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Wetting Envelope as a Tool for Maximizing Bond Strength

Choosing the right adhesive is critical to the quality and durability of an assembly. This is particularly true when using non-porous plastic substrates that do not provide the opportunity for strictly mechanical fastening. Adhesion of these materials takes place at the few rows of atoms closest to the bonding surfaces and is attributable to some combination of hydrogen bonding, covalent bonding and Van der Waals forces.

Wetting, or wet out, is a critical factor in determining the effectiveness of a bond. It describes how well a liquid, in this case, the adhesive, spreads across the surface of the substrate. It is determined by the interaction of molecules where the adhesive meets the outer layer of the substrate. Better wetting means better interactions and is largely determined by the relative surface energy of the substrate and surface tension of the adhesive. While many factors can impact the effectiveness of a particular adhesive with a particular substrate, surface energy, and surface tension are critical, and representing their relative values with tools like wetting envelope will simplify the choice of adhesive.

The surface energy of a substrate has two components. One is the polar force, which can be modified by surface treatment of the material. The other is the dispersive force, which is inherent to a material and cannot be significantly modified. Wetting envelope graphs both of these forces and provides a line of demarcation between those adhesives that should work with a given substrate and those that shouldn't. While actual calculation and graphing of the wetting envelope may be too complicated for a typical adhesive user, it is a tool that an adhesive supplier should have access to. Users should expect this kind of help from their adhesive supplier early in the process of choosing an adhesive.

H.B. Fuller has a long history of leadership in adhesive and material science. We are committed to exploring and developing tools and technologies to understand adhesive applications. Ideally, customers engage with H.B. Fuller experts in the early phases of material selection and manufacturing process engineering for assistance in choosing their adhesive and application methods.

For maximum wet-out, an adhesive's surface tension should be equal to or lower than the surface energy of the substrate in question. Simply put, if the surface energy of the adhesive is greater than that of the substrate, the material will be drawn to itself rather than to the substrate; if the substrate has higher surface energy, the adhesive will be drawn to it, resulting in better wetting. The challenge for users is determining the energy values of the substrates and choosing the right adhesive, and in some cases, surface treatment of the substrate. Wetting envelope is a useful tool in making that determination.

Why It Matters

Choosing adhesives and surface treatments has become particularly challenging in the automotive industry in recent years. The reason automakers and suppliers are using lighter-weight plastics, like polyolefins, is to reduce vehicle weight and material cost. In most cases, these have a lower surface energy than materials that were used in the past. For satisfactory wetting, these non-polar materials require lower-polarity adhesives. Urethane-based adhesives, for example, have long been the basis for many industrial adhesives. They are tough and reliable, but while their high polarity makes them ideal for use on polar substrates, they don't work well on newer, lower-polarity materials.

Simply stated, a liquid that beads on a low-energy substrate will wet out more effectively on a higher-energy substrate. Poor wet out results in beading on the surface resulting in a poor bond. The same liquid on a higher energy surface will spread, forming a smaller contact angle, resulting in better wetting and a better bond. These effects are depicted in Figure 1. The challenge is to determine the relative energies of the substrate and adhesive.

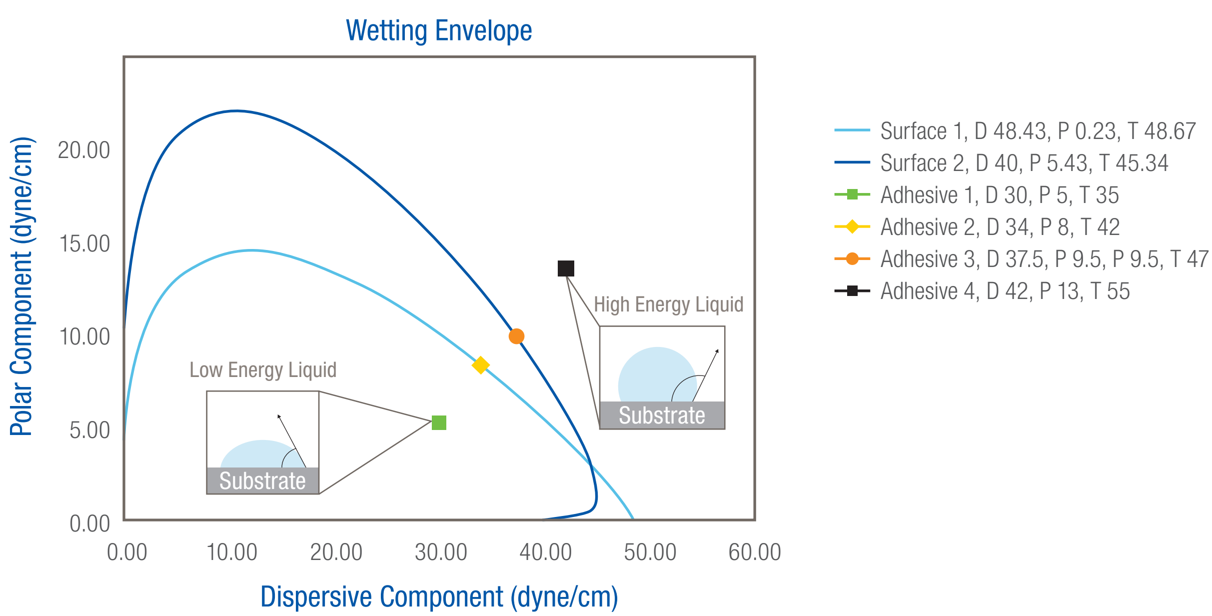
Figure 1: Poor wet out of a non-polar (l) substrate versus better wet out of a polar (r) substrate.

Water on silicone   Water on glass

Wetting envelope is a two-dimensional map that represents the surface energy of a substrate made up of the material's polar and dispersive forces. Its curve passes through the points where the contact angle of a test material with the substrate will be 90 degrees. Inside the curve, the contact angle will be less than 90 degrees, which is characteristic of good wetting. Outside the curve, the angle will be greater than 90 degrees, causing the liquid to resist wetting and bead on the surface.

The wetting envelope curve is graphed against two components, polar and dispersive. Points representing the energy of one or more adhesives can be placed on the graph, and their placement in relation to the curve indicates their suitability for use with that substrate.

Figure 2: Graph of the wetting envelope of two substrates and four different adhesives



The surface tension of a particular adhesive and its placement on the graph is determined by measuring the contact angle of the adhesive on two substrates of known surface energy, for example, glass and polyvinyl chloride. This is shown above in Figure 2. Then the determined value is overlaid on the wetting envelope graph to represent the relative surface energies of the substrate and adhesive. If the adhesive falls inside the envelope, it will wet-out. If it falls outside the envelope, it won't. The shape of the wetting envelope curve is determined by measuring the contact angles between two liquids of known surface tension and the solid surface in question. The liquids, typically water and diiodomethane, are placed onto the substrate surface, and the angles formed where the liquid meets the solid are measured using specialized equipment. The use of the two different liquids allows the two components of surface energy, polar and dispersive, to be determined. A set of formulas comprising the Owen-Wendt method are used to define wetting envelope for that material. The curve represents points at which the Owens–Wendt model is solved for a contact angle of 90 degrees.

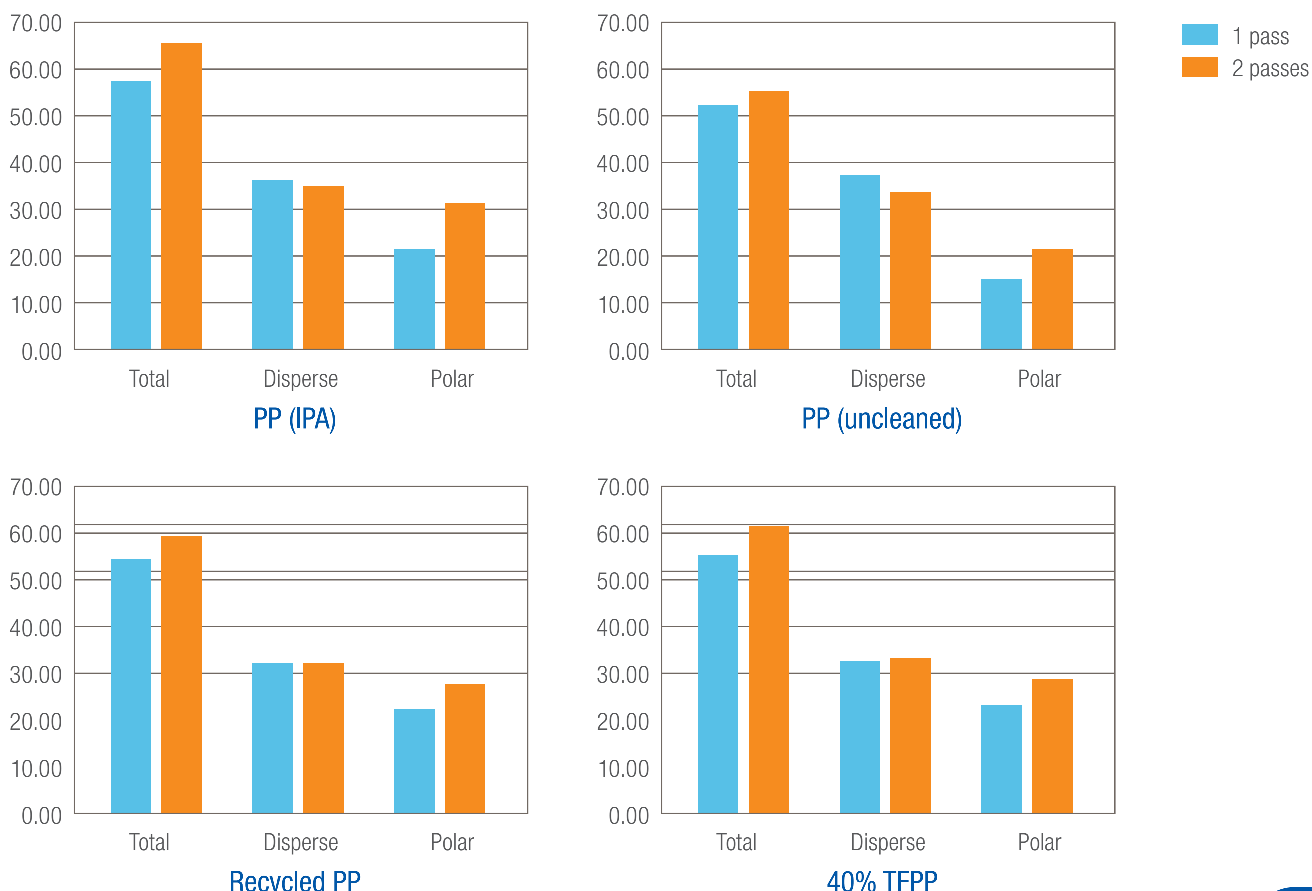
Surface Treatment

The dispersive element of a substrate's effective surface energy is inherent and cannot be significantly modified. The polar element, however, can often be modified by surface treatment. This is an option that can be used in some cases when an adhesive's polarity may appear too high for use with a particular substrate. There are several forms that treatment can take.

The Effect of Cleaning

The simplest way to modify the polar element of a substrate is to clean it. Debris—dust, oil, grease, plasticizers, or mold release chemicals—can mask a substrate material's inherent polarity. Removing all debris will bring the material to its greatest inherent polarity. In some cases, this may be sufficient to enable the use of an adhesive of lower or equal polarity. Cleaning can be as simple as applying isopropyl alcohol or soap and water. There are cases when cleaning may lower, rather than raise, the apparent polarity of a substrate, but cleaning should be done to ensure the adhesive is not blocked from the substrate surface by unwanted residues.

Figure 3: Effect of number of plasma gun passes on surface energy



The Effect of Plasma Treatment

The surface energy of a substrate can often be significantly increased by plasma treatment, which temporarily oxidizes the material's surface. The graph in Figure 3 shows the effects of one and two passes on several types of cleaned and uncleaned material.

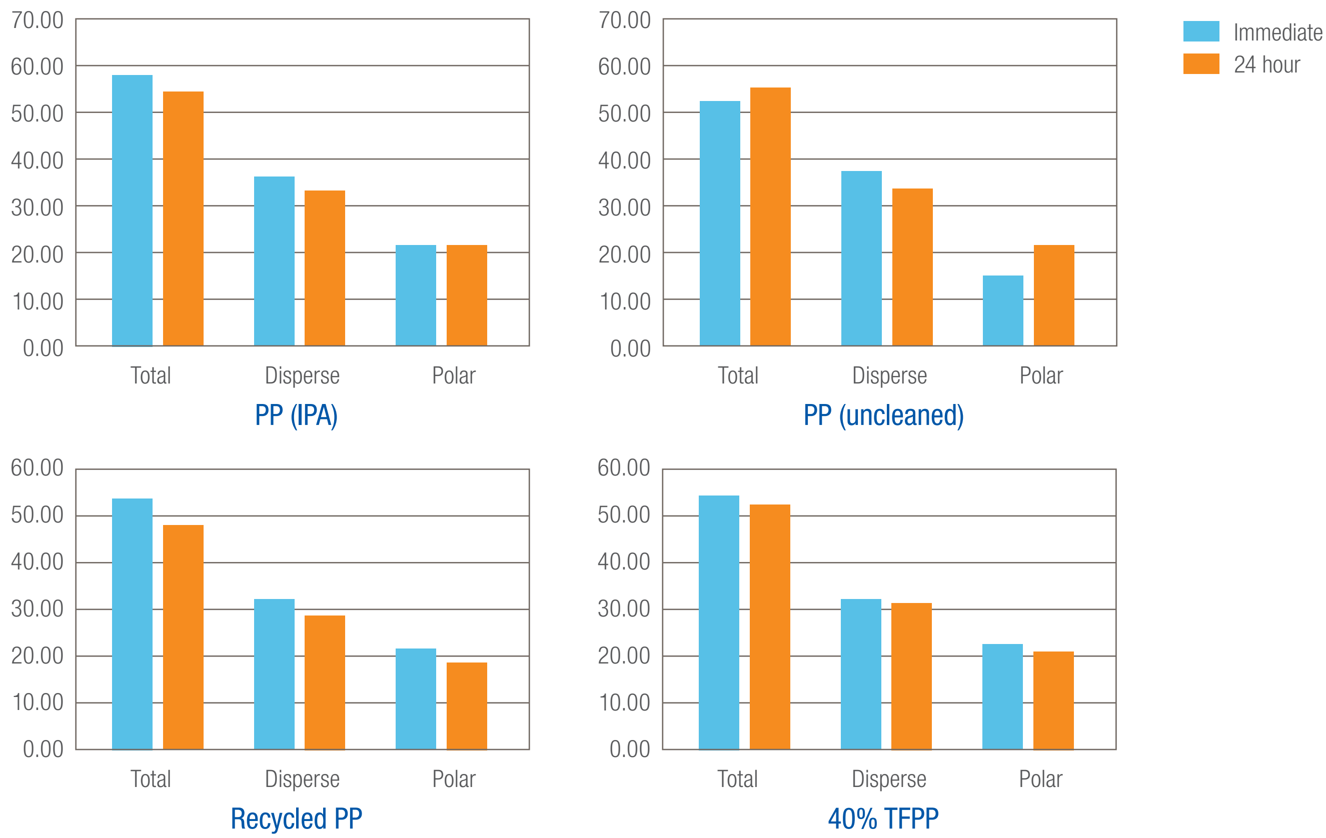
In all cases, the first treatment increases total surface energy and the second adds to the effect. Note that when the polar and dispersive elements are separated out, the overall difference in effect is due almost entirely to change in the polar aspect, while the dispersive aspect generally remains unchanged. In fact, on uncleaned polypropylene, the dispersive aspect of surface energy is actually reduced by plasma treatment. This supports the suggestion that substrates be cleaned before further surface treatment and application of adhesive.

The Effect of Delay after Plasma Treatment

As stated earlier, and shown in Figure 4, the effect of plasma treatment on surface energy is temporary and fades over time. Materials were tested immediately after and twenty-four hours after plasma treatment.

On three of the four materials tested, total surface energy after plasma treatment dropped over the twenty-four hour period. The amount of the change attributable to dispersive and polar elements varied. On the fourth material, the uncleaned polypropylene, the effect over time was the reverse of that of the other three materials.

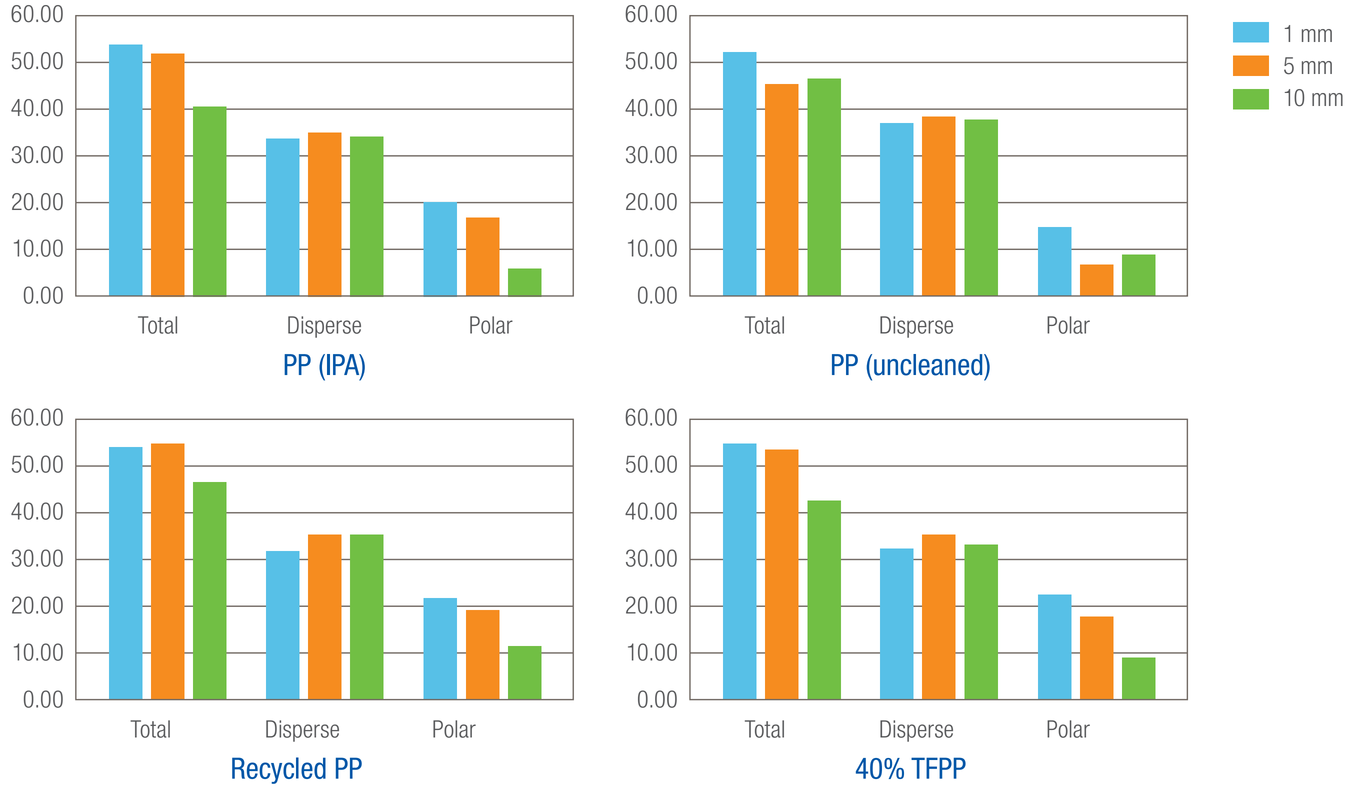
Figure 4: Effect on surface energy of elapsed time after plasma treatment



The Effect of Plasma Gun Height

Plasma gun height above the substrate surface affects the increase in surface energy as shown in Figure 5. In general, closer approach to the surface correlates with increased surface energy.

Figure 5: Effect of plasma gun height on surface energy



In tests on various substrates, surface energy generally increased as the plasma gun moved from 10 mm above the surface to 1 mm from the surface. Most of the increase in surface energy was attributable to change in the polar force while the dispersive element either changed relatively little or in some cases actually decreased as distance decreased. Also, the trend did not clearly apply to an uncleaned substrate.

The Effect of Plasma Gun Speed

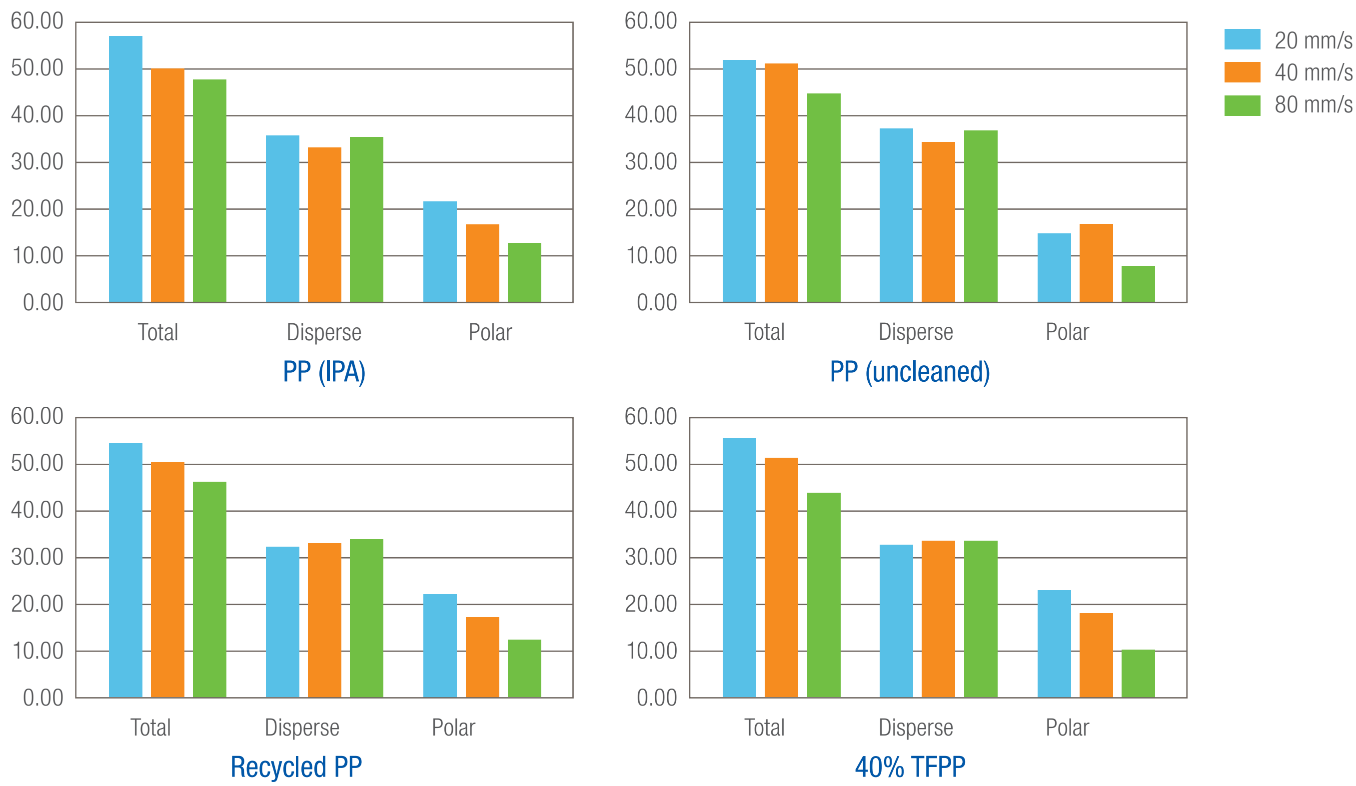
Moving the plasma gun more slowly over the surface increases the amount of plasma energy applied to each area, as seen in Figure 6. This is similar to the effect of closer plasma gun positioning, so slower speed generally correlated with a greater increase in substrate surface energy.

As in the case of gun height, the total change in surface energy was primarily attributable to change in the polar element, and the change was not as clear for the uncleaned substrate as for the cleaned materials.

Flame Treatment

Flame treatment is a viable alternative to plasma treatment as a way to increase a substrate's surface energy. However, overheating can liberate plasticizing additives in the substrate material, thereby reducing surface energy.

Figure 6: Effect of plasma gun speed on surface energy



Testing

In overlap shear tests, high and low polarity adhesives were used to bond identical substrates. As predicted by wetting envelope graphing, the bond using the high polarity adhesive failed to bond effectively to low polarity substrates. Where the low polarity adhesive was used, the substrate failed before the bond indicating very good bonding.

Summary

- Today's lower polarity plastic substrates require lower polarity adhesives.
- To wet out a particular substrate surface the adhesive must have lower surface energy than the substrate.
- Wetting envelope is a useful tool for predicting wet-out of an adhesive. The wetting envelope graph marks the boundary between wetting out (inside the curve) and nonwetting (outside of the curve).
- Surface treatments ranging from simple cleaning to plasma or flame treatment can increase the polarity of a substrate surface. Such treatment can allow the use of higher polarity adhesives that might not otherwise wet out effectively on the particular substrate surface.
- The effect of surface treatment fades over time, so the bond should be formed soon after treatment.

Choosing the right adhesive for a substrate is critical to the production of defect-free parts. A number of factors—the substrate's polar and dispersive forces, and the adhesive's surface tension—affect wet out and the suitability of an adhesive for a particular application, but wetting envelope is a useful tool for narrowing adhesive options. While development of the wetting envelope graph can be complex, a full-service adhesive provider will be able to assist in developing the tool and selecting the right material for the job.