Durability and Delayed Icing Performance of Silicone Rubber Superhydrophobic Surface Used to Improve Aircraft Propeller Anti-icing Performance

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Abstract: Aircraft propellers may encounter various harsh environments due to regional differences and weather changes during their service. Therefore, ideal rubber composites for aircraft propellers must have excellent superhydrophobic properties, delayed icing performance and environmental durability. In this paper, the silicone rubber superhydrophobic surface was prepared via the template method and high temperature treatment. The effects of low-temperature freezing, high-temperature heating and UV irradiation on the hydrophobic properties of superhydrophobic silicone rubber were investigated. In addition, the self-assembled delayed icing device was implemented to reveal the delayed freezing behavior of the superhydrophobic silicone rubber under the influence of moisture in the air. Scanning electron microscopy (SEM) and energy dispersive spectrometer (EDS) were employed to elucidate changes in superhydrophobic properties and delayed freezing mechanisms. The results show that the as-prepared superhydrophobic silicone rubber has demonstrated remarkable environmental durability and delayed freezing performance. It has important practical application value in superhydrophobic electric heating anti-icing of aircraft propeller.

Key words: superhydrophobic; silicone rubber; propeller; environmental durability; delayed freezing

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0 Introduction

It is well known that high-temperature vulcanized (HTV) silicone rubber is used widely in aerospace, automobile industry, medical apparatus and instruments, outdoor insulation and other fields due to its light weight, high air permeability, good weather resistance, ozone resistance, hydrophobicity, antifouling performance and electrical insulation[1-9]. Therefore, HTV silicone rubber, as a synthetic polymer with excellent comprehensive properties, has attracted great attention from scholars. HTV rubber has important applications in the anti-icing field of fixed-wing aircraft propellers, and it can be used as the outer covering material of the electric anti-icing heating device for the leading edge of the propeller. The anti-icing device of the aircraft propeller can ensure the safe and long-term operation of the aircraft under all-weather conditions, and electric heating deicing is one of the commonly used anti-icing technologies for aircraft propellers. The delayed icing characteristics of the superhydrophobic surface have been widely recognized by scholars[10-11]. Therefore, it is of great significance to improve the anti-icing efficiency of the propeller and save energy consumption by endowing the covering layer with superhydrophobic properties on the basis of electric heating and deicing of the aircraft propeller.

At present, relevant scholars have carried out research on the preparation of superhydrophobic surface of HTV silicone rubber and its antifouling per-

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formance, self-cleaning performance, delayed freezing performance and anti-corrosion performance. Chen et al.[12] used the nanosecond laser technology to prepare superhydrophobic surfaces with static contact angle and rolling angle of 160° and 3°, respectively. It was found that the superhydrophobic of silicone rubber should be attributed to the formation of rough surface structure. In addition, the anti-icing performance test was carried out and after multiple ice-covering and de-icing treatments, the superhydrophobic surface still had good hydrophobic performance[13]. Yan et al.[14] manufactured templates with special crater shape on the inner surface by picosecond laser technology, and then prepared silicone rubber superhydrophobic surface with excellent self-cleaning properties by hot-pressing and template method. Peng et al.[15] prepared a kind of superhydrophobic 1,1,1,3,3,3-hexamethyl disilazane (HMDS) -3-hydroxytyramine hydrochloride (DOPA) SiO_2 powders. Subsequently, silicone rubber composite was soaked into a mixture of the epoxy resin, curing agent and polyvinylidene fluoride (PVDF). The HMDS-DOPA SiO_2 powders were evenly dispersed on the surface of the samples via a sieve. At last, the samples were dried in an oven. Silicone rubber composite surfaces with extraordinary self-cleaning properties, anti-fouling properties, thermal stability, mechanical stability and anti-ice properties were obtained. Vazirinasab et al.[16] used an environmentally friendly atmospheric-pressure air plasma system to create a coral-like rough structure on the surface of silicone rubber, which had outstanding superhydrophobic properties. Maghsoudi et al.[17] found that chemical etching can be employed to prepare micro-nano structures on the surface of aluminum plates, then the superhydrophobic silicone rubber surface was successfully produced by using the template method and compression molding. Moreover, the surface was proved to have excellent anti-fouling and self-cleaning properties by various cleaning and antifouling tests.

From the above research, it can be found that the preparation of superhydrophobic surface of high temperature vulcanized silicone rubber is mainly based on the template method. In addition, there are relatively few studies on the environmental durability of superhydrophobic silicone rubber surfaces, so it is necessary to improve the research on the environmental durability of superhydrophobic silicone rubber. In this work, based on our previous studies, the silicone rubber superhydrophobic surface was fabricated via the hot pressing molding technique and the template method. By combining the template method with hot-pressing molding, the preparation of superhydrophobic silicone rubber becomes cost-effective and straightforward, eliminating the need for complicated procedures typically associated with conventional rubber composites. Furthermore, this approach is environmentally friendly, as it requires minimal introduction of chemical reagents. Through the template method and hot-pressing technique, it is also possible to obtain superhydrophobic rubber materials with controllable microstructures. The effects of high temperature treatment, accelerated aging of hot oxygen, cryogenic freezing and UV irradiation on the properties of superhydrophobic surface and the mechanism of hydrophobicity change were investigated in detail. The behavior and mechanism of delayed freezing on the superhydrophobic surface under the influence of moisture in the air were revealed by anti-freezing tests. The research results have important scientific significance for further improving the environmental durability and freezing delay performance of the superhydrophobic silicone rubber composite surface. In addition, it has important practical application value in the electric heating anti-icing device of the leading edge of the aircraft propeller.

1 Experiment

1.1 Main materials

Silicone rubber (Dongjue, NE-5150) was purchased from Xinhong Plastics Co., Ltd. (China). Vulcanizing agent (HC-14) was provided by Hong Kong Huaxing Technology Development Co., Ltd. (China). 304 stainless-steel woven mesh (800 mesh) was supplied from Lvruo Co., Ltd. (China). Release agent polydimethylsiloxane latex (effective material content of 30%) was purchased from Jiahong Technology Co., Ltd. (China). Deionized water was made in the laboratory.

1.2 Preparation of superhydrophobic samples

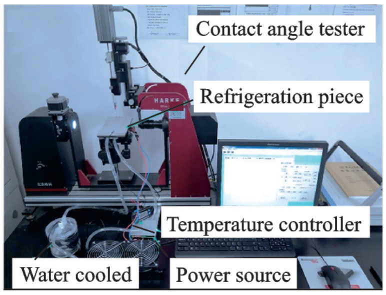
The preparation method of superhydrophobic silicone rubber samples is the same as the previous report of our research group[18]. Specifically, the prepared stainless-steel mesh was immersed in ethanol solution for 30 min with ultrasonic cleaning, and then dried in an oven. The dried stainless-steel mesh was then placed in the mold release solution for 30 s. Afterwards, it was treated in an oven at 175 ℃ for 15 min. 50 g of silicone rubber was mixed in a mill (LN-x (S) K160). Subsequently, vulcanizing agent (0.8 g) was added to the silicone rubber, and the roller spacing was adjusted to 2 mm when the silicone rubber was calendered evenly. Finally, it is removed from the roll for subsequent use.

The process of hot-pressing curing is crucial. Ethanol solution was used to clean the template, which was heated to 175 ℃ in a vulcanizing machine (LN-50T). And then the template was removed and the prepared silicone rubber was tiled into the mold. A pristine silicone rubber sample was vulcanized at a temperature of 175 ℃ for 8 min. The superhydrophobic silicone rubber was obtained in the following steps: The stainless-steel mesh was placed on the surface of the prepared silicone rubber; the mesh is put into the vulcanizing machine along with the silicone rubber; the curing temperature was set as 175 ℃. After 8 min, the mold was taken out, and the vulcanized silicone rubber with stainless steel mesh was removed and cooled at room temperature to approximately 45 ℃. The woven mesh was stripped from its surface, and the superhydrophobic surface of silicone rubber can thus be obtained. In our previous study, it was found that the high-temperature treatment was conducive to obtaining stronger superhydrophobic properties[19]. Therefore, the as-prepared superhydrophobic silicone rubber samples were put in the oven at 200 °C for 1 h.

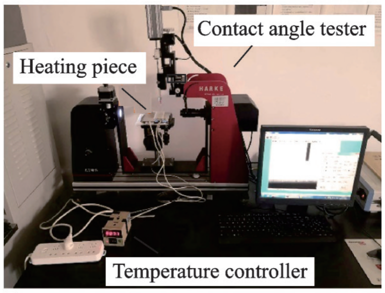
1.3 Characterization of superhydrophobic performance

The contact angle analyzer (HKCA-15, China) was employed to measure the contact angle (4 μL) and rolling angle (15 μL) between the surface of the superhydrophobic sample and water. Five different positions were recorded randomly for each contact angle and rolling angle test.

In order to explain the influence of temperature change on the hydrophobic properties of superhydrophobic silicone rubber surface, the cooling plate and heating plate with temperature control function and their related parts were purchased and used in combination with the contact angle analyzer to determine the change of contact angle and rolling angle under different temperature conditions. Fig.1 shows the configuration of the experimental device. An infrared camera (Testo 875, Germany) was utilized to detect the difference between the temperature of the thermostat and the temperature of the samples. We found that the temperature on the sample surface differed by about 2 ℃ from what was read by the thermostat, so we used an infrared thermal camera to measure the sample's temperature and reduce experimental error. The contact angle and rolling angle of samples at 0 ℃ and intervals of 10 ℃ from 5 ℃ to 65 ℃ were measured using the method described above.



(a) From 0 ℃ to 25 ℃



(b) From 35 ℃ to 65 ℃

Fig.1 Configuration of the experimental device at different temperatures

The sample was placed in a low-temperature testing chamber (DW-40, Cangzhou Luxin Test Instrument Co., Ltd., China) to investigate the influence of low-temperature freezing on its hydrophobic properties, and the temperature was set as −35 ℃ (with a temperature fluctuation range of 2 ℃). The sample was then taken out every 48 h and placed at room temperature (25 ℃) for 4 h before the contact angle and the rolling angle were tested.

The icing resistance of superhydrophobic surface was investigated via a self-assembled refrigeration unit. Droplets of different volumes were dropped onto the surface of the samples, and the temperature was set as −20 ℃. Subsequently, the sample was cooled from 25 ℃, and measurements were taken every 5 min until the droplets were completely frozen. The ambient temperature was 25 ℃ and the humidity was 40%. Plastic boxes were placed on top of the sample to accelerate the freezing process and reduce the influence of moisture in the air on the freezing process.

The samples were placed in an oven at 100 ℃ for 24 h to investigate the influence of high-temperature treatment and thermal oxygen aging at different temperatures on the surface hydrophobic performance. Afterwards, they were taken out and placed at room temperature for 4 h, and then the hydrophobic properties of the samples were tested. Finally, the samples were placed in environments of 200 ℃ and 300 ℃, respectively, and the above steps were repeated. For the sake of discussion, "untreated" represents samples that have not undergone any high-temperature treatment. "100 ℃ 24 h" signifies samples treated at 100 ℃ for 24 h. "200 ℃ 24 h" represents samples initially treated at 100 ℃ for 24 h and subsequently treated at 200 ℃ for 24 h. Alternatively, it can be described as samples treated separately at 100 ℃ and 200 ℃ for 24 h, respectively. "300 ℃ 24 h" indicates samples initially treated at 100 ℃ for 24 h, then at 200 ℃ for 24 h, and finally at 300 ℃ for 24 h. Alternatively, it can be described as samples treated separately at 100, 200 and 300 ℃ for 24 h, respectively.

It has been reported elsewhere that UV radiation will damage the hydrophobicity of the superhydrophobic surface[20], so we used the UV accelerated weathering test box (MU3089, Shanghai Moujing Industrial Co., Ltd., China) to investigate the influence of UV irradiation on the hydrophobic properties of the sample surface. The UV wavelength is 290—400 nm, the power is 3 kW, the distance between the sample and the center of the lamp is 50 mm, and the temperature in the box is 70 ℃ ± 1 ℃. The sample was taken out every 5 h and placed at room temperature for 4 h, and then the hydrophobic properties of the samples were measured. The duration of the UV irradiation was 60 h.

An scanning electron microscopy (SEM) was utilized to examine whether the surface morphology of the sample changed under different conditions. Energy dispersive spectrometer (EDS) analysis was performed to detect the changes of various elements and atomic contents before and after being treated under different conditions. Finally, the hydrophobic mechanism under different conditions was revealed.

2 Result and Discussion

2.1 Superhydrophobic properties

In our previous study, it was found that the superhydrophobic properties of the sample were improved through treatment at 200 ℃ for 1 h[19]. Therefore, in order to achieve the optimal superhydrophobic performance of silicone rubber samples in various tests, all the as-prepared samples were subjected to a temperature of 200 ℃ for 1 h. Fig.2 displays the changes in hydrophobic properties of the sample's surface before and after treatment, where A is untreated superhydrophobic sample and B the superhydrophobic sample heated at high temperature (200 ℃) for 1 h. As expected, the contact angle of the sample is almost unchanged. However, the rolling angle of the sample decreases significantly from 7.1° ± 0.65° to 5.8° ± 0.84°. It indicates that the adhesion of droplet to sample surface decreases, which makes droplet more likely to roll on

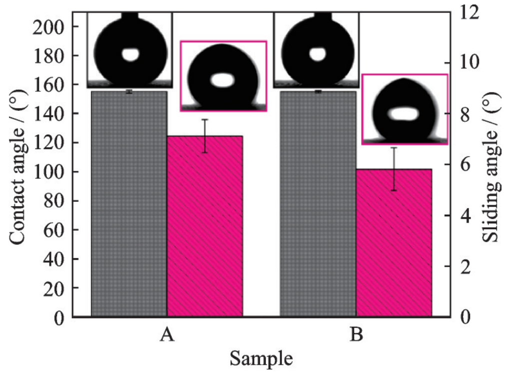
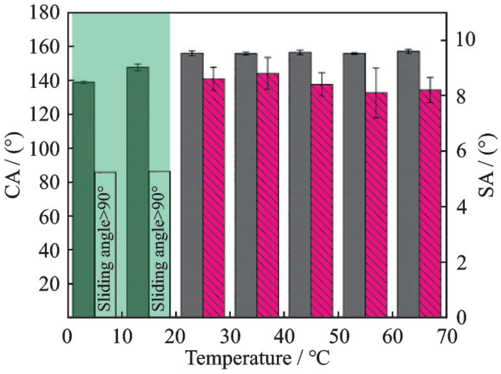


Fig.2 Changes of hydrophobic properties of samples surface before and after treatment

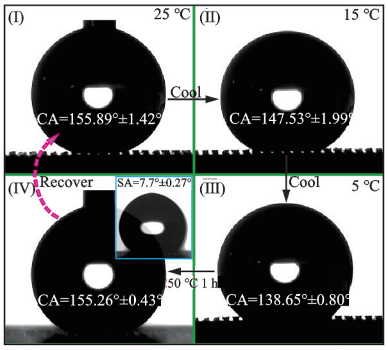
sample surface. The decline in adhesion force is mainly caused by the reduction of hydrophilic groups on the surface of silicone rubber[19].

2.2 Wetting behavior at different temperatures

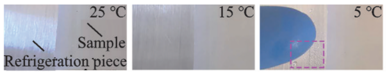
The hydrophobic properties of the superhydrophobic silicone rubber surface may be affected by temperature. Hence, the contact angle (CA) and rolling angle of the sample B were measured at different temperatures to discover the change rule of temperature's influence on hydrophobicity. The results are shown in Fig.3. The changes in CA and sliding angle (SA) at different temperatures are presented in Fig.3(a). The CA of the droplet remains roughly the same when the surface temperature of the sample decreases from 65 ℃ to 25 ℃, and the SA exhibiting a clear, smaller range of fluctuations. As the surface temperature of the sample decreases from 25 ℃ to 0, the CA of the sample decreases from 155.89° ± 1.42° to 138.64° ± 0.80°. At a temperature of 15 ℃, the CA of droplet has become 147.53° ± 1.99° and the SA is greater than 90° (green rectangular area). Therefore, the sample has lost its superhydrophobic characteristics.



(a) Contact angle and rolling angle of the sample B



(b) Contact state between droplet and sample B surface



(c) Moisture in the air is liquefied on the surface of the cooling sheet

Fig.3 Measured results of sample B at different temperatures

It's remarkable that the surface hydrophobicity of sample B begins to decrease rapidly as the temperature drops. By carefully observing the contact state between droplet and sample in Fig.3(b), we found that when the temperature dropped to 15 ℃, the contact area between droplet and sample surface increased significantly (the relative size of the contact area can be determined by the number of air gaps between the droplet and the sample surface). This indicates that the contact model between the droplet and the sample surface gradually transforms from Cassie to Cassie-Wenzel as the temperature continues to drop. When the temperature reduces to 5 ℃, the contact model changes from Cassie-Wenzel to Wenzel. As shown in Fig.3(c), when the temperature is 5 ℃, and the surface of the cooling plate is gently rubbed by rubber gloves, a layer of liquid water can be found on the surface of the cooling plate. Therefore, the change in the surface contact model of the sample is caused by the fact that the surface temperature of the sample is lower than room temperature and the moisture in the air is liquefied and attached to the surface of the sample. However, when dried at 50 ℃ for 1 h, the superhydrophobicity of the sample is restored. When the temperature of the sample surface is consistent with that of the surroundings, the sample should be able to maintain excellent superhydrophobic performance without being influenced by moisture in the air.

2.3 Low-temperature and freezing resistance

Fig.4 demonstrates the changes of contact an-

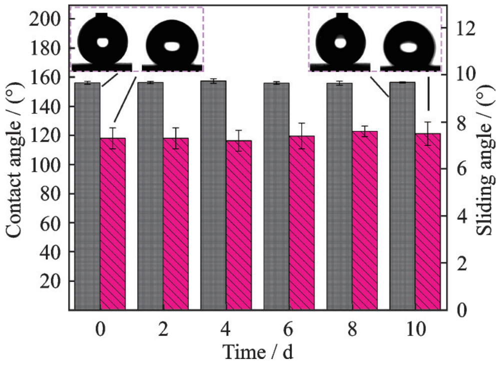
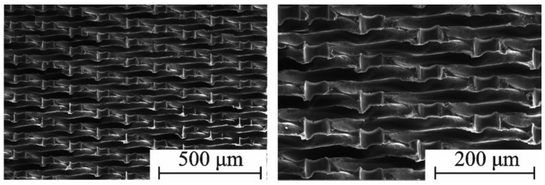
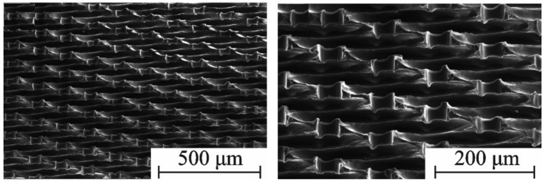


Fig.4 Changes of contact angle and rolling angle after cryopreservation for different durations

gle and rolling angle of the sample B after different time of cryogenic freezing. According to Fig.4, the contact angle and rolling angle almost remain unchanged with the increase of freezing time. The contact angle and rolling angle are 156.35° ± 0.43° and 7.5° ± 0.5°, respectively, after 10 d of freezing. This indicates that the sample still retains excellent superhydrophobic properties after a long period of freezing. The above phenomenon can be attributed to the excellent low-temperature resistance of silicone rubber[21]. Moreover, Fig.5 is carefully examined to prove that the microstructure of the sample surface has not been destroyed during cryogenic freezing. It verifies that the superhydrophobic silicone rubber has excellent low-temperature and freezing resistance.



(a) Before freezing

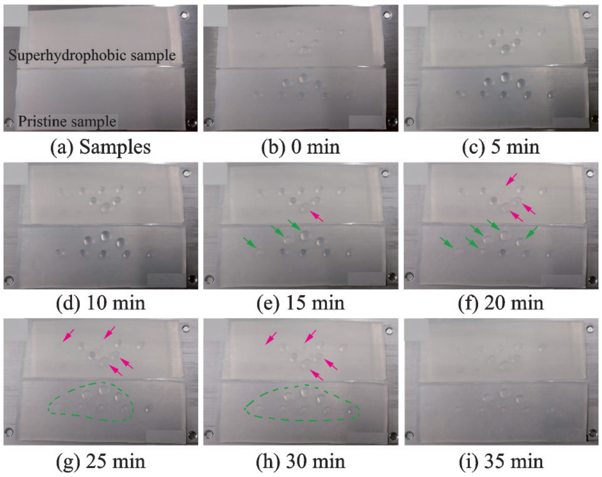


(b) After freezing

Fig.5 SEM images of sample B

2.4 Delayed freezing behavior

The freezing process of droplets on the surface of the pristine and superhydrophobic silicone rubber sample (sample B) is recorded, as shown in Fig.6. It can be clearly observed that within the first 10 min, the droplets of the two kinds of samples do not freeze. Because the entire experiment is conducted at room temperature, the freezing rate is relatively slow. 15 min later, icing occurs in three droplets (as indicated by the green arrows) on the surface of the pristine samples, as shown in Fig.6(e), while only the largest droplet on the surface of the superhydrophobic samples was frozen. As time increases, the droplets on the surface of the pristine sample freeze relatively quickly. 25 min later, only one droplet remained on the surface of the pristine sample, which was not completely frozen. However, half of the droplets on the superhydrophobic surface remained unfrozen. 30 min later, all the droplets on the ordinary surface had completely frozen, while half of the droplets on the superhydrophobic surface remained unfrozen, demonstrating that the superhydrophobic surface exhibits obvious delayed freezing performance. 35 min later, the surface of both samples is completely frozen.



(a) Samples (b) 0 min (c) 5 min (d) 10 min (e) 15 min (f) 20 min (g) 25 min (h) 30 min (i) 35 min

Fig.6 Freezing process of droplets of different volumes on the surface of samples

We know from previous reports that superhydrophobic surfaces have micro-nano structures. When droplets contact with a superhydrophobic surface, the microstructure-induced cavitation will reduce the heat transfer efficiency between the sample and the droplets, thereby delaying the freezing of the superhydrophobic surface[13,22]. The superhydrophobic silicone rubber samples prepared are consistent with the above report for a certain period at the beginning of the experiment. However, due to the influence of moisture in the air, small drops of water continuously accumulate on the surface of the samples as the temperature gradually decreases, and this accumulated water acts as a bridge between the droplets and the sample, reducing the contact angle. The Cassie model gradually transforms into the Wenzel model, as shown in Fig.7. It should be noted that a certain amount of time is required to convert the Cassie model into the Wenzel model; therefore, even under the influence of moisture in the air, the superhydrophobic surface can still function to delay freezing. Of course, in a cold outdoor environment, a superhydrophobic silicone rubber sur-

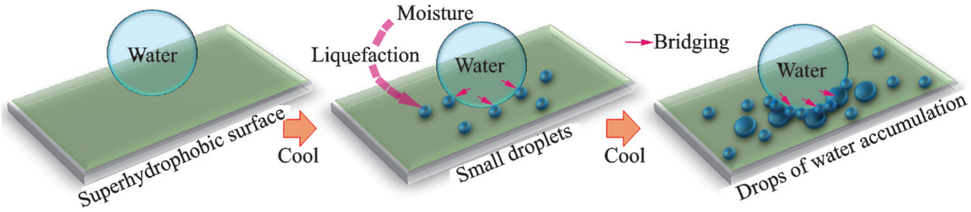


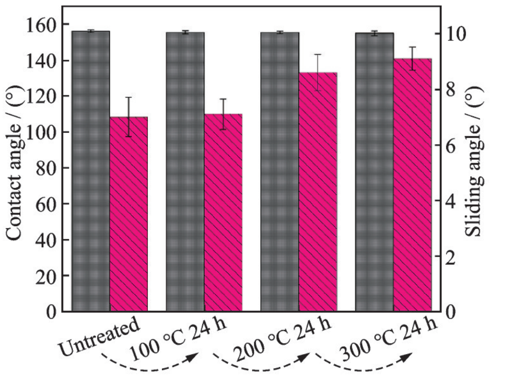
Fig.7 Schematic of moisture in air liquefaction and continuous accumulation on the surface of sample B

face can achieve a better delayed freezing effect without being affected by moisture in the air.

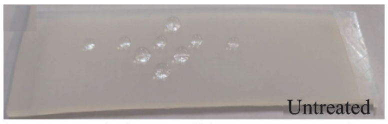
2.5 Effects of high temperature and thermal aging on hydrophobicity

We studied the effects of high-temperature treatment and accelerated thermal oxygen aging on the surface of sample B, and the results are shown in Fig.8. It can be found from Fig.8(a) that after being treated at 100, 200 and 300 ℃ for 24 h respectively, the contact angle of the sample B remains at about 155° without significant change. Based on Fig.9, the microstructure on the surface of the sample remains unchanged after being treated at high temperature. In addition, the groove structure on the surface of the sample is further magnified at different temperatures, and we can observe that the surface of the sample with the groove structure shows no noticeable change. The above phenomenon indicates that silicone rubber has outstanding resistance to high temperatures, and the surface structure of silicone rubber will not change significantly under high-temperature conditions. This is precisely because the surface microstructure of silicone rubber remains intact, the contact angle between the surface of superhydrophobic silicone rubber and droplets remains unchanged during the high-temperature treatment.

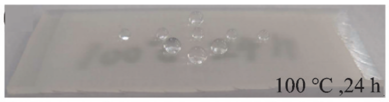
Interestingly, in the process of continuous high-



(a) Changes of contact angle and rolling angle of sample B after different temperature treatments

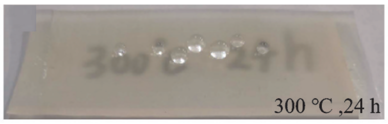


(b) An untreated picture of the contact state between sample B and drops of water



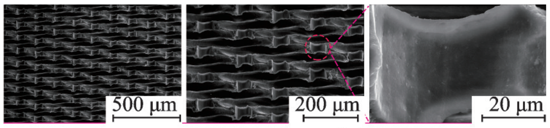
(c) A picture of the contact state after being treated at 100 °C for 24 h

(d) A picture of the contact state after being treated at 100 and 200 °C for 24 h, respectively

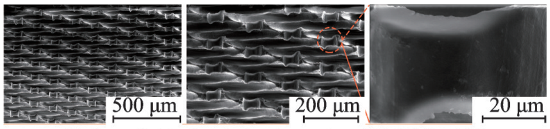


(e) A picture of the contact state after being treated at 100, 200 and 300 °C for 24 h, respectively

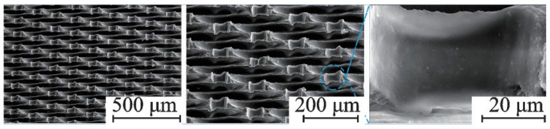
Fig.8 Effects of high-temperature treatment and accelerated thermal oxygen aging on the surface of sample B



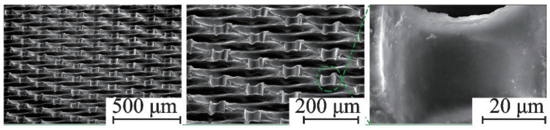
(a) Untreated sample B



(b) Sample B after being heated at 100 °C for 24 h



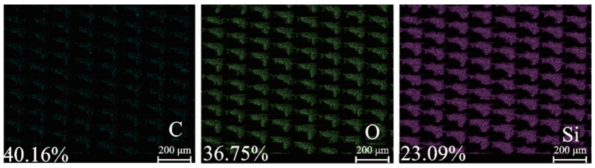
(c) Sample B after being heated at 100 and 200 °C for 24 h, respectively



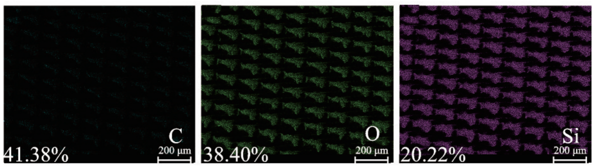
(d) Sample B after being heated at 100, 200 and 300 °C for 24 h, respectively

Fig.9 SEM images

temperature treatment, although the contact angle of the surface of the sample B does not change obviously, the rolling angle changes significantly. As the temperature increases, the rolling angle on the surface of sample B gradually increases, indicating enhanced adhesion of droplets to the silicone rubber surface after high-temperature treatment. In order to investigate the reasons for the improvement of adhesion of the superhydrophobic surface, EDS was carried out on the surface of the sample B and the sample B after treatment at 100, 200 and 300 ℃ for 24 h, respectively. The results are shown in Fig.10. The superhydrophobic structure on the silicone rubber surface is uniform in size and equally distributed, which is indirectly demonstrated by the element distribution in Fig.10. By comparing the atomic percentages of elements before and after high-temperature treatment, it was observed that the proportion of oxygen atoms significantly increased on the superhydrophobic surface after high-temperature treatment, while the proportion of silicon atoms decreased significantly, indicating that thermal oxygen aging occurred on the surface of the samples. The methyl groups on silicone rubber side chains are prone to oxidation after thermal oxygen aging, resulting in increased adhesion of the superhydrophobic surface to water due to the reduction in hydrophobic groups. Compared with the contact angle, the rolling angle is more susceptible to the adhesion force, so the rolling angle between the superhydrophobic silicone rubber surface and water increases significantly after thermal oxygen aging.



(a) Element distributions and atomic percentages of C,O,and Si on the surface of sample B



(b) Element distributions and atomic percentages of C, O and Si on the surface of the sample B after treatment at 100, 200 and 300 °C for 24 h, respectively

Fig.10 EDS results

2. 6 Effect of UV irradiation on hydrophobicity of samples

Superhydrophobic silicone rubber composite is inevitably exposed to UV irradiation during service. Therefore, the influence of UV radiation on the hydrophobic properties of silicone rubber was studied. Fig. 11 shows that the contact angle and rolling angle of the sample B do not change significantly after 60 h of UV irradiation, indicating that the superhydrophobic silicone rubber samples have a good resistance to UV irradiation, which may be attributed to the excellent UV irradiation resistance of silicone rubber[2]. From Fig.12, after 60 h of UV irradiation, the microstructure on the surface of silicone rubber does not undergo obvious deformation and destruction. After UV irradiation for 60 h, the atomic percentage of element O increases slightly, the atomic percentage of element Si fluctuates slightly, and the atomic percentage of element C decreases significantly compared to that before UV irradiation. This is mainly due to the increase in the content of Si-O-Si during the UV irradiation process, resulting

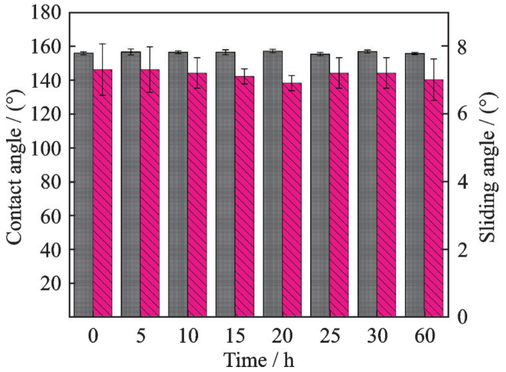
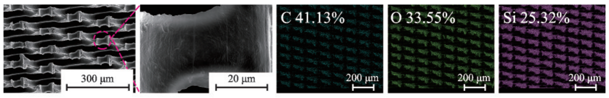
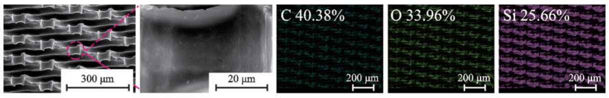


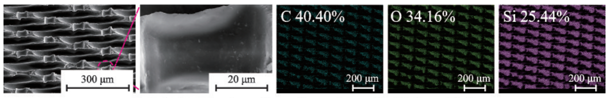
Fig.11 Changes of contact angle and rolling angle of sample B after UV irradiation for different time



(a) Without UV irradiation



(b) After being irradiated by UV for 30 h



(c) After being irradiated by UV for 60 h

Fig.12 Images of SEM and EDS on the surface of sample B in an increase in the percentage of O atoms. Alternatively, the methyl group generated by UV irradiation will react with its own methyl group to produce methane, resulting in a reduction in the percentage of C atoms[23]. However, the surface elements of the superhydrophobic silicone rubber samples do not change significantly in the UV irradiation process. Therefore, it proves that the superhydrophobic silicone rubber samples could still maintain excellent superhydrophobic performance after being subjected to harsh UV irradiation. In terms of achieving superhydrophobicity, compared with the method of preparing coatings on the silicone rubber surface[20], the method of directly constructing microstructure on the silicone rubber surface via its own hydrophobicity is simpler with better UV durability.

3 Conclusions

Superhydrophobic silicone rubber surfaces were fabricated by using the template method, and environmental durability and delayed freezing tests were carried out. Some main conclusions are presented as follows.

When the temperature of the superhydrophobic silicone rubber sample is higher than that of the surroundings, the contact angle of the superhydrophobic surface remains almost constant, and the rolling angle fluctuates within a small range. When the temperature of the superhydrophobic silicone rubber sample is lower than that of the surroundings, the surface of the sample loses its superhydrophobic properties due to the influence of moisture in the air, and the rolling angle increases sharply. The superhydrophobic surface of silicone rubber has extraordinarily low-temperature and high-temperature resistance. The surface morphology of superhydrophobic silicone rubber will not be damaged by a high-temperature environment, but the reduction of hydrophobic groups caused by thermal oxygen aging on the sample surface will increase the adhesion of droplets to the silicone rubber surface, thus increasing the rolling angle. Although the molecular chain of silicone rubber is destroyed via UV irradiation, its surface microstructure remains unchanged. The superhydrophobic properties of silicone rubber can be maintained due to its excellent UV radiation resistance.

When the temperature of the superhydrophobic samples is lower than that of the surroundings, the droplets formed on the sample surface by moisture liquefaction will act as a bridge between the sample and the droplets used in the contact angle test. Thus, the contact model between the droplet and the sample is gradually transformed from Cassie to Wenzel. Since a certain period of time is required to advance the transformation, the excellent delayed freezing performance of the superhydrophobic surface can still be demonstrated.

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用于改善飞机螺旋桨防结冰性能的硅橡胶超疏水表面耐久性和延迟结冰性能研究

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摘要：飞机螺旋桨在服役过程中由于地域性差异和天气的变化可能会遇到各种苛刻的环境。因此，理想的飞机螺旋桨用橡胶复合材料必须具备极好的超疏水性能、延迟结冰性能和环境耐久性。本文通过模板法和高温处理制备了硅橡胶超疏水表面，研究了低温冷冻、高温加热和紫外辐照对超疏水硅橡胶疏水性能的影响。此外，为了揭示超疏水硅橡胶在空气湿度影响下的延迟冻结行为，设计了延迟结冰装置，并利用扫描电子显微镜（Scanning electron microscopy，SEM）和能谱仪（Enery dispersive spectrometer，EDS）分析了超疏水性能的变化和延迟冻结机理。结果表明，制备的超疏水硅橡胶具有良好的环境耐久性和延迟冻结性能，在飞机螺旋桨超疏水电热防冰方面具有实际应用价值。

关键词：超疏水；硅橡胶；螺旋桨；环境耐久；延迟结冰