Lotus-*Effect*® - Surfaces

Edwin Nun, Markus Oles and Bernhard Schleich

Degussa AG, D-45764 Marl, Germany

Summary: Surfaces are often characterized with phrases like "easy to clean", "dirt repellent", "dirt resistant", "self cleaning" or "**Lotus**-Effect®".Every one of those phrases is used to describe a behavior of surfaces – similar to each other but still different. This article is providing the definition of the **Lotus**-Effect®, techniques to manufacture self cleaning surfaces and methods to characterize them as well. How to generate a self cleaning surface depends on the substrate and the use later on. It can be as easy as a spray on but on the other hand as complicated as a three step process. Self cleaning surfaces are defined by four parameters – contact angle, roll-off angle, hystereses and C.I.E-Lab Δ-L value.

Introduction

Lotus-Effect® surfaces are hydrophobic nano-structured surfaces being cleaned by moving water! Surfaces are often characterized with phrases like "easy to clean", "dirt repellent", "dirt resistant", "self-cleaning" or " **Lotus**-Effect®". Each one of these expressions is used to describe a behavior of a surface – similar to each other but still different.

"Easy to clean" surfaces are smooth and hydrophobic and well known since decades. As indicated, it is not difficult to remove soil from such surfaces. Wiping with a wet cloth will clean them.

"Dirt repellent" suggests a surface that repels dirt. As of today no such surface is known.

"Dirt resistant" – it is harder to soil these surfaces but not impossible. This expression provides no hint how to clean.

" **Lotus**-Effect® " and "self-cleaning" are used synonymously. Some dirt might soil the surface. But a human cleaning activity is not necessary. Just expose the surface to precipitation and watch how water does the work.

Self-cleaning surfaces is the topic this lecture deals with.

The basic requirements for **Lotus**-Effect® surfaces are a combination of hydrophobicity and structure. As early as 1982 Abramzon [1)] described that the structure of a Lotus leaf's surface and the hydrophobicity together create water drops having contact angles of 150 degrees. What he did not noticed at all was the self cleaning behavior. This property was also missed by SEKISUI

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CHEMICAL CO. LTD who filed a Japanese patent application in 1994 [2]. In 1997 Barthlott[3] described the Lotus-leaf's surface self cleaning behavior. The following illustration shows a surface of a lotus leaf (Fig. 1).

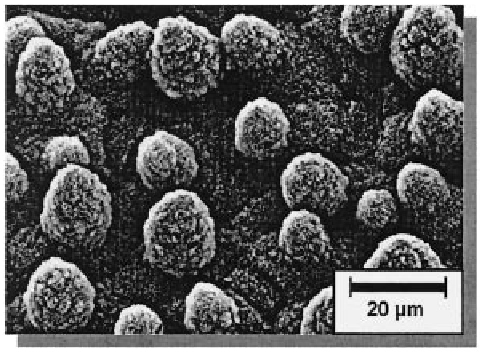

Figure 1. SEM image of a Lotus leaf (Nelumbo nucifera)

Other plants, too, force water to build out droplets rolling off at the slightest inclination [3]. Widely known is this behavior on cabbage, kohlrabi, nasturtium or gingko.

Not surprisingly each of these plants has a unique surface patterns. In common the plant leaves have a very hydrophobic top-layer and a structured surface.

As conclusion it can be stated that there is not only one possible surface structure for self-cleaning surfaces, there are a wide variety!

Results and Discussion

This wide variety of possible self cleaning surfaces opens up several possibilities to produce them.

The first approach was copying Lotus leaf's surface. But soon it was found that due to isolated structures the mechanical ability to withstand mechanical stress was very poor. Therefore the design was changed. A better mechanical stability should result by connecting the hydrophobic "knobs" to each other like it is realized in egg-shapes. In addition, the influence of the structure's size was evaluated. It was found that the self-cleaning behavior is not limited to the structure size found at Lotus plants. Even repeating structures from 250 nm and below are fulfilling the requirements for **Lotus**-Effect® surfaces.

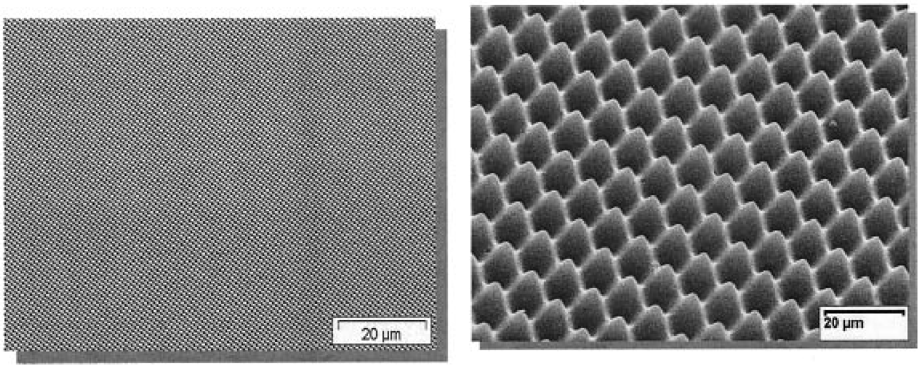

Figure 2. SEM image of self-cleaning surfaces with different structure size

Alone the knowledge of working structures is not sufficient to manufacture **Lotus**-Effect® surfaces. Know how about the embossing tool, the embossing process and how to create a permanent hydrophobic surface are some of the keys being successful.

Currently it is in favor to emboss in a hydrophobic lacquer system under simultaneous cure. Most critical is the lacquer system that must have excellent adhesion to a carrier and must be nano-structured and hydrophobic after cure.

An other approach to create self cleaning surfaces is to tether nano-structured hydrophobic particles onto surfaces, accordingly (Fig. 2).

Bonding nano-structured hydrophobic particles onto any surface is a difficult task. It is to assure that the bounding is permanent. Usually, surfaces are more or less hydrophilic. Thus hydrophobic particles and common plastic surfaces are rather incompatible. Bridging these conflicting behaviors is the task for a coating system.

We developed this coating system with an excellent adhesion to most of the common polymer surfaces and showing affinity to hydrophobic nano-structured particles as well. Due to this unique combination of properties **Lotus**-Effect® surfaces on plastics are accessible. Even complicated 3d-shapes can be equipped.

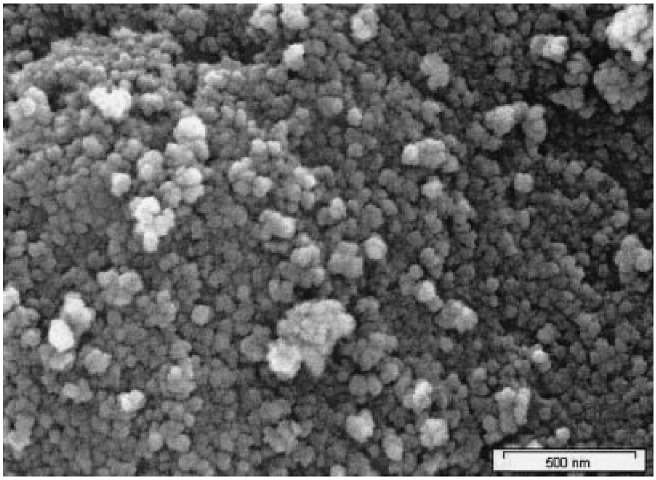

Figure 3: SEM image of self-cleaning Plexiglas® (PMMA) surface with nano-structured hydrophobic particles.

The image above illustrates how polymer surfaces are covered with hydrophobic nano-scale particles. The very dense layer of particles covers the bonding resin completely. On this very surface the contact angle to water is above 150 ° and the roll-off angle below 2 °.

The ability to withstand mechanical stress is much higher than mother nature's model. It can be touched and brushed as well without diminishing self-cleaning performance.

Yet, it is not simply a paint. A standard lacquer system with the particles suspended in would fill the nano-structured particle's surface. And, as on Lotus plant's leaves too, losing structure is equal to losing self-cleaning performance.

Embossing hydrophobic lacquer or tethering hydrophobic nano-structured particles are leading to durable self-cleaning surfaces. A third kind of **Lotus-**Effect® surface is for non-permanent possible use.

An application for a European patent [4)] reveals formulations of nano-structured particles mixed with binders to generate self-cleaning surfaces just by spraying onto surfaces. Depending on binders those surfaces are neither permanent nor non-permanent.

We developed a spray for non-permanent self-cleaning surfaces. No binder that will remain on a surface is needed to fix nano-structured particles onto nearly any surface. Just making use of some physical properties manufactures smart self-cleaning surfaces.

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"**Lotus**-Effect® " and "self-cleaning" are used synonymously. Some dirt might soil the surface. But a human cleaning activity is not necessary. Just expose the surface to precipitation and watch how water does the work.

- So it is stated at the beginning of this lecture.

What actually is the definition for self-cleaning or **Lotus**-Effect® ?

There is no ASTM, DIN or ISO standard to characterize self-cleaning performance. Practically four essential analytical parameters were found. Only if all of them together meet the requirements a surface will be characterized as self-cleaning surface

- Contact angle to water: Young's equation for contact angles is related to the hydrophobicity of a surface. [5] Even very hydrophobic smooth surfaces have contact angles up to approximately 120° only. But with the right nano-structures on hydrophobic surfaces the contact angles increase. With a structured surface the question of baseline (cos θ) in Young's equation becomes indistinct. For practical purposes the angle is measured as it appears with having the surface on a scale pretending to be smooth.

  The first parameter that is necessary for self-cleaning surfaces is a contact angle above 140°.

- Hystereses of advancing and retreating angle. The advancing angle is the contact angle of water while increasing the volume of a drop that is pinned to a surface by a syringe. Decreasing the volume of the very same drop of water results in the retreating angle. The difference between advancing and retreating angle is called hysteresis.

  The second parameter, the hystereses, must be below 10°.

- The third geometrical characterization is the roll-off angle. A water droplet of 60 µl volume is placed on a horizontal surface. Tilting the surface and measuring of the angle when the drop begins to move gives the roll-off angle.

  The third parameter, the roll off angle, must be below 10°.

- The proof of self-cleaning behavior is performed in a so called "soil test". The surface in question will be soiled under standardized conditions with Printex 60® (Carbon black). Later on water mist precipitates the surface mounted in an angle of 45°. Immediately the carbon black starts to be washed off the surface. Typically, this procedure is repeated for 60 times. Afterwards the ΔL value is measured (CIE-L*a*b*) and it is defined as the difference of the L-values before soiling took place and after self-cleaning occurred,

  The forth parameter ΔL should not exceed 10.

Applications

Finally, some possible applications for the different types of **Lotus**-Effect® surfaces are presented.

Embossed self-cleaning surfaces are very useful on various overlaminates and protective films. **Lotus**-Effect® surfaces show pristine appearance even during nasty weather. Other fields of application are in traffic guidance and signs, window frames and solar cells.

Anchored particles can be used to manufacture self-cleaning surfaces on awnings, tarpaulins, wood, appliances or in bathrooms.

Non-permanent self-cleaning surfaces are preferably used to grand cleanness and dryness during a temporary outside storage or to protect furniture while transported on open trailers.

Of course there are much more applications.

References

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5) T. Young, Phil. Trans. R. Soc. London, 95, 65 (1805)