Impact of Spray-Casting Height and Pressure on Durability and Superhydrophobicity of Nanocomposite Coatings

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ABSTRACT

This work investigates the effect of spray-casting heights and air pressures on the superhydrophobicity and durability of nanocomposite coatings. Coatings at different spray heights and pressures were fabricated and their superhydrophobicity and durability measured via water contact angle, roll-off angle and mechanical linear abrasion, respectively. Results showed that coatings fabricated at high spray-casting heights and low air pressures were more superhydrophobic than coatings fabricated at low spray-casting heights and high air pressures. However, the later coatings were remarkably more resistant towards strong linear abrasion as compared to the former coatings. Therefore, this study demonstrates that it is critical to consider spray-casting deposition parameters such as spray-casting height and spray-casting air perssure when creating superhydrophobic nanocomposite coatings.

Keywords: nanocomposites, spray-casting height, spray-casting pressure, superhydrophobic, durability

1 INTRODUCTION

Since discovering that nano and micro length scale surface morphology as the key parameter for superhydrophobicity, researchers have been successful in fabricating various synthethic surfaces that are highly water repellent. Fabrication methods include surface etching techniques (plasma, laser, chemical), lithography (photolithography, electron beam, X-ray), electrochemical deposition processes as well as electrospinning techniques. [1], [2] The goal is to engineer these synthetic superhydrophobic surfaces to provide solutions in areas such as anti-corrosion/fouling surface applications, icing protection on aircraft, power lines and wind turbines as well as drag reduction in marine and fluid powered systems.

However, since the aforementioned fabrication techniques involve expensive and restrictive fabrication processes, it is both uneconomical and impractical to adopt these fabrication methods for realistic large-area applications. To resolve this problem, researchers have recently employed a spray-casting technique in which a nanoparticle-polymer suspension is atomized and dispersed on a surface using an air-atomizing spray nozzle. [3]–[9] This creates a superhydrophobic nanocomposite coating fabricated from a simple one-step process which can be applied to a large area and to a variety of substrate materials.

Although the mechanism for the formation of superhydrophobic nanocomposites by spray atomization has been documented [3], questions still remain on the impact of spray deposition parameters on the superhydrophobic performance and mechanical durability of the coating. To the authors knowledge, there has not been any publications which have examined these issues. Understanding these effects is critical for large-scale manufacturing applications where coatings of consistent durability and superhydrophobicity are desired. Therefore, in this work, an experiment was designed to systematically fabricate superhydrophobic coatings from different spray-casting heights and air pressures. Superhydrophobic performances (by measurement of contact (CA) and roll-off angles (ROA)) and mechanical durability (by linear surface abrasion) of all the coatings were measured to quantify the spray-cast application effects.

2 MATERIALS AND METHODS

2.1 Nanocomposite Fabrication

Precursor solutions were first created, followed by spray casting and then thermosetting to produce the final nanocomposite coatings.

First, polyurethane was dispersed in acetone. Next, as-received dimethyl dialkyl C14-C18 amine functionalized montmorillonite clay particles (Nanoclay, Nanocor Inc., USA) were dispersed in the polyurethane-acetone mixture. Finally, waterborne fluorinated acrylic copolymer (25% wt polymer, 75% wt water; Dupont) was added slowly to the polyurethane-nanoclay suspension and blended with vortex mixing for 15 minutes, creating a Pickering emulsion. To further promote homogeniety in the solution, the slurry was sonicated at 35% amplitude at a frequency of 20khz for two minutes with an ultrasonicator (Model VC750, Sonics & Materials, Inc., USA) Additional solvent (acetone) was added as necessary into the sonicated solution to reduce the viscosity of the mixture.

To create the nanocomposite coatings from this precursor solution, the slurries were spray-casted onto aluminum substrates from various spray-casting heights and air pressures and then heat cured at 100°C overnight.

2.2 Experimental Set-Up and Process

To ensure consistency in the spray-casting process and ultimately in the quality of the nanocomposite coatings, the aluminum substrate was placed on a motorized platform and translated in controlled longitudinal (Y axis) and lateral (X axis) motions while the air-atomizing nozzle sprayed the nanocomposite mixture above the platform (Figure 1). The motorized platform was controlled by two linear slides driven by stepper motors (Xslide, Velmex Inc., USA).

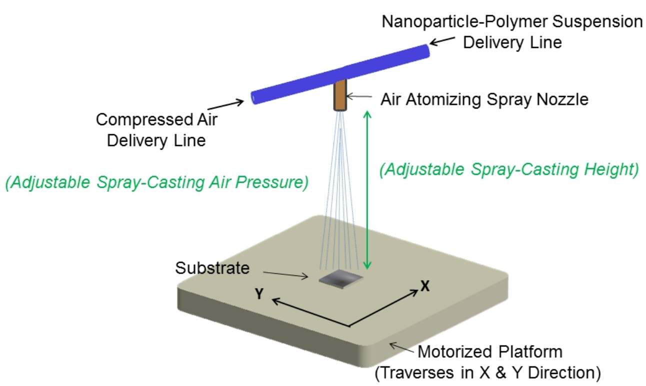

Figure 1: Schematic of the Spray-Casting Process

The air-atomizing spray nozzle was an internal mix model (1/4JCO series, Spray Systems Co., USA) with a round spray pattern and with the capacity of approximately 0.75 gallons/hr at 40psi air pressure. Regulated air pressure was provided by an external air compressor (3 hp, Craftsman) while the polyurethane-nanoclay slurry was siphoned into the spray nozzle.

The spray-casting process began when the air-atomizing nozzle was set at a fixed height above the substrate to deliver a fine mist of polymer-nanoclay mixture droplets. The motorized platform was then programmed to step in the lateral direction (X axis) for a distance of 0.2 inches before traversing in the longitudinal direction at a speed of 6 inches/second. The programmed motion was repeated until the entire substrate was coated. Various spray heights (1-6 inches) and air pressures (20-100psi) were used to create different nanocomposite coatings for quantitative superhydrophobic and mechanical durability measurements.

Static water CA measurements were performed by capturing three digital images of a water droplet (10μl diameter) through a digital SLR camera (Canon EOS T2i, macro lens MP-E). The images were then analyzed using a B-spline snake approach pioneered by Stalder *et.al.* [10] as a plug-in program within the Image-J software to provide an averaged CA measurement. Roll-off angles were acquired by measuring the tilt angle of the coating where a 10μl water droplet would slide off the surface. ROA measurements were also repeated five times so that an averaged ROA value could be acquired.

To assess the mechanical durability of the coatings, a linear abraser (Model 5750, Taber Industries) was used. This device consisted of an adbradant tip attached to a horizontal arm which reciprocated in a linear fashion at a force determined by weight discs. The abradant tip (H-10 Calibrade, Taber Industries) was made of aluminum oxide abrasive particles designed to provide medium abrasive action. 900g of weight discs were placed on the arm and the nanocomposite surfaces were abrased until the point of coating break-through. Coating break-through was defined as the point where the abradant tip completely wears the coating at which the surface of the underlying aluminum substrate was visible.

3 RESULTS AND DISCUSSION

Figure 2 shows the effect of spray-casting height on the superhydrophobicity of the coatings when spray-casting air pressure was fixed at 60psi.

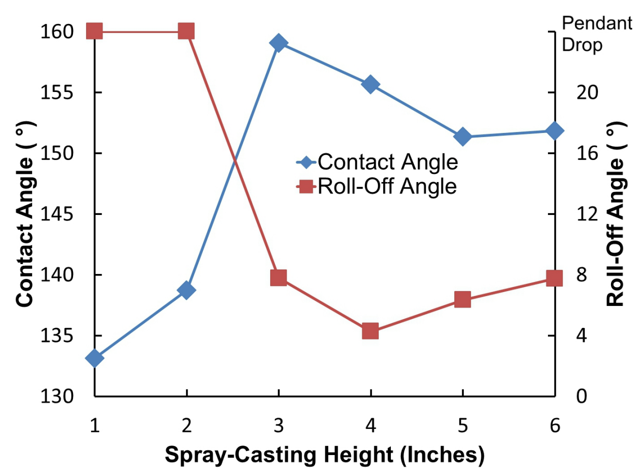

Figure 2: Effect of spray-casting height on superhydrophobicity of the nanocomposite coating (spray-casting air pressure fixed at 60psi)

It can be observed that nanocomposite coatings fabricated at less than or equal to 2 inch spray-casting heights were not superhydrophobic. Static water CA angles did not exceed 140° and roll-off angle measurements resulted in a pinned droplet on the surface. However, at 3 inch spray-casting heights, the superhydrophobic performance of the coatings improved tremendously. Static water CA increased to nearly 160° with a ROA of approximately 8°. Further increase of the spray-casting height showed that coatings remained superhydrophobic, albeit with a slight drop-off in superhydrophobicity.

This effect can by explained by considering the mechanism of nanocomposite formation by spray atomization. After atomization, the nanoclay-polymer suspension travels through air from the nozzle to the substrate in the form of droplets. Each of these droplets contain solvent which acts as a medium of transport while evaporating during the time of flight, leaving mainly nanoclay and polymer components on the substrate to form a nanocomposite coating. The degree of evaporation is however linked to the height between the spray nozzle and substrate.

For a low spray-casting height, there is insufficient time for the solvent to evaporate, therefore creating a "wet" coating on the substrate. This leads to the "coffee stain" effect [11] which causes non-uniform coatings through surface tension effects. Therefore, this results in a decrease in superhydrophobicity. On the other hand, at higher spray-casting heights, most of the solvent evaporates during time of flight, leaving a high concentration of nanoclay and polymer components on the substrate to form a more porous nanocomposite coating with hierarchal nanotextured surface morphology and with high superhydrophobicity.

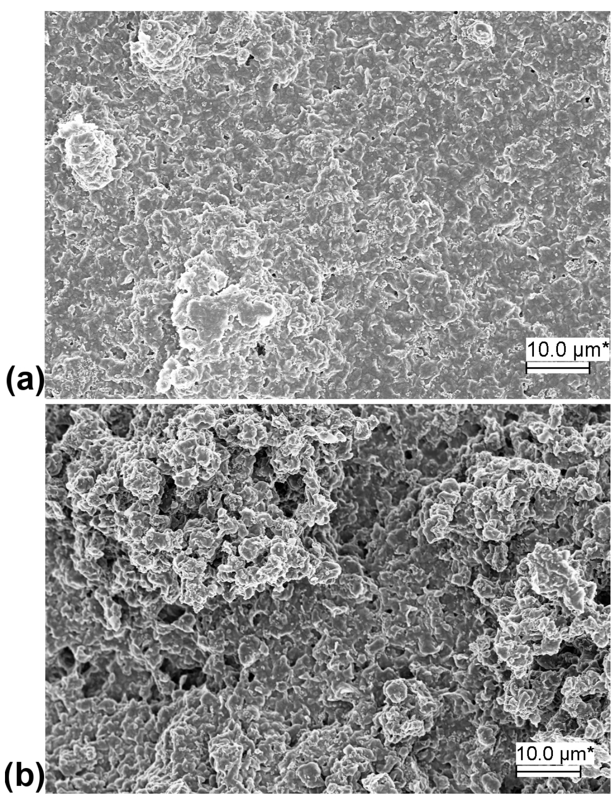

Figure 3: SEM images of nanocomposite coatings spray-casted at a height of (a) 2 inches (b) 3 inches

Scanning electron microscope (SEM) images were acquired for coatings spray-casted at heights of 2 and 3 inches to demonstrate this effect. For a spray height of 2 inches shown in Figure 3a, a "flat" surface texture was observed. In comparison, the SEM image of a surface coated at a height of 3 inches depicted more texture at different length scales (Figure 3b).

Figure 4 shows the effect of spray air pressure on the superhydrophobicity of the coatings when spray height was fixed at 3 inches. It can be observed that at spray-casting air pressures between 20 and 60 psi, the nanocomposite remained superhydrophobic with static water CA between 151° and 159° with ROA less than 8°. However, superhydrophobic performance degraded at a spray-casting air pressure of 80 psi with a complete lost of superhydrophobicity for coatings fabricated at an air pressure of 100psi.

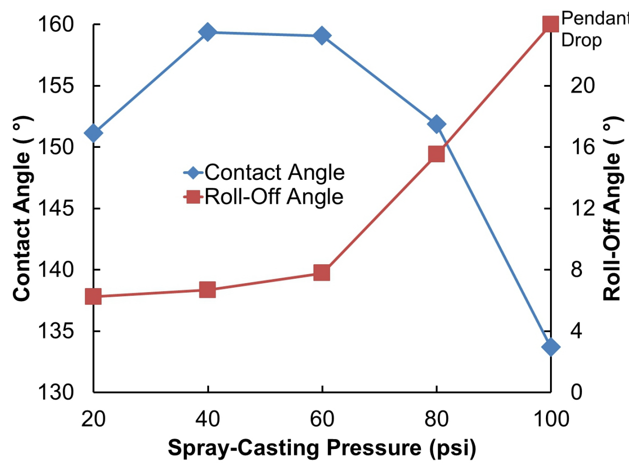

Figure 4: Effect of spray-casting air pressure on superhydrophobicity of the nanocomposite coating (spray-casting height fixed at 3 inches)

Figure 5 shows the mechanical durability of the nanocomposite coating at different spray-casting heights while fixed at an air atomizing pressure of 60psi. It can be observed that the fabricated coating at 2 inch spray-casting height was able to resist 160 cycles before a breakthrough of the coating was detected. However, increasing the spray-casting height above 2 inches resulted in a significant degradation in coating mechanical durability. This effect corresponds with the hypothesis that a "wet" coating from a low spray height is mechanically stronger than a porous coating fabricated from a higher spray height.

A similar experiment was performed on nanocomposite coatings fabricated at different spray-casting air pressures while fixed at a 3 inch spray-casting height. Results in Figure 6 showed that coatings fabricated at higher pressures demonstrated remarkable resistance to

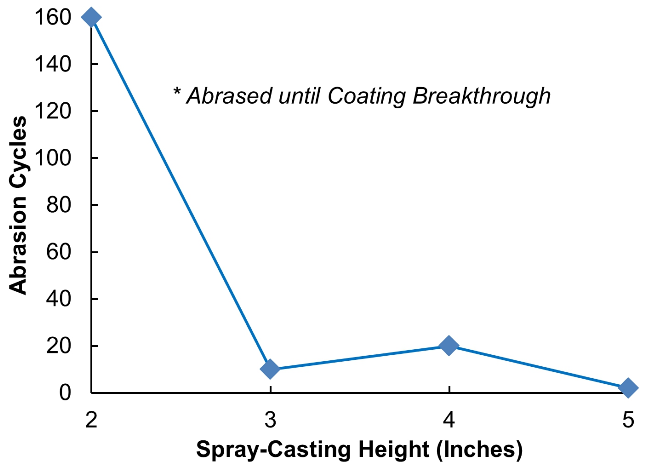

Figure 5: Effect of spray-casting height on mechanical durability of nanocomposite coating (spray-casting pressure fixed at 60psi

abrasion since a higher volume of slurry was delivered by the spray nozzle to the substrate to create a "wet" coating. In comparison, coatings fabricated at low spray pressures were more porous and therefore mechanically more fragile.

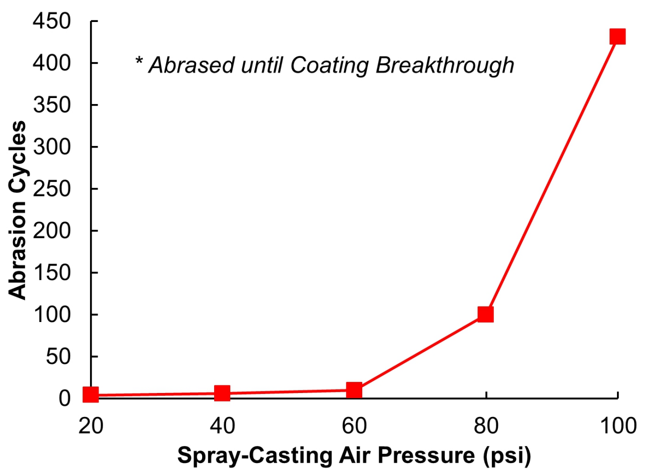

Figure 6: Effect of spray-casting pressure on mechanical durability of nanocomposite coating (spray-casting height fixed at 3 inches)

4 CONCLUSIONS

The study of spray-casting height and air pressure effects on the superhydrophobicity and durability of polyurethane-organoclay nanocomposite coatings were conducted. Results indicate that coatings manufactured from a high spray-casting height were superhydrophobic. However, at low spray-casting heights, the "coffee stain effect" was observed, hence dramatically reducing the hydrophobicity of the coating. A similar reduction in superhydrophobicity was observed with high spray-casting air pressures where a high volume of nanoclay-polymer mixture was delivered to the substrate to form a "wet" coating. Although lacking in hydrophobicity, these "wet" coatings provided a remarkably higher resistance towards mechanical abrasion as compared to a more porous coating fabricated from a higher spray-casting height or lower air pressure. This study demonstrates that is is critical to consider spray-casting parameters such as height and air perssure when creating superhydrophobic nanocomposite coatings.

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