Wetting of Hydrophobic Coated Fabric

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We explored how efficiently a commercially available hydrophobic coating protects absorbent fabrics against water. The focus was in determining if the coating was more or less effective against different types of water exposures: submersion, droplets, and high humidity. The primary audience of this paper is individuals interested in improving hydrophobic coating or interested in using this technology in products or projects. We found that the hydrophobic coating reduced both the rate at which the fabric absorbed water as well as the total water which the fabric finally absorbed. When treated fabrics were submersed in liquid water, sprayed with water droplets, and exposed to very high levels of humidity, the hydrophobic coating was most effective in protecting the fabric against water vapor (high humidity). The results also showed that there is little difference in the protection afforded by double coating the fabric with the spray versus in applying only a single coat.

I. SCIENCE OF HYDROPHOBICITY

Many naturally occurring materials are proficient at resisting moisture (hydrophobic), such as materials whose surfaces have waxy and oily coatings. However, even hydrophilic (water absorbent) materials can be rendered more water repellent with the utilization of a hydrophobic coating. The technology of these coatings comes from the observation and subsequent application of the Lotus flowers ability to repel water. With the use of a scanning electron microscope, the surface structure of this plant was seen to have microscopic pillars of wax crystalloids [1].

It was already known that there was a relationship between the roughness of a material and the water repellency, but this **Lotus-effect** (as it was called by Dr. W. Barthlott) is the superhydrophobic effect witnessed when water droplets exceed a contact angle of 150 [1][2]. Normally to be hydrophobic, the water droplets just need to have a contact angle greater than 90 [2].

With hydrophobic coatings available to the public, many users assume that it will protect against all types of moisture exposure (vapor, submersion, droplets). This research seeks to explore the reliability of a currently available hydrophobic coating when subjected to a variety of exposures to moisture. In looking at the ways in which this product responds to moisture in various states, we hope to identify specific areas for improvement in this and possibly other products in the future.

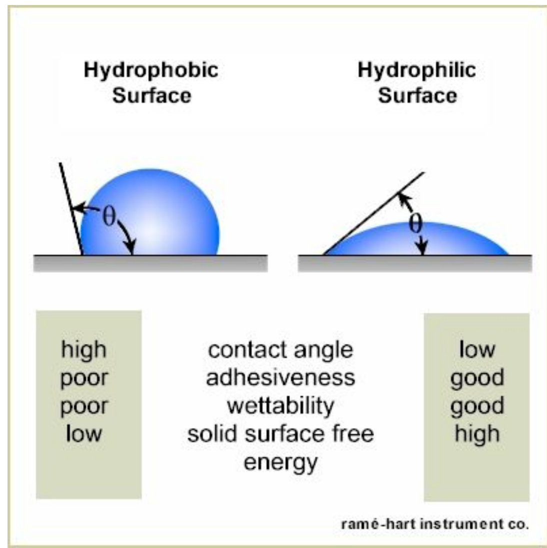

FIG. 1. Higher contact angle with surface interface means a hydrophobic surface wear as smaller contact angle means water is attracted to surface. Source: Ramehart.com/contactangle.htm

II. METHODOLOGY

To determine the efficiency of the coating, we measured the moisture content in a 100% cotton cloth fabric cut into 1 m^2 squares, before and after timed exposures. The industry standard for measuring moisture content in a substance is the Loss on Drying method [3]. The substance is weighed while it is wet and then placed into an oven to evaporate moisture and cooled in a desiccant to prevent moisture from the air absorbing into the material, then weighed after cooled. For this experiment the Loss on Drying technique was modified due to the specialized equipment needed and possible fire hazards. We substituted the Reverse Loss on Drying method, where the trial swatches are massed after exposure to moisture. The commercial hydrophobic spray used in this experiment will be **3"03 Fabric Guard Spray"** The fabric swatches were each sprayed with one layer of coating on both sides of the fabrics. A secondary coating was applied on a selection of swatches to help determine if additional coatings provide any added protection against the

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moisture. For humidifier testing, the humidifier used was the **"Fancii Mini Humidifier"** and was placed into a foam-sealed tub. A mesh platform was placed over the humidifier spout. The fabric is then positioned directly over the vapor to maximize the exposure. For continuous spray testing the fabric was positioned vertically to prevent pooling of the water and the sprayer used was the **"Instapark AHS-803"**. The test swatch was weighed at various time intervals and their mass as well as the total amount of water to which it has been exposed recorded. Several trials were performed to obtain averaged values for rate of absorption versus duration of exposure and the volume of water to which it was exposed. Plotting saturation versus time and saturation versus volume of water, we find the amount of water absorbed increasing and eventually reaching a plateau at maximum saturation.

III. HOW WET DID IT GET?

A. Submersion

The result of the Submersion Trials shown in Table 1. shows that hydrophobic coating does have an effect on how much the cotton fabric is able to absorb before and after coating. The data shows that the commercial hydrophobic coating is able to reduce the amount of water absorbed by the fabric up to 50% less than without coating when the fabric is submerged in water with only one coating. The difference in the rate of absorption and amount of absorption between a single coated and double coated fabric shows that there is a diminishing returns relationship for adding more layers of coating when testing the fabrics durability against submersion in water. The data also shows the coated fabrics take more time to become fully saturated with water as shown by how the single and double coated fabrics both have much more data points before they stabilize and hit a plateau. This shows that when a hydrophobic coated fabric is exposed to submersion, both the amount of water absorbed and rate of absorption are reduced.

B. Spray

Results of the sprayer trials, shown in Table 2, revealed a continued pattern of the non-coated fabric absorbing more water and more quickly than either of the coated swatches. The sprayer is a continuous non-pumping device and in order to calculate how much water the fabric was exposed to for .5 sec, the spray rate is calculated using a graduated cylinder and timed for 30 sec. The spray rate was approximately 92ml which gives 1.53ml of water exposed to the fabric per half second. To reduce error from the possibility of only one side of the fabric being exposed to the water, the fabric was quickly turned when it is placed in the stream of water.

Submersion Trials			
Time (s)	Single Coat Avg. Mass (g)	Double Coat Avg. Mass (g)	Control Avg. Mass (g)
0	0.70	0.68	0.62
0.5	0.95	1.15	1.90
1.0	1.16	1.54	2.93
1.5	1.43	1.53	3.40
2.0	1.71	1.77	3.71
2.5	1.81	1.81	3.61
3.0	1.91	1.82	3.57
3.5	1.95	2.15	3.55
4.0	2.14	1.85	3.61
4.5	2.08	1.88	
5.0	2.21	1.90	
5.5	2.41		
6.0	2.41		
6.5	2.41		

TABLE I. Average mass of fabric after submerging for .5 sec intervals. Ended trials after 3 measurements within .1 grams.

Spray Trials			
Time (s)	Single Coat Avg. Mass (g)	Double Coat Avg. Mass (g)	Control Avg. Mass (g)
0	0.66	0.61	0.57
0.5	0.96	0.83	1.51
1.0	1.25	1.01	2.43
1.5	1.47	1.21	3.43
2.0	1.68	1.42	3.46
2.5	1.88	1.61	3.90
3.0	1.84	1.69	4.00
3.5	2.08	1.75	3.33
4.0	2.09	1.88	
4.5	2.26	1.94	
5.0	2.16	1.86	
5.5		1.88	
6.0		2.02	
6.5		2.08	
7.0		2.14	
7.5		1.99	
8.0		1.93	

TABLE II. Average mass of fabric after being subject to constant spray for .5 sec intervals. Ended trials after roughly 3 measurements within .1 grams.

C. Humidifier

We initially hypothesized vapor presents a unique challenge to hydrophobic coatings, due to the very small radii of the water droplets. As can be seen from the results of the non-coated test swatch, fabric exposed to vapor easily absorbs this moisture. We theorized that the hydrophobic coating would be less effective against exposures to high humidity. However, the data suggest that the contrary is the case. The hydrophobic coating is most effective in repelling absorption of water vapor.

Humidifier Trials			
Time (min)	Single Coat Avg. Mass (g)	Double Coat Avg. Mass (g)	Control Avg. Mass (g)
0	0.7	0.7	0.6
100	0.8	0.7	0.6
200	.95	1.0	0.8
300	1.0	1.0	0.9
400	1.0	.95	1.1
500	1.0	1.1	2.1
600	.95	1.0	2.1
700	1.0	1.1	2.3
800	1.1	1.15	2.8
900	1.3	1.1	3.4

TABLE III. Average mass of fabric after being subject to constant spraying humidifier. Time interval chosen based on the rate of water usage by the humidifier. Trial ended early due to batteries dying.

IV. ANALYSIS

All of the different type of water exposures that the cotton fabric was presented with revealed that there was indeed a substantial difference from being coated with hydrophobic coating than without as shown in Figure 2.

All the trials showed that hydrophobic coating was able to reduce the amount of water absorbed by the fabric and the rate of absorption of the fabric by up to 50% with only one coating.

The results also showed that adding more layers of coating to the fabric did improve the resistance against water but there is a diminishing returns relationship between the number of coatings and the percentage of water absorbed on all exposures.

The hydrophobic coating seemed to have the greatest efficiency towards the exposure that minimized the amount of water in contact with the fabric as that allowed the hydrophobic coating more time to deflect water off it's surface before another water molecule came in contact with the same point. This shows why the greatest gap in amount of water absorbed and original fabric mass is the fabric that underwent the vapor trials. However, this could also be due to not coming in direct contact with the humidifier vapor nozzle and only being in a 100% humidity environment.

V. DISCUSSION

For every type of water exposure a clear distinction between coated and non- coated fabric is clear. For submersion and sprayer trials, the double coated fabrics on average reached saturation at a lower mass than that of the single coated fabric. Nothing could be discerned between the sprayer and submersion vapor trial. To calculate the the amount of water exposed, the rates of exposure had to be calculated for each method. This was straight forward for the sprayer and humidifier methods, but the

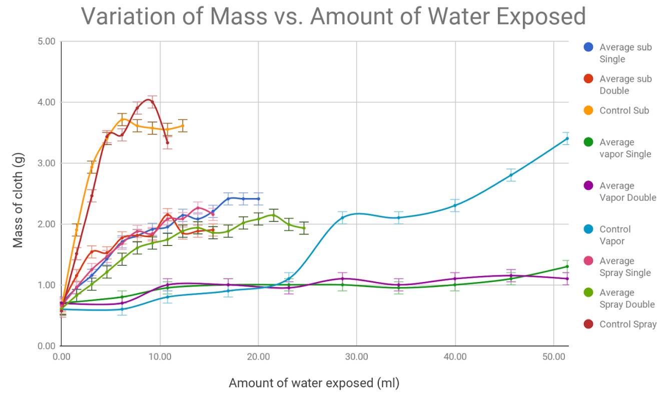

FIG. 2. Comparing all trials mass gain to amount of water exposed.

Trial	% Water Absorbed	Error (±)
Sub Control	498.4	40.8
Sub Single	244.3	18.2
Sub Double	217.6	16.8
Spray Control	601.8	53.4
Spray Single	243.9	19.3
Spray double	256.7	22.3
Vapor Control	466.7	394.9
Vapor Single	85.7	69.5
Vapor double	64.3	53.8

TABLE IV. Comparisons of the % of water absorbed.

submersion method is more difficult. It was decided that the volume of water exposed would equal the difference between the physically measured volume and the volume of water displaced by the fabric in a graduated cylinder.

Another important quality to look at is the % water absorbed. This will give us a more direct comparison between the hydrophobic coated fabric between the trails.To calculate [4],

$$\%_{absorb} = \frac{m_{sat} - m_{dry}}{m_{dry}} * 100 \tag{1}$$

For a reasonable approximation, the range was used as the wet -dry masses since some trials did not reach saturation. Amounts greater than 100 mean that the saturation point allows more mass of water in the substance than the mass of the substance itself. This is typically seen in absorbent materials while non-absorbent materials, like rock, will have a smaller percent absorbed. Error was calculated with error propagation formula.

Some error will have been introduce by the fact that .5 sec was estimated during the trial as it was to small for a human to accurately keep track of. As the fabric neared saturation water clung to the outside of the fabric even after shaking. This small accumulation would lead to a gain in weight over time that was not from the water being absorbed into the fabric. When this was left water droplets in the beaker the trial was stopped since saturation was either achieved or close enough for this experiment.

VI. ACKNOWLEDGEMENTS

- **Minh Mai** - for allowing us to borrow equipment.

VII. CONTRIBUTIONS

- **Steven Li** introduced the initial project idea, coated the fabrics, structured the paper and was responsible for the abstract, submersion and analysis of the paper.
- **Victoria Hickman** refined the methodology was responsible for the vapor trial testing, vapor trial and spray trial portion of the paper.
- **Sara Grover** attempted to standardized the methodology to only favor rate of exposure as a variable, analyzed the data and created the graphs, responsible for the theory and over viewed the paper.

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