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Fabrication and Testing of Self Cleaning Dry Adhesives Utilizing Hydrophobicity Gradient

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Abstract

In this paper we present a method to create a hydrophobicity gradient on the surface of a Polydimethylsiloxane (PDMS) dry adhesive. The method consists of the partial silanization of the surface of the dry adhesive by Chemical Vapour Deposition (CVD) of octadecyltrichlorosilane (OTS). The partial silanization of the surface of the sample results in a hydrophobic to hydrophilic gradient across the surface of the dry adhesive. The resulting change in hydrophobicity across the surface of the dry adhesive results in the uphill motion of a droplet of water, which appears to be directly proportional to the area of contact between the droplet and the adhesive. Normal adhesion testing is performed to quantify the effect of the hydrophobic gradient across the surface of the sample. While a variation in adhesion strength across the sample is measured, the adhesive properties are only minimally affected by the silanization, and the motion of the droplet of water doesn't cause any loss of adhesion.

Keywords: dry adhesion, self cleaning, hydrophobic, silanization, polymers, PDMS

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1 Introduction

Dry adhesives provide multiple advantages over wet adhesives including adhering without leaving residue[1,2], they can adhere to a wide variety of surfaces, are easy to attach and detach, and can be reused an indeterminate amount of times[3,4]. However, their efficiency can be compromised by the presence of dirt or particles that adhere to the adhesive surface[5]. Although, the initial properties of the adhesive can be restored after cleaning, this option might not always be available. In this paper we present a solution to potentially obtain a self cleaning dry adhesive. By introducing a hydrophobicity gradient on the surface of the dry adhesives, they are able to generate the motion of a droplet of water on contact. In this way the dry adhesive properties could potentially be maintained or restored by simply exposing the surface of the adhesive to a wet or humid environment.

The adhesion mechanism utilized by biomimetic dry adhesives is similar to the one utilized in nature by geckos to climb on a variety of surfaces and is based on van der Waals forces[6]. This type of electromagnetic forces such as dipole-dipole, dipole-induced dipole, or even induced dipole-induced dipole are active whenever the surfaces of two objects come in close proximity to each other at the atomic level. Therefore, one of the most important conditions for these forces to act is that the two objects come in very close proximity. Nature achieves this in geckos through a multitude of microscopic fibrils present on the epithelium of their feet[7]. These setae are approximately 5 μm in diameter and can conform and comply to surfaces with a wide range of roughness. In the case of the adhesives used in this work, the same principle is utilized by fabricating micro mushroom cap structures on the surface of a silicon based polymer: Polydimethylsiloxane (PDMS)[8]. The softness of the polymer provides a first level of compliance to large scale roughness, while the micro caps provide a second level of compliance for finer roughnesses. Unless the adhesive are constantly used in a clean environment, they are bound to attract dirt or more in general smaller particles due to the same forces responsible for their adhesion[9–11]. These particles could

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remain trapped in the mushroom caps structure and thus compromise their compliance and close approach to the objects to be attached to. In nature, animals like geckos constantly groom their skin and new fibrils are replaced on a daily basis. As this is impossible or extremely inconvenient for artificial dry adhesives, it is necessary to find a solution to maintain their adhesion properties unaltered[12–16].

In this paper a gradient of hydrophobicity was achieved by partially silanizing the PDMS of the dry adhesive. A motion of water droplet was observed and characterized as a consequence of this gradient. This can be utilized as a simple way to clean the dry adhesive without using any external object that might damage the surface of the polymer and its adhesive properties.

2 Experimental

2.1 Fabrication

PDMS elastomer kit (Sylgard 184, Dow Conring) was used as received. The fabrication of molds was based on previously described methods[5,17–19]. The PDMS was poured into the initial mold and spin coated at 2000 rpm for one minute in order to achieve a layer thickness of less than 1 mm. Successively, the mold and the liquid precursor were placed under vacuum for 10 minutes to remove the bubbles and allow the silicone to penetrate the negative mushroom cap features of the mold followed by the curing of the PDMS in an oven at 80 ˚C for 3 hours. A Scanning Electron Microscope (SEM) image of the dry adhesive surface is shown in Fig. 1.

The structure of the dry adhesive consists of micro mushroom caps with a ‘T’ cross section. The diameter of the caps is around 15 μm, the thickness is around 2 μm and the post measures 15 μm in height and about 10 μm–12 μm in diameter. In general the adhesion strength is directly proportional to the overhang between the cap and the post. However, excessive overhang can result in the tear of the caps from the posts. As a result the 1 μm – 2 μm overhang has been reached as the optimum compromise[5,17,18].

2.2 Surface treatment

A procedure to obtain a gradient of hydrophobicity on a silicon wafer has been proposed in the literature[20,21]. In this work, different surface methods were explored to obtain a hydrophobicity gradient on a micro-structured PDMS substrate. A main difference between a silicon wafer and a PDMS substrate is that without any treatment the surface of PDMS is already hydrophobic, while silicon is usually covered by a layer of oxide which makes it neither hydrophilic nor hydrophobic. While the hydrophobicity of the PDMS can be an advantage when considering polar contaminants, if a gradient is needed, the surface has to be at least in part modified. The first step in our process was to make the surface hydrophilic, this step has two consequences: it prepares the substrate for the attachment of the polymer, and it creates the hydrophilicity toward the direction which the water or the polar solvent will move to. The adhesive was made hydrophilic by exposing it to UV light for 30 minutes. UV photons have the property to break the bonds on the surface of the PDMS making them more prone to bind to a polar molecule such as water. Subsequently, the polymeric dry adhesive is exposed to octadecyltrichlorosilane (OTS) so that the silicon of the silane is attached to the silicon of the PDMS through an atom of oxygen. This process is known as silanization. The substrate becomes hydrophobic again because the three chlorine atoms are exposed on the surface, and thus polar solvents are repelled.

In general there are several methods to silanize the surface[22]. The first method consists of dipping the sample, in this case a piece of adhesive, into the liquid silane as shown in Fig. 2a. This process needs to be carried out in an inert atmosphere such as nitrogen to avoid water adhering to the surface and compromising the silanization. The amount of silane deposited in this

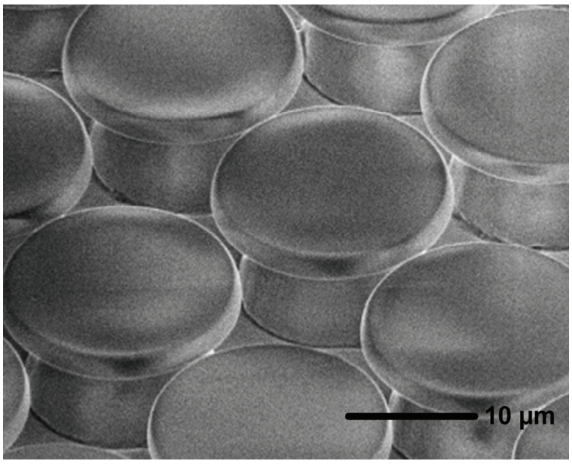

Fig. 1 SEM image of a portion of a dry adhesive.