The Bonds That Bind

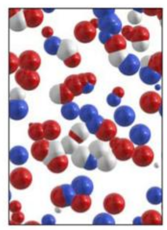
By Jason Smith

Whether it's stain being applied to a deck or a highly waxed car in a dealer's showroom, ---what you're seeing is adhesion at work. Although there is no single theory on the property known as adhesion, there are five basic mechanisms commonly used to describe it.

Chemical adhesion is what happens when two substrates form a chemical compound at their interface, either by swapping or sharing atoms (which creates a very strong bond) or through hydrogen bonding (which is a weaker interaction that applies to substrates containing oxygen, nitrogen, or fluorine atoms.) Hydrogen bonding is also sometimes referred to as dispersive adhesion, which is described below.

Mechanical adhesion is best evidenced by the grip of Velcro, and can also be seen in rough or etched substrates. Coatings that use mechanical adhesion actually penetrate into the pores or voids of a rough surface, then interlock onto the substrate. Applying a coating to a polyurethane foam roof is one example of mechanical adhesion. In addition to a chemical interaction that occurs at the coating/foam interface, the coating flows (or "wets out") into the nooks and crannies of the foam, then locks into place once the coating has dried or cured.

Electrostatic adhesion occurs when an electrostatic charge is applied over one substrate, creating an attractive force that draws in the other substrate. One example of this kind of adhesion is what happens when you forget to put a softener sheet into the clothes dryer. When you try to pull the clothes apart, a static charge is dissipated, creating a crackling or snapping noise.

	Chemical Adhesion • Ionic Bonding • Covalent Bonding
	Mechanical Adhesion • Velcro®
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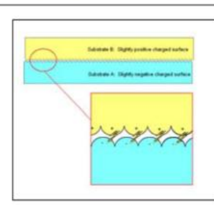	Dispersive Adhesion • Bonds between polar and non-polar substrates and coatings

Diffusive adhesion occurs when one substrate's molecules move and intermingle (diffuse) with that of the other substrates. PVC pipe bonded with solvent-based pipe adhesive is an example of a substrate that is bonded using diffusive adhesion.

Dispersive adhesion occurs between atoms or molecules of two substrates in close proximity to each other. Taken on an individual basis, the interactions are not very strong. However, when the interactions are summed as a whole, their combined bond strength can become significant. It is dispersive adhesion that enables the bonding of polar and non-polar surfaces and coatings.

Factors Influencing Adhesion

Each of these five mechanisms of adhesion is affected by common factors:

- Surface energy and substrate polarity
- Surface area covered and contact points achieved
- Surface contamination
- Surface texture
- Coating cohesive strength

Surface Energy and Substrate Polarity

The type of coating chosen will depend greatly on the surface energy of the substrate (and ultimately, whether the surface is polar or non-polar). Polar substrates carry a positive or negative charge and adhere best to other polar coatings. Non-polar substrates are charge-neutral and have to rely on other adhesion mechanisms, such as diffusive or mechanical bonds, for bonding.

For example, thermoplastic olefin (TPO) single-ply roofs are non-polar because they are made of polyethylene and polypropylene. TPOs are very hard to coat, especially with polar coatings like polyurethanes or acrylic, because these coatings have no charged surface with which to interact. As a result, the cured film can be removed easily from the surface. In order to coat a TPO, a diffusive bond must be formed with a solvent-based primer. The suitable primer then becomes a more compatible substrate onto which a topcoat is applied.

In contrast, polar substrates, such as polyurethane foams, can be coated easily with acrylic or polyurethane coatings, which are also polar. In such cases, the polar coating interacts with the polar surface to create a dispersive force which, when taken over the whole area, is very strong. In addition, other factors such as surface contamination and surface texture further strengthen the bond.

Surface Area Covered and Contact Points Achieved

The polarity of the substrate also affects its surface energy. Surface energy is what enables a coating to wet out or bead on a substrate. “Wet out,” as the phrase implies, is the ability of the coating or adhesive to spread onto the surface to which it is applied. In contrast, beading is what occurs when the adhesive or coating is not wetting out well (think of water on a waxed car). Simply put, the more the coating is able to wet out, the more surface area is covered. The more surface area covered, the more contact points achieved. The more contact points achieved, the better the adhesion to the substrate.

Surface Contamination

When a substrate is contaminated with dust, oil, or debris, coating adhesion is impaired. Areas with high concentrations of contaminates provide an alternate substrate over the intended substrate. Because the coating adheres so well to these polar contaminate particles, it has only partial or no contact with the intended substrate. An inadequate coating bond to the substrate can lead to blistering, peeling, or film delamination. This is why coating manufacturers and distributors stress a clean surface prior to coating application. The surface also must be dry, because water can act as a contaminate.

For example, a roof coating that covers a water droplet is a prime candidate for cracking and blistering. When the water droplet dries and diffuses through the coating, the void left underneath the coating will expand and contract with changing atmosphere and, depending on the strength of the coating, will crack. If this occurs on a roof, it will lead to water absorption and eventual leakage. In addition, if the water droplet is trapped between two non-porous substrates, the droplet itself could expand within its confines during a hot day and actually cause localized delamination or blistering.

Surface Texture

The texture of a substrate also can impact the adhesive bond. You will recall that the greater the surface area covered by a coating or adhesive, the better the adhesion. A substrate has more surface area when its surface is rough than when it is smooth. The simple act of etching or abrading a surface even a few microns deep, prior to coating, will increase the surface area the coating will “see.” The greater the area covered, the greater the contact points that improve adhesion. There is a catch, however. If the substrate has a low surface energy, the coating will not wet out and will not cover as much area. This reduced surface coverage means fewer contact points, especially if the surface is etched. A non-polar, low-energy substrate will not allow a coating to fill all of the voids.

An etched, polar high-energy surface will wet out a polar coating and adhere at an infinite number of contact points along its bond line, resulting in very strong adhesion.

Porous substrates, such as wood or foam, provide the additional possibility of forming a mechanical bond with a coating. A wood deck coating or stain is able to flow into the cellulose pores of the aged wood and, upon drying, form an anchored mechanical bond. In addition to being an aesthetic improvement to the deck, the coating itself becomes a barrier to further attack from moisture and the elements.

Coating Cohesive Strength

The final factor affecting adhesion is the coating’s cohesive strength.

Cohesive strength, or rather, how well the coating “sticks” to itself, comes from the Latin cohaerere, which means to "stick or stay together.” Cohesion is a chemical attraction of like molecules within the coating, which holds the molecules together.

Water is very polar, and by virtue of its wide “V” shape, has very high cohesive strength that enables it to bead without much difficulty on a surface. When the surface energy of the substrate becomes high enough to exceed that of the cohesive strength of the water droplet, the water bead can no longer hold itself together and the bead flattens.

Likewise, an acrylic coating on a low-energy surface such as polyethylene will bead because the cohesive strength of the coating is much higher than the surface energy of the polyethylene. If that same coating is applied to, say, polyurethane foam, which has a higher surface energy than the coating, the coating will not be able to bead and will wet out. In such cases, it is the thickness of the film that provides the coating its internal strength.

Jason Smith is a research and development chemist for The Garland Company, Inc. Prior to joining Garland, Smith was a senior development chemist for an international manufacturer and distributor specializing in adhesives for the industrial and consumer markets. He has an M.S. in polymer chemistry and coatings technology from DePaul University, Chicago.

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