Effect of oleophilicity on Pistia inspired surface roughness

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ABSTRACT

Comprehensive application in nanostructured and advanced design bring science communities great interest towards these materials design. Biomimetic field is one of interests that allows scientist or researchers to take idea from nature and imitate it into numerous technology of structures, products and devices. Pistia stratiotes for example has intrinsic oleophilicity which rarely discovered. An investigation into pistia leaf inspired surface roughness for oleophilicity behaviour is studied. Four different nanocomposites materials with different nanofillers epoxy resin-based were successfully fabricated namely are epoxy polymer, graphene-filled, multiwall carbon nanotube (MWCNT)-filled and nanoclay-filled. Dinolite digital microscope was used to observe middle pistia inspired surfaces of the substrates and the surface roughness of the substrates had been measured using Alicona non-contact profilometer. The contact angle meter was deployed to measure the contact angle values of three different lubricants namely palm oil, palm oil + TiO_2 and VG 68 lubricant oil. Nanocomposite of graphene-filled gave the highest oleophilicity behaviour on all oils tested when compared with the other substrates with 13.295 μm of surface roughness value. It was believed that surface roughness has the most effect on oleophilicity behaviour for the case of pistia inspired surfaces.

Keywords: *Oleophilicity; Pistia Leaves; Nanocomposite; Polymer; Lubrication.*

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Introduction

The material surface can be associated with roughness or cavities that related to a textures. The roughness may be random or deterministic in nature. The random roughness may be caused by dust, foreign particles, additive in lubricant and so on. Surface roughness of a material can have an impact and influence to a performance of a machine especially in lubrication system.

There are times where limits have been reached and therefore an alternative approach to traditional engineering must be created to attain at innovative solutions [1]. The materials and commercial devices of design and fabrication are best understood based on the structures, functions and principles of the objects. Many researchers, engineers, and material scientists resort to nature for alternative and functional solutions. This is known as biomimetics which about biological structures, functions and principles of numerous things is found in nature.

In recent years, functional surfaces with bio-mimicking micro textures have gained much interest of many researchers and industry players due to the great advantages and potentials in applications related to hydrophobicity, hydrophilicity, self-cleaning, anti-adhesion, and self-healing [2] especially after a wide approval that liquid spreading control can simply be accomplished through changes in surface roughness and topography [3]. These correlated applications often employ high-technology materials and surface preparation to control properties related to wettability [4].

Biomimetics which are referred as the application of methods found in living nature to the study and design of engineering systems and modern technology [5], [6]. Many materials in living nature have outstanding properties which cannot be accomplished by traditional engineering methods.

Biomimetic surface area is frequently noticed as a subset of the broader field of biomimetic materials. Several ideas have been recommended to design biomimetic micro and nanostructured functional surfaces. For instance, self-lubricating biomimetic surfaces can have both low friction and wear rate. It is often unbearable to directly apply in engineering solution found in nature. However, it is possible to take biological systems as an origin and a source of motivation for engineering design [6]. For instance, inspired by the self-cleaning silver ragwort leaf, Yasuhiro et al (2006) successfully fabricated a biomimetic superhydrophobic fibrous mat surface using electrospinning method. They found that, the hydrophobicity of porous fibrous mat increase when the surface roughness of microfibers increases [7]. However, an electrospinning technique currently has several limitations. One of them is in preparation of organic nanofibers. The structure and performance of nanofibers are not well reached [8].

In an investigation into oil-water separation, Ritchie et al. (2019) presented fast switching oleophobic-hydrophilic properties bioinspired. They improved the coating substrate with nanoparticle to enhance the surface roughness [9].

In this paper, the aim of the study is to detect physiological responses of middle pistia leaves inspired that produced by casting method to palm oil, palm oil + TiO_2 [10] and VG 68 lubrication oil droplet. Middle Pistia leaves inspired at different nanofillers were tested for oleophilicity using contact angle meter. Characterization of the inspired surface was done using Dinolite digital microscope. The inspired surface roughness was measured using Alicona profilometer with 3D isometric captured.

Methodology

Digital microscopic

All the substrates of pistia were analyzed macroscopically and with the aid a Dino-Lite Edge AM4815 series digital microscope as presented in figure 1 in order to access the presence of hairy structure, using magnifications up to 65x. The sample was put at the center of the base. The microscope was controlled up and down in order to get clear images on the computer. The freely adjustable polarizer helps to reveal more details and enhance the contrast on the surface by reducing or eliminating the reflections. For high contrast or reflective surface, the extended dynamic range (EDR) capture mode were used to reveal the details of dark or bright areas, which may lose in normal capture mode, by stacking images taken at different exposure levels. The extended depth of field (EDOF) capture mode were controlled to view a rough surface with height range out of depth of focus. Therefore, several pictures were taken at different focus levels and automatically stacked within a click. The front cap was detached to extend the range of use. Removing the front cap provides a greater working distance and access to the full magnification range.

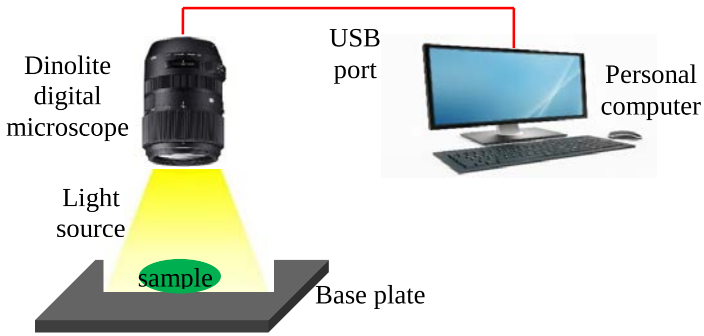

Figure 1: Schematic diagram of Dino-Lite Edge Digital microscope AM4815 series.

Profilometer

An optical non-contact method (Figure 2) is preferred for measuring the surface topography of the pistia leaves substrates. Alicona InfiniteFocus 3D optical microscope, which employs the technique of focus variation combined with small depth of focus measure surface [10], was used to measure surface topography of all substrates in 3D in this study. A 5x magnification was selected to scan the images. The total scanned area was 6 mm x 200 µm. The vertical resolution was 25 nm and the lateral resolution was 3 µm. Coaxial light and ring light were used to illuminate the test surface to measure the textures. After scanning, a line was drawn directly on the scanned surface to extract the surface profile along the line. The length of the line was about ± 2 mm.

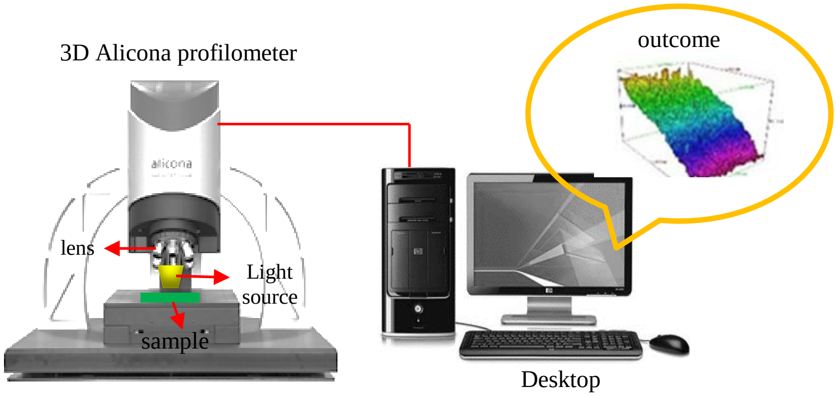

Figure 2: Schematic diagram of Infinite Focus Alicona profilometer surface topography machine.

Contact angle

The static contact angle of oils droplet with 2µL of volume droplet was measured by using contact angle meter (model OCA 15EC) at ambient temperature. The liquid was injected manually on the leaf surface substrates and left it for 5 s before the image is being captured. Each sample was measured 10 times at 10 random locations on the surface substrates. Figure 3 shows the general schematic diagram of contact angle measurement. Table 1 shows the droplet properties used in the contact angle measurement.

Table 1: Properties of droplets

Type of droplets	Palm oil	Palm oil + 1.0 wt % TiO_2	VG 68 lubricant
Kinematic Viscosity at 40 °C (cSt) [11]	49.32	49.72	71.36
Viscosity index [11]	205	212	191
Colour	yellowish	yellowish	yellowish

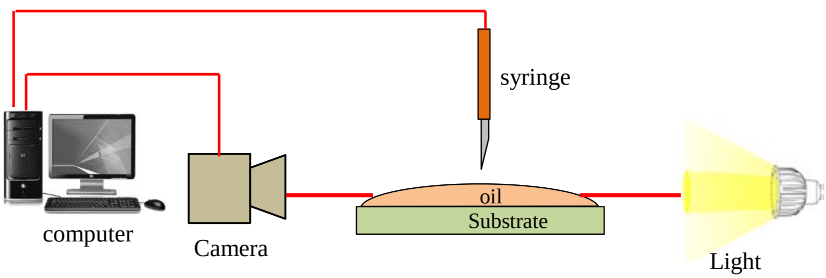

Figure 3: Schematic diagram of contact angle meter.

Results and Discussions

Morphology analyses

The topographies of the polymer of epoxy, graphene-filled, MWCNT-filled and nanoclay-filled of middle pistia substrates were observed using Dinolite Digital Microscopic. The hairy structures of the middle pistia leaves substrates look like remain unchanges each other eventhough different nanofillers were used as shown in Figure 4. The hairy structures of all substrates could be observed on the primary surfaces of the substrates by naked eye. A ridge of a hair has constant segment from the terminal to the end of the ridge. Figure 4 (a) and (d) are epoxy and nanoclay-filled look shinny due to the material colour itself meanwhile figure 4 (b) and (c) are MWCNT-filled and graphene-filled come with black tone colour, respectively. The secondary epidermal cell did not clear observed due to limitation of the magnification of the digital microscope. However, it can be clearly observed based on the study before [12]. Surprisingly, they have been proven that the microstructures such as length of hair, distance between two hairs and cell diameter quite similar with real middle pistia leaf as referred in Figure 5. The length of hair is around 332.3 µm to 333.4 µm, distance between two hairs is between 82.8 µm to 87.18 µm as well as 30.06 µm to 31.33 µm for cell diameter.

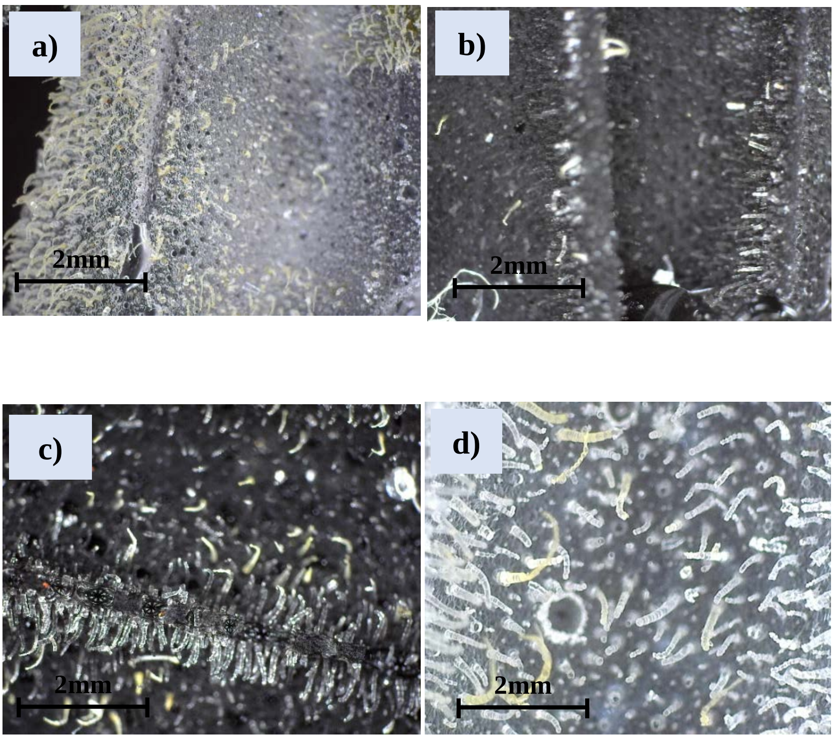

Figure 4: Digital microscope images of middle pistia substrates obtained by 3D Optical Noncontact Profilometer Alicona; a) epoxy, b) graphene, c) MWCNT and d) nanoclay.

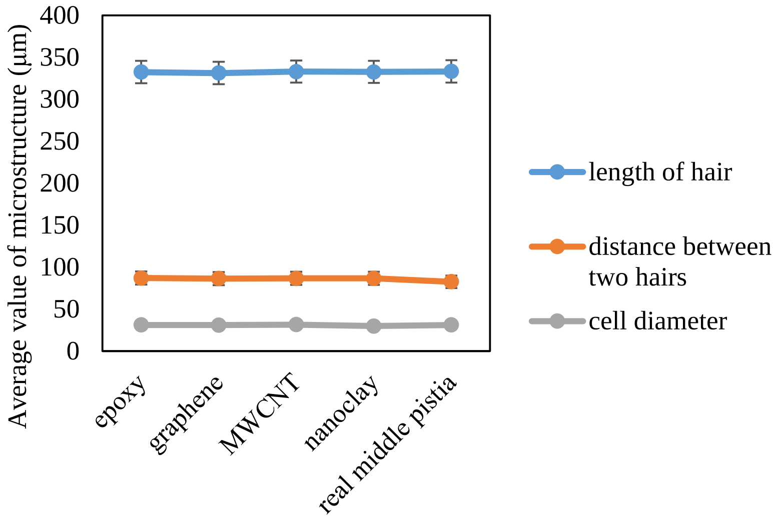

Figure 5: Average values of microstructures of middle pistia leaves of real leaf and their substrates.

Surface roughness analyses

Different substrates have different surface characteristics including colour, shininess/reflectivity, transparency and hardness. These polymer substrates are hard, not shiny, opaque and black colour for graphene-filled and MWCNT-filled, but they are not suitable using Stylus profilometer contact method due to the surface condition even though it is good for hard sample and not sensitive to the surface reflectance or colour. Alicona InfiniteFocus 3D profilometer is particularly suited to measure surface topography. There are small amounts of pores in the polymer substrates. The pores in substrates cause spikes in the imaging using Alicona profilometer, resulting in inaccurate roughness calculation. Therefore, the suitable image was tried several times until the images could be scan successfully. Figure 6 shows illustrates 3D surface topography of pistia leaves surface substrates with surface roughness (Ra) of 13.974 µm, 13.295 µm, 10.214 µm and 12.789 µm for polymer epoxy, graphene-filled, MWCNT-filled and nanoclay-filled respectively. The surface roughness values were drawing in figure 7. The colour of the contours shows the different height and depth of the samples surfaces during scanning image. These surface roughness values are not quite different changed since 36.8% of percentage of changed are obtained.

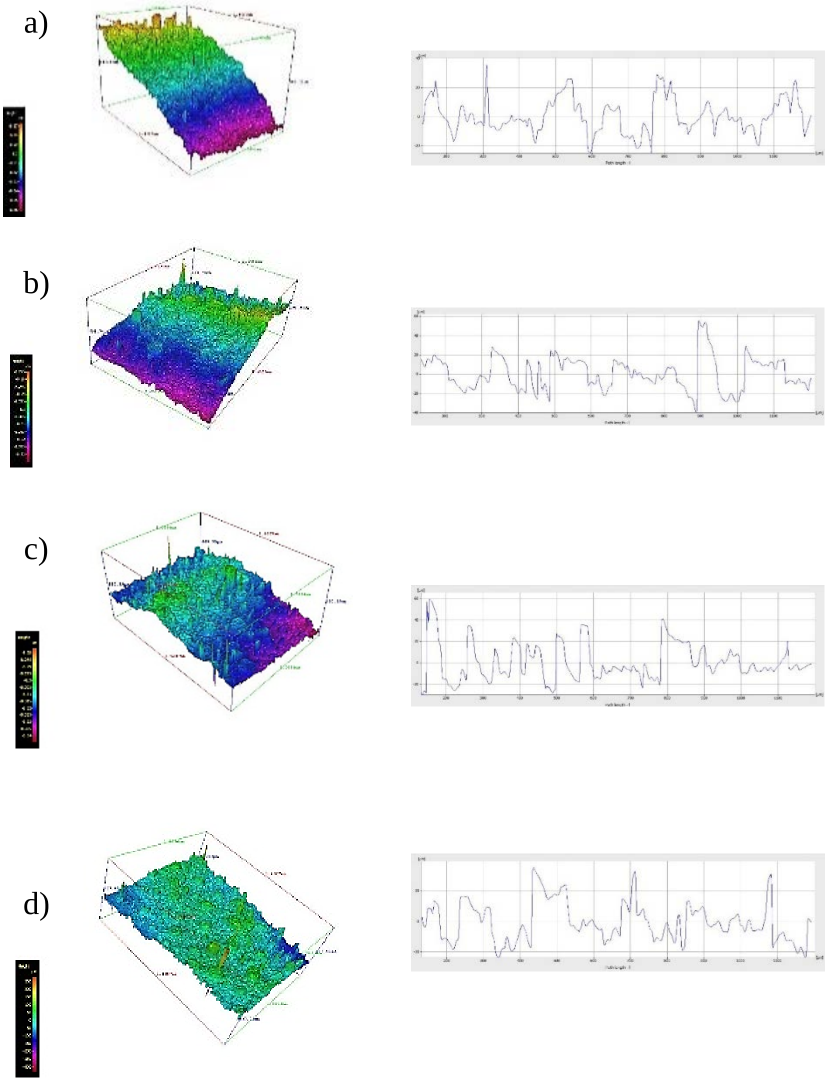

Figure 6: 3D isometric views of pistia substrates a) epoxy polymer, b) graphene-filled, c) MWCNT-filled and d) nanoclay-filled.

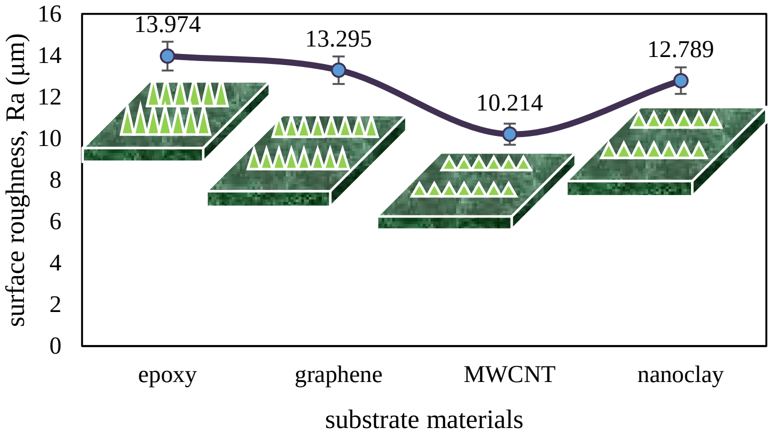

Figure 7: Surface roughness values of pistia substrates with schematic surface roughness images.

Contact angle analyses

Figure 8 shows the contact angle value of middle pistia leaves substrates. Even though the data were fluctuated, overall, graphene gave the lowest contact angle value among the other nanocomposites. The second lowest value of contact angle is MWCNT-filled followed by nanoclay-filled and polymer epoxy on all oils tested. VG 68 lubricant oil gave the lowest value of contact angle for all the substrates than palm oil with TiO_2 additive and palm oil. For palm oil, the contact angles recorded for epoxy, graphene-filled, MWCNT-filled and nanoclay-filled of pistia leaves substrate were found to be 28.81°, 24.63°, 29.1° and 30.16° respectively. However, the contact angles for palm oil + TiO_2 were found lower which were 24.94°, 21.53°, 23.52° and 19.41° for epoxy, graphene-filled, MWCNT-filled and nanoclay-filled respectively. Amazingly, the VG 68 lubricant oil contact angle was observed 8.3°, 4.68°, 4.9° and 7.41° for epoxy, graphene-filled, MWCNT-filled and nanoclay-filled respectively.

Differences in contact angle values at different leaves maturity are believed due to the effect of topography on the wetting nanoscale patterns. It was showed that the topography has influenced the wetting properties [13]. In conjunction with chemical composition, the rheology of oil also influences to the wettability of the surfaces as reported by Bhusan [14]. The organic oil and synthetic oil had lower surface tension that cause oil to spread out easily on the pistia leaf substrates.

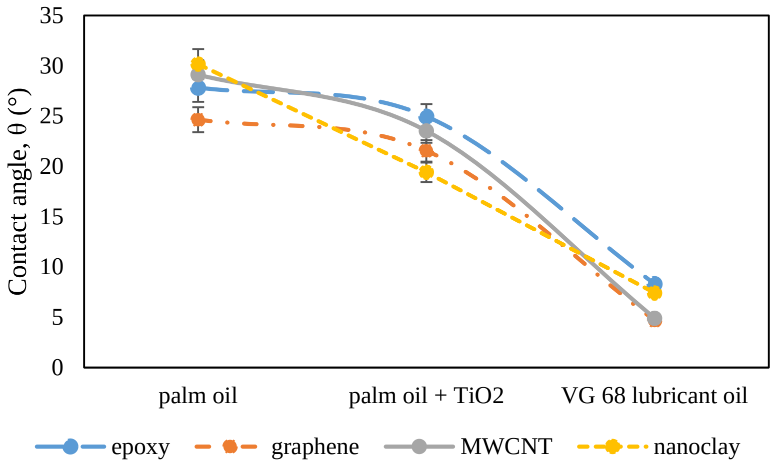

Figure 8: Contact angle value of middle pistia surface substrates

Conclusion

In conclusion, middle Pistia leaves inspired substrates were successfully fabricated. Four different nanomaterials were deployed in the fabrication processes namely epoxy polymer, graphene-filled, MWCNT-filled and nanoclay-filled. The casting method was used to produce the substrates samples. Based on the results, graphene-filled gave the highest oleophilicity behaviour compared to the other three materials. Matching the material's structure and function to the desired practical conditions is of significant importance, which of course is sometimes a complicated process. This work laid the basis for further work related to biomimetics in creating and designing engineering surfaces with superior tribological properties for oleophilicity and oleophobicity applications especially in machinery system to reduce friction and wear. The authors believe that enlightening the nature's secret and further subtracting the beautiful mechanism can promote innovative inspirations, help people to guide the scientific research and bridge the gap between academic research and practical application. Indeed, the spectrum of opportunities is endless and there are a lot to learn from natures.

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