions.

Next, a simulated water source was well covered by superhydrophobic sea sand grains, as demonstrated in Fig. 6(b), to evaluate their ability to minimize evaporative water loss in arid and desert areas. A beaker was filled with 25 mL of deionized (DI) water, and the upper surface was covered with a thin layer of SS-Si/FDTS, which floated on the water because of its superhydrophobicity. In the other beaker, unmodified sand was added to the same amount of water, immediately settling to the bottom. Both beakers were kept undisturbed for 4 d while measuring evaporative water loss. The results summarized in Table 2 show the water loss was modest (12%) for the water source covered by the superhydrophobic sand. However, significant water loss (28.4%) was observed in the unmodified SS case. Herein, the water loss in case of unmodified SS was considered as control experiment. The rate of evaporation seems to be more pronounced in case of unmodified SS as compared to that of modified SS. Thus, the overall outcomes suggest that water loss due to evaporation and percolation can be addressed by functionalized sand particles, and that this approach could be a fundamental research topic for improving agricultural productivity and water storage in desert areas.

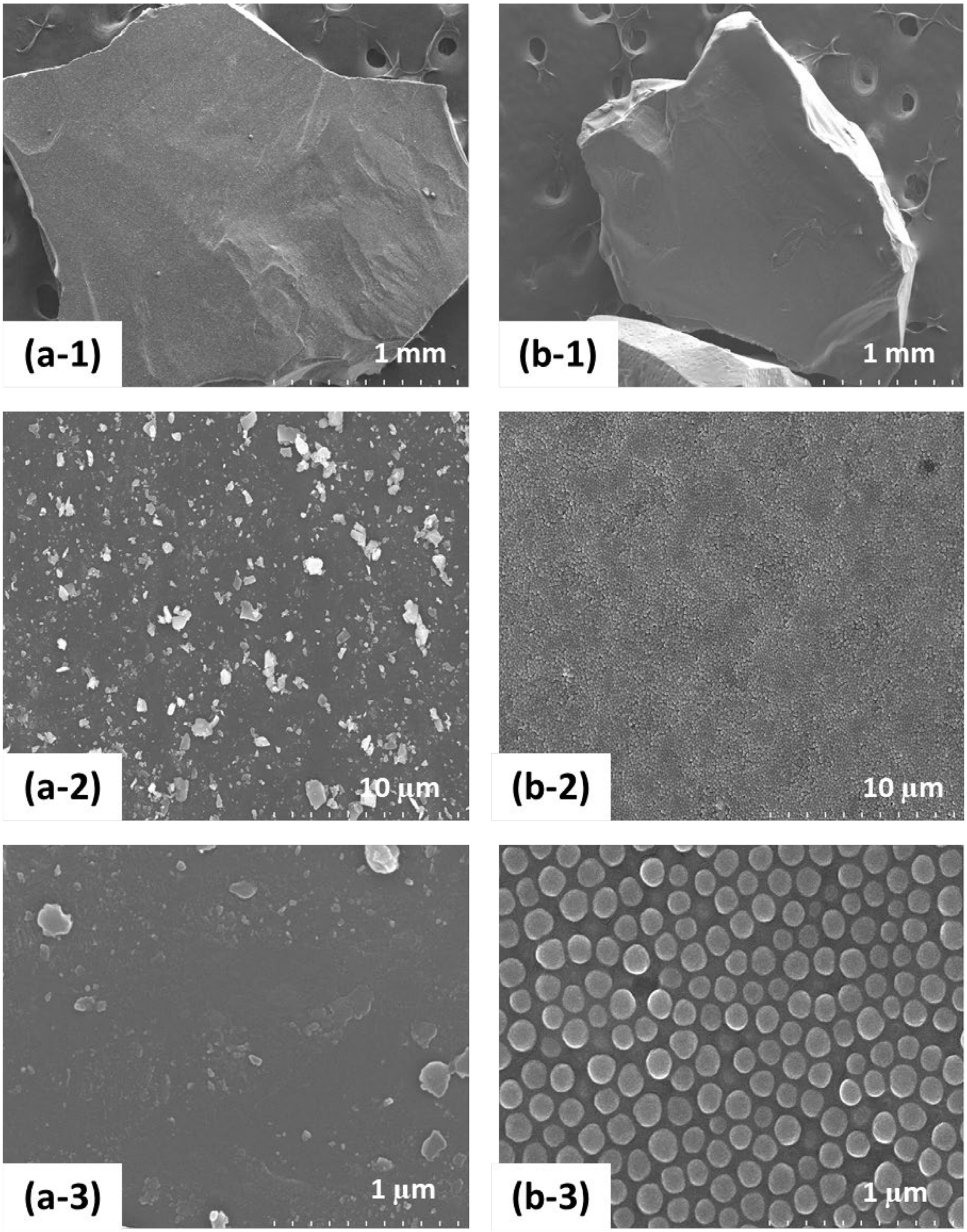


Fig. 3. SEM images showing the surface morphology of (a) unmodified SS grains and (b) modified SS (SS-Si/FDTS) at several scales.

In arid regions, acquiring fresh water is a major challenge because deep wells must be dug for underwater uptake (Ju et al., 2012). Therefore, it is necessary to develop a sustainable method that allows the water source to remain on the sand surface. The production of hydrophobic sand is useful for both fundamental research and practical applications. Additionally, to obtain reliable water storage in desert regions, superhydrophobic modified sand can play a key role during water transportation. Thus, to confirm the flow-dragging mechanism of the fabricated sand, a simple experiment was conducted as a simulation of real conditions, whereby water droplets were poured onto unmodified and modified SS. Movie 1 shows the water holding and storage capacity of the modified SS, where water droplets remained smooth.

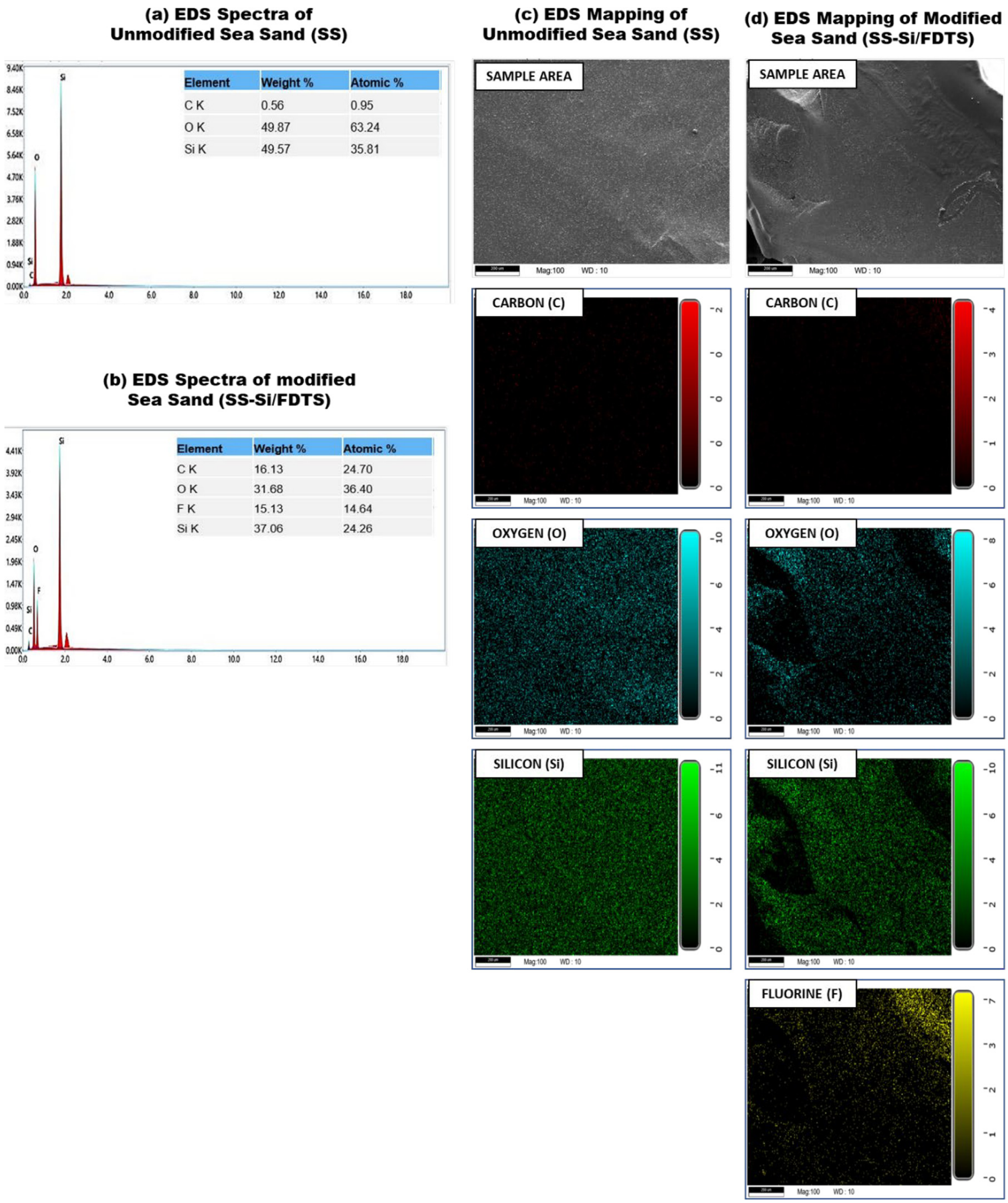


Fig. 4. EDS spectra confirming the elemental composition of (a) unmodified SS and (b) modified SS; and EDS mapping (c) unmodified SS and (d) SS-Si/FDTS confirming the uniform deposition of surface modifiers on the latter.

However, the water droplets were immediately absorbed by the unmodified SS. Fundamentally, SS/desert sand is superhydrophilic in nature; thus, water storage and transportation are impractical. Therefore, the movie indicates the significance of superhydrophobic sand for applications such as water storage and transportation under harsh conditions in arid areas.

Thus, the overall outcomes suggest that water loss due to evaporation and percolation can be addressed by functionalizing sand particles in arid or desert areas.

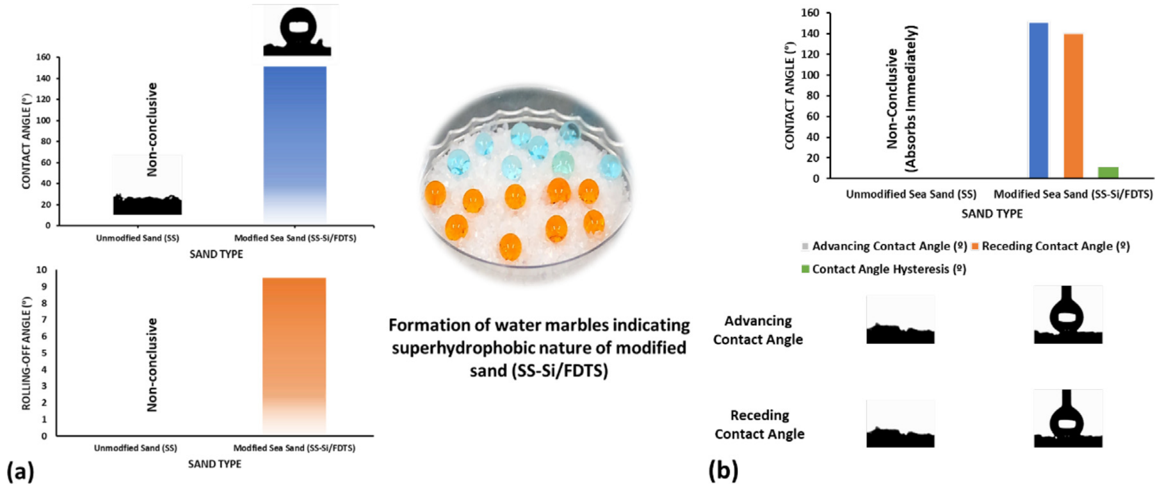


Fig. 5. Analysis of wettability of unmodified and modified SS (a) the water contact angle and rolling-off angle, (b) contact angle hysteresis of unmodified and modified SS. Advancing and receding contact angles were measured applying the sessile drop technique.

Table 2
Water storage capacity of modified sea sand.

Sand type	Status of sand	Initial volume of water at DAY 1 (mL)	Final volume of water at DAY 4 (mL)	Reduction in volume (mL)	% volume evaporated
Unmodified sand (SS)	Settled down immediately	25	17.9	7.1	28.4%
Modified sand (SS-Si/FDTS)	Formed a layer on top of the water source	25	22	3.0	12%

Note: Conditions maintained: Temperature: 22 °C.

Typically, sand particles and SS are exposed to various foulants and acid rain. Thus, the effectiveness of the hydrophobic coating may be minimized owing to fouling and the gradual loss of hydrophobic functional groups. Therefore, the robustness of the modified SS coating was carefully analyzed using an ultra-slow-motion camera. Movie 2 shows a water droplet immediately rolling off the chemically functionalized SS particles, demonstrating their water repellence and superhydrophobic properties. Furthermore, self-cleaning behavior was evaluated by sliding a water droplet propelled by gravitational action over the modified sand. Dyed water droplets were dispensed onto SS-Si/FDTS, which were kept at a certain angle. Interestingly, the dyed water slid off immediately owing to the low-adhesion superhydrophobic surface of the modified SS, demonstrating an excellent lotus-like effect. Therefore, it can be concluded that the modified SS particles had a slippery surface and demonstrated antiwetting behavior.

3.6. Application of superhydrophobic engineered nanomaterials on regular sand

A similar procedure was applied to regular sand (RS), which has the advantages of low cost, easy availability, and extremely high chemical stability, and its superhydrophobicity and water repellence properties were then evaluated. As shown in Movie 3, dyed water droplets poured onto unmodified RS were immediately absorbed by the sand surface, leading to a water contact angle of 0°. Thus, unmodified RS demonstrated a low water holding capacity and water storage capacity. However, contrasting effects were observed for modified RS (RS-Si/FDTS), where the dripped water droplets remained spherical. Therefore, the overall results demonstrate the effectiveness of superhydrophobic engineered nanomaterials (Si-NPs/FDTS) on various surfaces such as RS, which is commonly available worldwide. It is worth noting that Si-NP/FDTS is capable of changing the surface texture, providing a high-water contact angle and low rolling-off angle. This combination of silica nanoparticles functionalization with FDTS can be used to transform a superhydrophilic surface to a superhydrophobic one.

3.7. Oil/water separation application

Overall, the experiments revealed that SS-Si/FDTS and RS-Si/FDTS are superhydrophobic and are suitable candidates for oil/water separation. The modified sand can readily repel water but becomes wet by oil. As shown in Fig. 7, oil/water

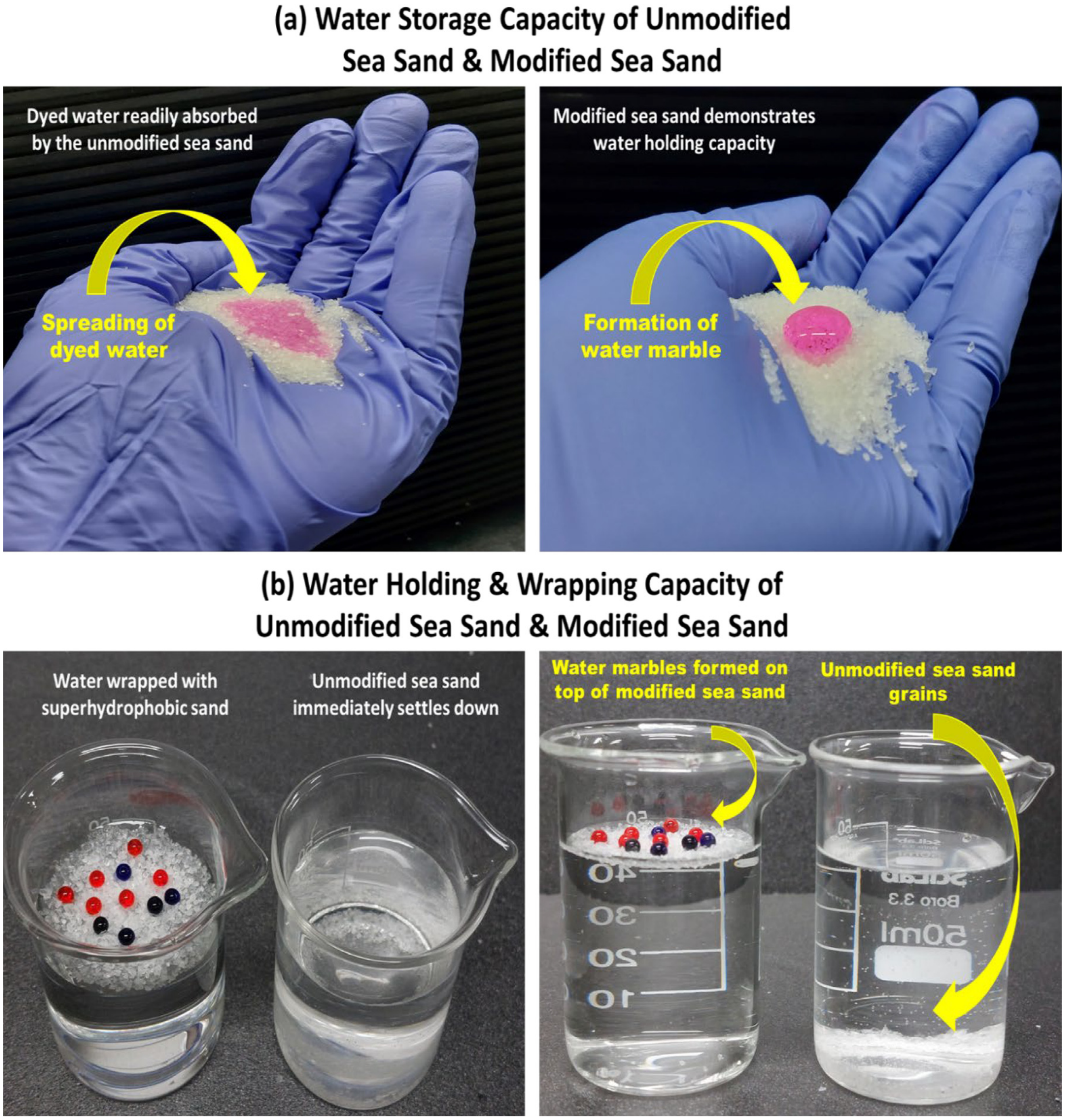


Fig. 6. Experimental analysis of water holding and storage capacity: (a) Demonstration of water storage capacity of unmodified SS and SS-Si/FDTS. (b) Illustration of water holding and wrapping capacity of unmodified and modified SS.

separation was performed for a mixture of chloroform and dyed water using 1 g of modified regular sand (RS-Si/FDTS) as a filter. As soon as the mixture of water and chloroform was poured into the funnel, chloroform started permeating immediately through the modified RS filter. This process was observed over 1 h. During the separation process, the chloroform permeated completely after 13 min. However, the dyed water did not permeate, as confirmed by the absence of color change in the cotton or by the transparent chloroform at the bottom of the conical flask. Therefore, the results indicate that a small amount of RS-Si/FDTS can effectively separate water and oil mixtures.

3.8. Abrasion test

The abrasion test with vigorous stirring of coated sand grains (SS-Si/FDTS and RS-Si/FDTS) in water has been performed for modified sand grains for evaluating the mechanical and chemical stability. The stirring continued for 120 min and then the sand grains were filtered and dried overnight. The modified sand grains were subjected to contact angle analysis to evaluate the change in hydrophobicity. However, negligible change in contact angle (0.99% and 0.7% respectively) has been

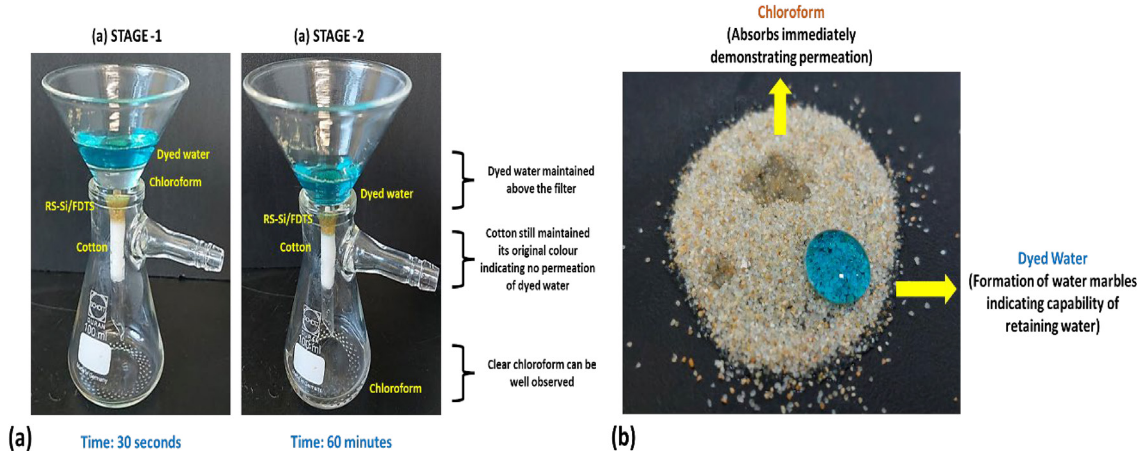


Fig. 7. (a) Chloroform/water separation using RS-Si/FDTS as a filter (b) representation of retention of water droplets and permeation of chloroform using modified RS.

Table 3
Abrasion test in terms of change in contact angle and sliding angle after vigorous stirring of sand grains.

Sand type	Duration of vigorous stirring	Initial contact angle	Final contact angle after abrasion test	% Reduction of contact angle
Modified sea sand (SS-Si/FDTS)	120 min	151°	149.5	0.993%
Modified regular sea sand (RS-SSi/FDTS)	120 min	152.1°	151	0.723%

observed indicating high mechanical and chemical stability of superhydrophobic coating of modified sea sand. Table 3 indicates the change in contact angle of the modified sea sand after the abrasion test.

4. Conclusion

The functionalization of sand grains with stable superhydrophobic coatings is a prominent challenge. In this study, sand grains were modified with a well-adhered and durable superhydrophobic coating. Thus, superhydrophobic sand grains offer a revolutionary solution for arid land agriculture with inadequate water resources. The coating was derived from hydrophobic Si NPs modified with hydrolyzed FDTS. Si/FDTS-coated sand grains demonstrated highly stable superhydrophobic features with an average contact angle of 151° Interestingly, and water droplets rolled off the functionalized sea sand grains and were not absorbed. The treatment of sand grains with Si/FDTS resulted in a lower sliding angle of 9.5°, imparting self-cleaning capabilities and higher hydrophobic efficiency. The modified sea sand grains demonstrated excellent water holding and storage capabilities in long-term experiments, which could be harnessed to improve agriculture in arid regions. Herein, superhydrophobic sand grains were fabricated via a one-step dip coating technique with advantages of manual application and low operational costs. Importantly, the superhydrophobic modified sand maintains high separation efficiency and selectivity after oil–water separation, thus offering huge viability and potential for practical application in oil–water separation. Thus, it can be concluded that the present research study can play a key role in expanding sustainable agricultural technology relying on limited water sources, including Middle East countries, African countries, China, and India.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

Acknowledgments

This research study was financially aided by the support of National Research Foundation (NRF), Republic of Korea as endorsed by Ministry of Education, Science and Technology (NRF-2018R1D1A1B07043609 and 2022R1A2C1011787) as well as by the Korea Institute of Energy Technology Evaluation and Planning (KETEP) grant sponsored by Republic of Korea Government (MOTIE) (20202020800330). Thus, all the authors are thankful for the continuous financial aid.

Appendix A. Supplementary data

Supplementary material related to this article can be found online at https://doi.org/10.1016/j.eti.2022.102849.

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