White Paper

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Adhesion

How to Use Contact Angle Measurements to Predict Adhesion and Bonding?

Biolin Scientific
[Progress Together]

Adhesion troubleshooting checklist

If adhesion fails in some products while others are perfectly fine, the most probable cause is the chemical variation between substrates prior adhesion process. This checklist helps you to understand how to tackle your adhesion issues and prevent them in the future.

Isolate the source

Several steps in the production process can affect the surface chemistry.

1. Has there been changes in raw material supplied?

2. How is the material stored? Can that cause variation in the material surface?

3. What type of cleaning or other pre-treatment method is used? Has there been any change in that process? Is it possible that some samples are treated differently than others?

4. How the material is stored after the pre-treatment step? Any possible variation sources in that?

Measure the static, advancing, and receding contact angle with water

After identifying the possible sources for variation, measure the static, advancing, and receding contact angle on substrates at different process points. Static contact angle might not always be enough to detect the differences which is why we recommend measuring the advancing and receding contact angles from the start.

Check for variations in contact angle data

At this point, it is still difficult to know what the absolute contact angle value should be, but at least the values should be consistent from substrate to substrate. For example, if there is a large variation in CA data of your raw material it means that there is chemical variation in the raw material itself. If you detect variation after the cleaning step, there is a good chance that the cleaning process is not enough to reliably remove the contamination from the surface.

+ Surface free energy

Surface free energy calculations can be meaningful especially if the surface treatment is expected to change only either the polar or dispersive part of the SFE. To get the full picture of your surface chemistry, the surface free energies should be calculated. For example, plasma treatments on polymers typically only increase the polar component of the SFE. Note here though that surface roughness can affect your surface free energy values.

Modify the process to reach as low contact angle variation as possible

Modify the identified process to reach as low variation in contact angles as possible. Do you need to talk to your raw material supplier to reduce variation in raw material? Or should you implement an additional cleaning process to get more homogenous substrate chemistry? Try to identify and remove the possible sources; for example, is there a too long storage time, or is there variation in the storage conditions?

Correlate the contact angle data with your adhesion success

This step is not necessarily straightforward but if possible try to correlate your contact angle data with adhesion. For example, can you make a test batch that you utilize for adhesion tests? This might require longer monitoring of the process but will give you more assurance that you are looking at the right figures.

Set up a QC procedure to prevent issues in the future

For the successful adhesion process, you must make sure that the materials and processes you are using are consistent also in the future. As you now know the contact angle values required at each step of the process, set up a QC protocol to make sure you reach those values also in the future.

Adhesion

How to Use Contact Angle Measurements to Predict Adhesion and Bonding

Adhesion is important in all applications where two different materials are bonded together. This includes the application of coating such as paint or varnish, bonding with the help of adhesive, and printing.

Wettability is required for good adhesion, and because of this contact angle, and surface free energy measurements are often used to evaluate the surface before the bonding process.

This white paper is started with a short definition of the concepts of contact angle, surface tension, and surface free energy (SFE). If these concepts are already familiar to you, you can start reading from the section "Adhesion mechanisms".

Definition of the concepts used

Contact angle

A contact angle is measured when a drop of liquid is placed on the solid surface. The contact angle is determined by the balance of forces that affect the three-phase contact point where air, liquid, and solid meet. Experimentally, the contact angle measurement is straightforward. The image of a droplet is taken, and the software provided with the instrument can automatically determine the contact angle. Contact angle measurement of a water drop is shown in Figure 1.

Contact angles are typically divided into static and dynamic contact angles. The static contact angle is measured when the droplet sits stationary on the sample.

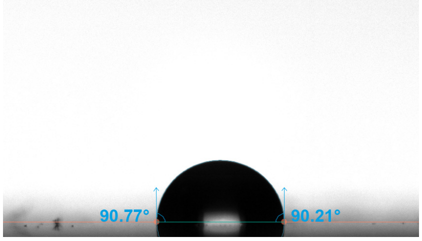


Figure 1
Static water droplet on solid surface.

Dynamic contact angles are measured when the contact line is moving. The simplest way to understand this is when the size of the droplet is gradually increased, and the liquid front advances, the advancing angle is measured. When the liquid is drawn off the surface and the contact line is receding the receding angle is measured. The difference between the advancing and the receding angle is called contact angle hysteresis. In addition to static and dynamic contact angles, so-called roughness corrected contact angles can be measured. These are discussed also later in the white paper.

More information about contact angle measurements can be found in our previously published white paper [1].

Surface tension

Surface tension is the property of the liquid. Surface tension can be easily measured optically. The drop of liquid is dispensed at the needle tip, and the software will automatically fit a curve around the drop and calculate the surface tension value. An image of a pendant drop is shown in Figure 2. To read more about surface tension measurement, see our previously published white paper [2].

Figure 2
Pendant drop for surface tension measurement.

Surface free energy

Surface free energy is the property of the solid sometimes also called a surface tension of the solid. Surface free energy cannot be measured directly but instead, it is determined through contact angle measurements with pure liquids with known surface tension values. Modeling of the interfacial tension between solid and liquid needs to be done to calculated surface free energy. Surface free energy is typically divided into different components; polar and dispersive. To read more about surface free energy, see our previously published white paper [3].

Adhesion mechanisms

Adhesion is the attraction between two dissimilar phases. There is no single theory to explain adhesion, but it is commonly divided into physical bonding, mechanical interlocking, and chemical bonding. Different adhesion mechanisms are presented in Figure 3. Most typically adhesion occurs because of the combination of different mechanisms explained below.

Physical bonding

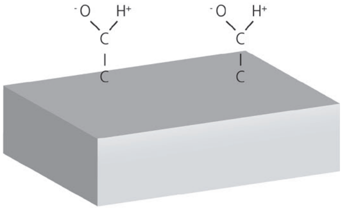
Adsorption occurs from molecular contact between two materials and the surface forces that develop. The forces present are typically short distance van der Waals forces. As the effective distance is short, the physical contact between the two materials should not be more than five angstroms. This means that the coating should make intimate contact with the material being coated.

Mechanical interlocking

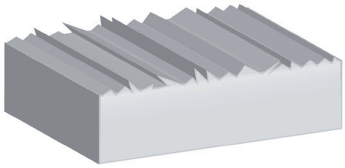
Mechanical interlocking happens when two dissimilar phases attach by mechanical forces only. This typically requires a somewhat rough surface where the other material can penetrate. For example, a low viscosity adhesive that flows into pores and cracks in the surface of a material. This results in mechanical anchoring between two components when the adhesive has hardened. With this knowledge, you can assume that rough surfaces would be easy to fix together with glue. However, a too rough surface can lead to stress peaks and insufficient filling of the surface structures. How well the adhesive fills the cavities on the surface, depends on the shape of the cavities, the viscosity and the surface tension of the adhesive as well as the surface energy of the surface. Additionally, the roughness will increase the bonding area which is an advantage especially when the bonding happens through van der Waals forces which are relatively weak.

Chemical bonding

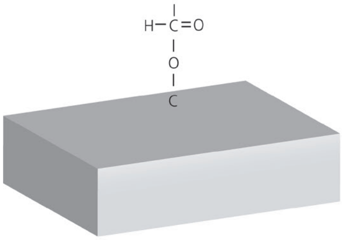
Chemical bonding includes covalent, ionic, and metallic bonding which are much stronger than physical bonds. Chemical bonds are responsible for cohesive forces inside the material itself which can be very strong. However, chemical bonding between two dissimilar materials is much more complicated, and there are typically only a few available bonding sites. One of the most used methods to increase the number of binding sites is plasma treatment.



Physical bonding



Mechanical interlocking



Chemical bonding

Figure 3

Adhesion mechanisms

Adhesion failure mechanisms

To understand why bonding fails, we need to first define the ways the failure can occur. These can be divided into three categories (see Figure 4):

- Adhesive failure
- Cohesive failure
- Substrate failure

Adhesive failure, or delamination, is one of the most common types of failure mechanisms. There the two dissimilar materials detach from each other. The failure can happen between a paint and a substrate, or between the adhesive and either of the two substrates, it is bonding together. Cohesive failure happens in the adhesive itself or inside the layer of a coating. Substrate failure is not related to the bonding process itself as it is a problem in the substrate.

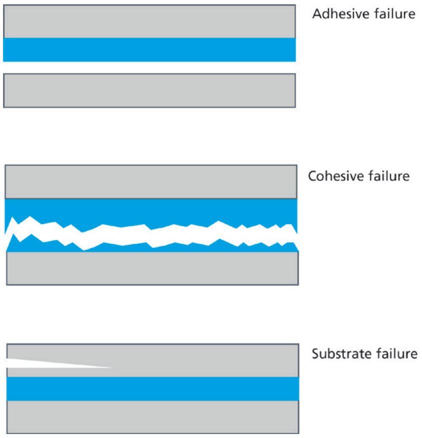


Figure 4

Adhesion failure mechanisms

Requirements for adhesion

Wettability is a prerequisite to good adhesion [4]. The criteria for good wettability is that the surface tension of the coating formulation or adhesive used is lower than the surface free energy (SFE) of the surface. Surface free energy values for common materials are shown in Table 1. Materials such as glass and

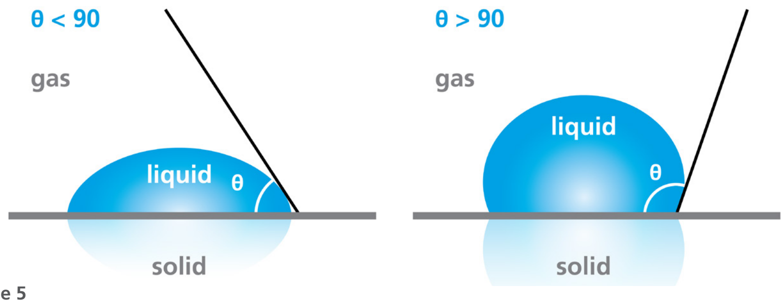


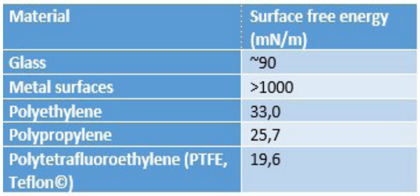
Figure 5

Water contact angle indicating surface hydrophilicity (left) and hydrophobicity (right)

metals have a naturally high surface free energy value and almost any liquid, in theory, will wet these surfaces. However, due to high surface free energy, these surfaces are prone to contamination when in contact with air. In practice, such high surface free energy values are not typically measured as the adsorbed contamination will greatly diminish the wettability of the surface. Polymers, on the other hand, have a very low surface free energy value and different types of surface treatments are needed to increase their wettability.

Table 1

List of surface free energy values for different materials



Material	Surface free energy (mN/m)
Glass	~90
Metal surfaces	>1000
Polyethylene	33,0
Polypropylene	25,7
Polytetrafluoroethylene (PTFE, Teflon©)	19,6

Another requirement, closely related to wettability, is a clean surface. Adhesion to inherently high SFE materials can be poor if there is any kind of contamination on the surface. Contamination can be grease or oil, including one from our fingers. This type of contamination will decrease the surface free energy of the glass and metal surfaces and reduce wettability. Any kind of dust or dirt will also weaken the bonding as the coating will adhere to the particle rather than the surface itself. On metals, the surface treatment might also be needed due to weakly bound naturally grown oxides. Cleaning is thus one of the most important steps before coating.

Contact angle measurement with water to estimate the surface free energy

A contact angle is a measure of wettability. When the contact angle with water is below 90 degrees, the surface is said to be hydrophilic. When the contact angle is above 90 degrees the surface is hydrophobic as shown in Figure 5. Hydrophilicity and -phobicity are important properties in many applications. For example, hydrophilic coatings are often used to improve the biocompatibility of catheters, whereas hydrophobic properties are important for water repellent materials. In adhesion studies, the hydrophilic properties are typically favored as it indicates good spreading of the coating formulation on the surface to be coated.

Water contact angle measurements offer several benefits

- Direct measurement
- Fast
- Gives estimation of the surface free energy value of the substrate
- Non-toxic
- No contamination issues

Water contact angle (WCA) is easy to perform as it only requires the placement of one water drop on the sample surface. The measurement is fast and direct since the contact angle is determined directly from the image. In addition to the contact angle value, the water contact angle measurement can estimate the surface free energy value. The total surface tension of water is 72,8 mN/m and it can be divided into polar and dispersive components which are 51 mN/m and 21,8 mN/m, respectively. Due to relatively high values for both components, water will interact with both polar and dispersive parts of the surface.

For this reason, the water contact angle measurement alone can predict the surface free energy value of the surface. If the water contact angle is high, the surface free energy is low and vice versa.

In addition, water is non-toxic, and it doesn't contaminate the surface which is especially important when contact angle measurements are used in quality control.

Example 1: The surface treatment by plasma will decrease the water contact angle

Plasma treatment is often used prior to the bonding or coating process. It will clean any organic contaminants, modify the surface topography, modify the crystalline structure of the surface layer, and deposit functional chemical groups. Several studies have investigated the effect of different types of plasma treatments on polymer surfaces. The water contact angle is shown to decrease which is related to the introduction of polar functional groups such as -hydroxyl groups [5]. In general, the surface pretreatment methods such as ozone, plasma, or corona are increasing the polar part of the surface free energy while dispersive is relatively unchanged [6].

The main purpose of the surface treatment prior to bonding, whether it is

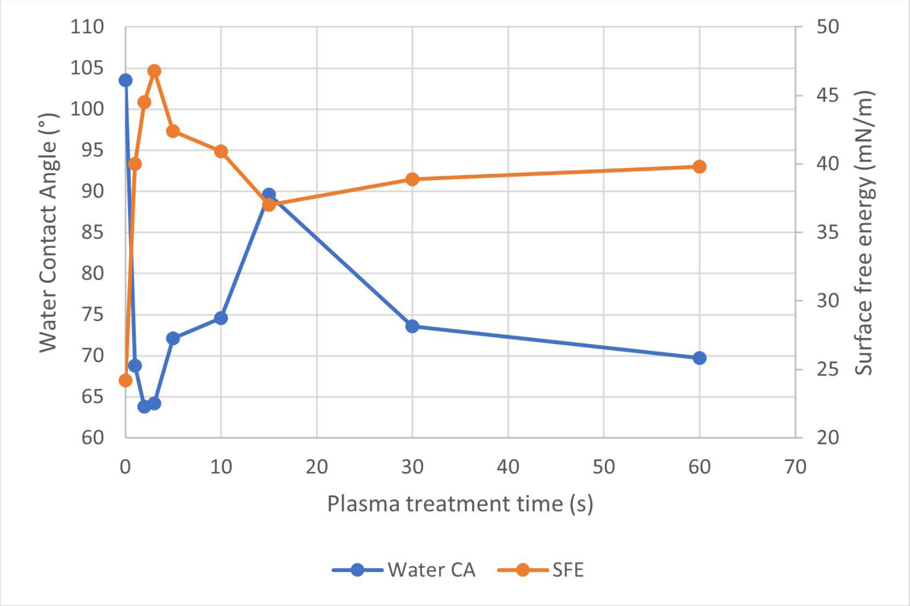


Figure 6

Water contact angle and surface free energy as a function of plasma treatment time. Modified from [7].

Low water contact angle indicates high surface free energy.

cleaning or plasma treatment step, is to increase the surface free energy of the surface. As surface free energy increases the wettability of the surface increases and the water contact angle decreases. From Figure 6 it can be seen that the water contact angle is at the lowest when surface free energy reaches the highest level. The water contact angle can thus be used to find the optimum surface treatment parameters, such as time, power, and plasma type. WCA can also be used to check if the surface treatment has been successful and the surface is ready for the bonding step.

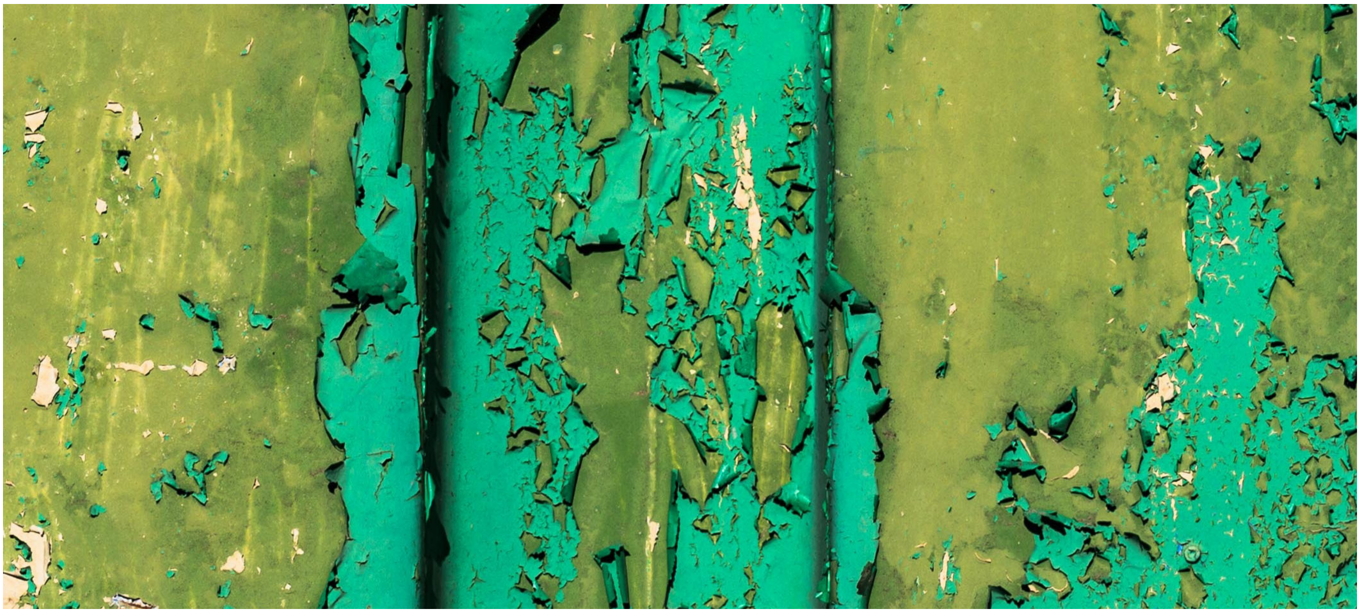
Example 2: Hydrophobic surface pre-treatment by coating

Although not as common, in some applications, the pre-treatment can also be hydrophobic. One such example is the hexamethyldisilazane (HMDS) priming commonly used in the semiconductor industry. In the photolithography process, a photoresist is applied on top of a silicon wafer. The water contact angle on a silicon wafer is typically quite low due to adsorbed and surface layer of water from ambient humidity. If the water layer is not removed prior to the photoresist application, there is a risk of complete delamination of the photoresist during subsequent development or chemical etching processes. For this reason, a hydrophobic HMDS coating is often applied to render the surface more hydrophobic and thus less prone to water absorption. Water contact angle measurements can be used to find the optimum HMDS treatment protocol as well as to check that the treatment has been successful [8].

Advancing and receding contact angles for full wettability characterization

There has been a long debate on the validity of the static contact angle [9]. In empirical studies, it has been shown that instead of having one stable contact angle, most surfaces exhibit a wide range of contact angle values. The maximum contact angle for the surface is termed advancing contact angle and the minimum receding contact angle. The difference between the two is called contact angle hysteresis.

It is widely accepted that practically all real surfaces exhibit contact angle hysteresis. Contact angle hysteresis arises from chemical and topological non-idealities. In theory,



there is no contact angle hysteresis on an ideal surface. An ideal surface is chemically homogenous, rigid, flat on an atomic scale, and does not interact with the liquid used for contact angle measurements in any way. In practice, it has been shown that the roughness of the nanometer scale can contribute to contact angle hysteresis [10]. Also, chemical heterogeneity as small as 6-12 nm still causes contact angle hysteresis [11]. With these in mind, it is safe to say that an ideal surface hardly exists, and the contact angle hysteresis caused by surface roughness and chemical heterogeneity is always present. This also means that there is no equilibrium contact angle, and thus the static contact angle values are somewhat meaningless [12]. Instead, one should always measure the advancing (highest possible contact angle) and the receding contact angle (the lowest possible contact angle) to get the true picture of the surface wettability.

The advancing angle is measured when the liquid wets the previously dry surface. This is typically done with the so-called needle method, where water is gradually applied on the surface. When the contact line starts to move, the advancing contact angle can be measured. The advancing angle is thought to be more sensitive to hydrophobic components of the solid surface [13]. Advancing contact angles are then utilized when the surface cleanliness of the hydrophilic surface is being evaluated as most of the contaminants are organic and thus hydrophobic [14]. The measured advancing contact angle is expected to correlate well with the tendency of the surface to either attract or repel the probing liquid [15].

The receding angle describes the de-wetting state as the contact angle is measured when the liquid is withdrawn. The receding angle is thought to be more sensitive to the hydrophilic components of the solid surface [13]. The measured receding contact angle has been shown to correlate well with the adhesion force between the solid and the liquid [15].

Additionally, it is possible to measure a so-called roll-off angle. The roll-off angle is measured by tilting the sample with the drop of liquid (typically water) on top. The roll-off angle is measured as the droplet starts to move. At the same time, it is possible to determine the advancing contact angle at the front edge of the drop and the receding contact angle at the back edge of the drop. Contact angle hysteresis can also be calculated.

The roll-off angle is especially used to evaluate the hydrophobic and superhydrophobic coatings when water droplets

Receding contact angle has been shown to correlate well with the adhesion force between the solid and the liquid.

should not stick on the surface (such as self-cleaning surfaces).

Advancing and receding contact angles are mostly measured with water, but some authors propose to do the measurement also with completely dispersive liquid, for example, hexadecane or di-iodomethane [9]. The measurement of advancing and receding contact angle with water and either of the completely dispersive liquids will give all the information needed to evaluate the surface wettability. Advancing and receding contact angle values, when measurements are properly done, are also completely non-controversial compared to surface free energy calculations discussed later in this white paper.

Contact angle measurements with coating formulation or adhesive

As the adhesion is dependent on how the coating formulation wets the surface, a straightforward method is to measure the contact angle between the coating formulation itself and the surface it should be applied to.

Contact angle measurement between coating formulation or adhesive and the substrate can be used to determine the best surface treatment method or the optimum coating formulation for the particular surface. Low contact angle values, lead to better wettability and thus better adhesion.

The water contact angle is probably still the best option if the coating formulation is water-based [16]. Lower water contact angle values will indicate also better wettability with the coating formulation.

There are cases where the measurement with the coating formulation makes more sense than contact angle measurements with water. For example, if the surface you are applying the coating to is hydrophobic (water contact angle above 90 degrees), and your coating formulation is dispersive such as oil-based coating. In this case, the contact angle measurements with water might not be enough as the wettability will be relatively poor with such a polar liquid. Measurement with dispersive liquid, however, can reveal differences between different coating formulations, or primers used.

When coating formulations are directly used, it is typically advantageous to use disposable tip dispensers that allow an easy and contamination-free change from one test liquid to another. As the tips used are disposable, there is no need to do laborious cleaning in between the different samples tested. Also, as the disposable tips are used with automated dispensers, the measurements can still be automated and no user interaction is required during the measurement.

Work of adhesion between the coating and the substrate

Work of adhesion (WoA) is a concept presented in a nineteenth-century physical chemistry text that discussed the wetting of solid by liquids. Due to its clear connection to wetting of solid by adhesive, it has been part of many discussions of adhesion.

Thermodynamic work of adhesion is defined as work required to separate two phases from each other as shown in Figure 7.

If the two phases are solid and liquid, the work of adhesion can be easily calculated by measuring the surface tension of the coating formulation and the contact angle between the substrate and formulation. As both of these are easy to measure by using an optical tensiometer.

It is also possible to calculate the work of adhesion through dispersive and polar components. There the surface free energy theories are utilized to model the interfacial tension between the two phases. For example, with the OWRK method, the work of adhesion can then be written as

$$W_A = 2\left(\sqrt{\gamma_1^d \gamma_2^d} + \sqrt{\gamma_1^p \gamma_2^p}\right)$$

For 2 different surfaces, the work of adhesion:
Surface 1 and surface 2 are created as the interface 12 is destroyed.

$$\mathbf{W_A = \gamma_1 + \gamma_2 - \gamma_{12}}$$

If the one is liquid and one solid, the equation can be written as

$$\mathbf{W_{sl} = \gamma_s + \gamma_l - \gamma_{sl}}$$

If combined with Young equation

$$\mathbf{\gamma_{sl} = \gamma_s + \gamma_l \cos \Theta}$$

We get Young - Duprée equation

$$\mathbf{W_{sl} = \gamma_l (\cos \Theta + 1)}$$

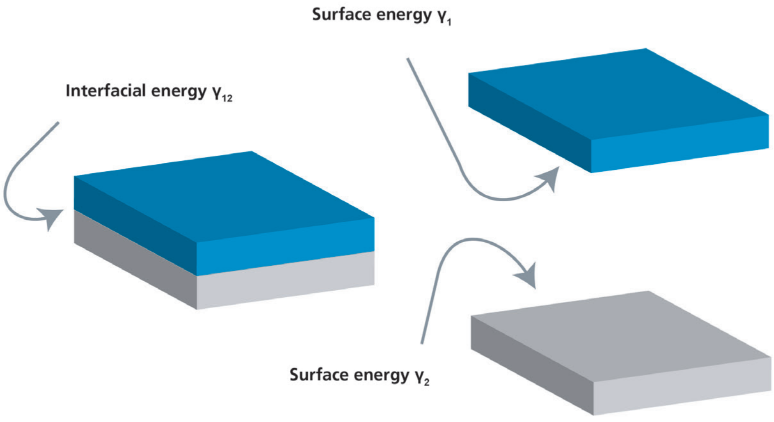


Figure 7
Thermodynamic work of adhesion explained.

The work of adhesion is based on thermodynamics which deals with ideal systems. There has been a lot of discussion what is the relationship between this so-called fundamental adhesion and practical adhesion. Practical adhesion is concerned with the magnitude of mechanical force which has to be applied to break an adhesive bond. Practical adhesion thus is extremely important and can be measured with different laboratory measurements. However, practical adhesion can only be evaluated after the bond has been formed, whereas work of adhesion tries to do the same proactively before the bonding is done. Although fundamental adhesion is a prerequisite for the existence of practical adhesion, some authors have claimed that there is no relation between the two in practice [17].

There are, however, examples where the calculated work of adhesion is shown to correlate with measured lap shear strength on aluminum-epoxy coating systems [18]. The use of work of adhesion has also been recommended to determine the proper surface treatment for titanium-epoxy systems [19].

Surface free energy (SFE) calculations

The requirement for wettability is that the surface free energy (SFE) of the solid is higher than that of the coating formulation. For this reason, SFE is often measured and compared to the surface tension of the solid. Compared to the water contact angle measurements which can indicate whether the surface free energy is high or low, the SFE measurement will give a numerical value for surface free energy. The calculated surface free energy value can be compared to the surface tension value of the coating formulation. If the ST of the coating formulation is lower than the SFE of the surface, the liquid will spread on the surface which indicates good adhesion. As a general rule, acceptable bonding adhesion is achieved when the surface free energy of the substrate is 10 mN/m greater than the surface tension of the liquid [20].

Another benefit of the surface free energy measurement is that in addition to measuring the total surface free energy values of your solid, you can also analyze the surface in terms of polar and dispersive interactions. Most of the surface free energy theories will give both the polar and dispersive components for your surface which can then be compared to those of your coating formulation.

The main difficulty with surface free energy is that it cannot be directly measured. Surface free energy is calculated through static contact angle measurements. For this, the contact angles with pure liquids need to be measured on the solid surface. Water is typically used as a polar liquid and diiodomethane as the dispersive one. The measured contact angle values together with the known polar and dispersive components of the probe liquids are then used to model the interfacial tension between the solid and the liquid. When the interfacial tension value is known, the surface free energy can be directly calculated from Young's equation.

One should then note that although the surface free energy concept is valid, its calculation is always an estimation. Most often the static contact angles are also used for measurements which are somewhat controversial as discussed previously. Some authors propose that if the surface free energy calculations are done, advancing and receding angles should be used [9]. Roughness corrected contact angles offer another option for the surface free energy calculations as discussed next.

Roughness corrected contact angles

One aspect of adhesion yet to be discussed, is surface roughness. Surface roughness is typically beneficial for adhesion if the coating formulation or adhesive can penetrate the surface roughness features. There are a few reasons for this.

First, the surface roughness increases the surface area which increases the available binding sites for the coating formulation. Also, in the case of pores (again if the liquid is able to penetrate to them), they can make the adhesion strength depend also on the cohesive force in the coating as adhesion failure would then require a

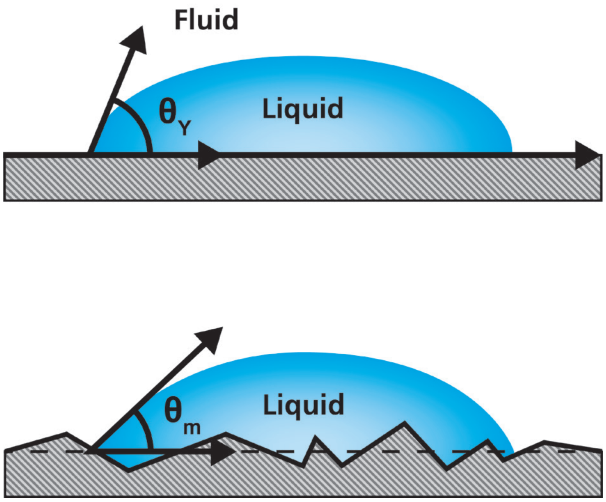


Figure 8

Contact angle on smooth and rough surface breakage on the coating layer itself.

Furthermore, the surface roughness will increase wettability if the underlining surface chemistry supports the wetting. This means that if the contact angle on an ideally smooth surface would be less than 90 degrees, adding roughness to the surface will further enhance wettability. This was formulated by Wenzel already in 1936 [21] by equation

$\cos\Theta_m = r\cos\Theta_Y$

, where Θ_m is the measured contact angle, r is the roughness ratio and Θ_Y is the Young contact angle (in reality one should call this a roughness corrected contact angle rather than Young contact angle). The concept is shown in Figure 8.

The roughness ratio is defined as the ratio between the actual and projected solid surface area (r = 1 for a smooth surface and > 1 for a rough surface). It is important to note that the Wenzel equation is based on the assumption that the liquid completely penetrates the surface structures. To read more about roughness corrected contact angle, please refer to [22].

All the real surfaces are rough at some level. For this reason, it can be useful to evaluate also the surface roughness to understand when the contact angle variation is caused by roughness and when by surface chemistry. Also, the surface free energy calculations typically need the static contact angle values to be measured. As already discussed earlier in this white paper, the static contact angle values are controversial as they do not represent any stable contact angle values. Roughness corrected contact angle is a step closer to the so-called most stable contact angle value and is thus better suited for surface free energy calculations than static contact angle.

The roughness corrected contact angles can be measured with integrated surface roughness and contact angle measurement instrument. The surface roughness is first measured after which the sample is brought under the dispenser where the contact angle is measured on the same spot.

Summary

The science of adhesion is a complex one and the attempts to predict the adhesion strength are numerous. However, the main requirement remains; the wettability of the surface should be high. This means that the contact angle between the solid and the liquid; whether adhesive, ink, or a coating formulation, needs to be as low as possible, and preferably 0 °. This ensures the intimate contact between the liquid and solid but also improves the possibility of mechanical interlocking as the adhesive can flow into the pores of the solid. The minimum contact angle will lead to

- Maximum area and intimate contact between the liquid and solid
- Maximum thermodynamic work of adhesion

In Table 2, the list of the wettability measurements commonly used to predict adhesion is presented. The table summarizes the measurement method and utilization of all the different measurement types. Although there are several possible methods to predict adhesion, this is not an issue from the instrumentation point of view. All the above-mentioned measurements are easy to conduct with an optical tensiometer. Even the roughness corrected contact angle can be obtained with the additional 3D topography module. In addition to contact angles, the optical tensiometer can also be used to measure the surface tension of the coating formulation.

Table 2: Summary of the wettability measurement methods used to predict adhesion

	DIRECT MEASUREMENT AVAILABLE	MEASUREMENT METHOD	WHEN TO UTILIZE?	HOW TO UTILIZE?
Water contact angle (WCA)	YES	Sessile drop	Quality control, when evaluating water-based coating adhesion	Determine the optimum surface treatment parameters, check the success of surface treatment
Advancing and receding contact angle	YES	Needle method	Always recommended for reliable and repeatable surface evaluation.	Measure advancing and receding contact angle values with water and if needed dispersive liquid such as di-iodomethane.
Roll-off angle, advancing and receding angle	YES	Tilting method	For the determination of roll-off angle. Mainly for hydrophobic coatings when water sticking is unwanted.	Check the homogeneity of the coating / surface treatment. Low roll-off angles indicate lower adhesion with the liquid.
Contact angle with adhesive, coating formulation, or ink	YES	Sessile drop	When only few coating formulations that need to be tested.	Test different formulations' ability to wet the surface.
Work of adhesion (WoA)	NO	Sessile drop, pendant drop	Comparison of the effect of both the surface treatment and coating formulation modification.	Determine the highest W_A for coating formulation - solid combination.
Surface free energy (SFE)	NO	Sessile drop and modelling	When the SFE of the surface is changed by changing both polar and dispersive components, when the ST of several formulations are known and the best formulation is looked for.	Make sure the SFE of the solid is higher than ST of the formulation. Determine the different surface free energy components.
Roughness corrected contact angle	NO	Integrated contact angle and roughness measurements	When there is clear surface roughness, when pre-tretment can introduce surface roughness.	Separate the effect of roughness from the contact angle data. Get roughness corrected contact angles that are better suited for surface free energy calculations.

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