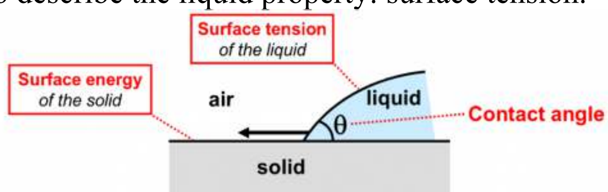
Assessing Adhesion of Prepainted Metal

The degree of adhesion of a coating to a substrate is a difficult property to understand and measure. This tool kit provides various techniques and test methods to assess adhesion of coatings to metal substrate. It is important to first discuss the complexities of adhesion and the myriad theories before discussing how to assess the adhesion of coatings used in the prepainted metal industry.

Surface Wetting

In the prepainted metal industry, metallic-coated steel or aluminum, or any other metal substrate, is considered the surface. When thinking about adhesion, the surface is the uppermost molecular layers of the metal, where oxide layers exist, as well as thin layers of oil or other contaminants. Significant effort is made to replace these few molecular layers with pretreatment chemicals, which optimize adhesion between the substrate and the organic coating that is applied to it.
By cleaning and pretreating the substrate, the surface energy is increased. Surface energy is essentially the substrate's ability to "pull down" a drop of liquid. A similar term may be used to describe the liquid property: surface tension.



Source: UL Prospector Knowledge Center, Lewarchik

A high energy surface that is capable of "pulling down" a drop of liquid and allowing it to flow over the surface is ideal. This phenomenon is called wetting, and without proper wetting, achieving acceptable adhesion is not possible. The relationship between ***surface wetting*** and adhesion is the first factor to be considered in designing a coating to optimize adhesion. If a coating in a liquid state does not spread spontaneously over the substrate surface, then there is limited opportunity to form mechanical and chemical bonds with the substrate surface.

A liquid will spread spontaneously on the surface of the substrate if the surface tension (force/unit length or dyne/cm) of the liquid is lower than the surface energy of the substrate to be coated. For example, the image below provides a visualization of various degrees of wetting properties for a drop of liquid applied onto the surface to be wet.

This Tool Kit is part of a series of educational aids developed by the members of the National Coil Coating Association. NCCA is a trade association of coil coaters and suppliers of raw materials and equipment used in the coil coating process. The association concentrates its efforts on providing educational resources and assisting its members in providing superior products and services to their customers. NCCA Tool Kits are information tools and should not be used as substitutes for instructions from individual manufacturers. Always consult with individual manufacturers for specific instructions regarding their products and equipment.

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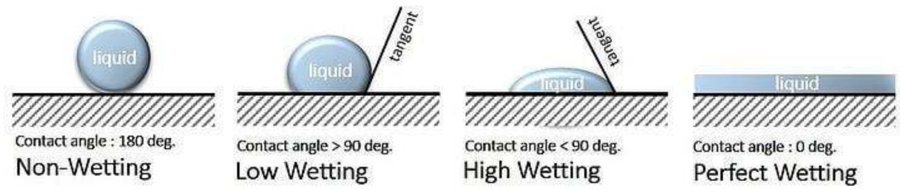
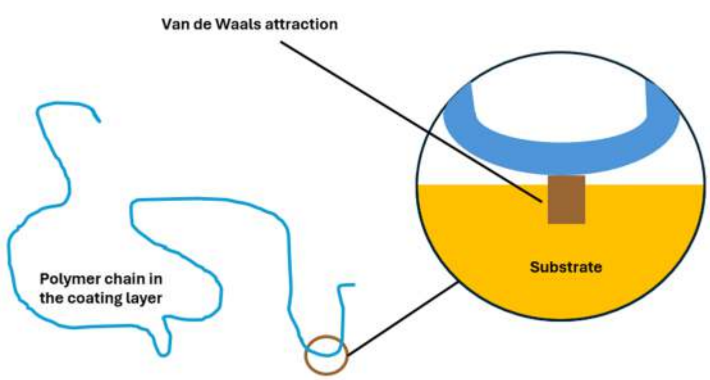


Source: UL Prospector Knowledge Center, Lewarchik

Adhesion

While surface wetting is an obvious necessity to produce acceptable adhesion, *how* two surfaces adhere to each other at a molecular level is not obvious. There are a few reigning theories that are promoted to describe why a liquid that spreads effectively over a surface adheres to that surface. They are:

- **Adsorption theory**: With this theory, two materials adhere to each other due to attractive forces, often called van der Waals forces. Although these forces are very weak, there are trillions of molecules, each with its own Van der Waals force, attracting a film to the substrate. Excellent molecular contact with the substrate surface is a necessity. Think of this concept as a magnet "adhering" to a piece of steel: There is no physical link between the magnet and the steel, just an attractive force.



- **Chemisorption theory**: In some cases, adhesion occurs when chemical bonds are formed across the interface. This is the mechanism at play when using a silicone adhesive to glue glass plates, as is done with aquaria. The silicone adhesive is reacting with the SiO-groups on the surface of the glass. Adhesion promoters used in coatings work according to chemisorption theory, where one end of the molecule of an adhesion promoter is attracted to the organic coating, but the other end prefers to react with the oxide layer of the pretreated substrate.

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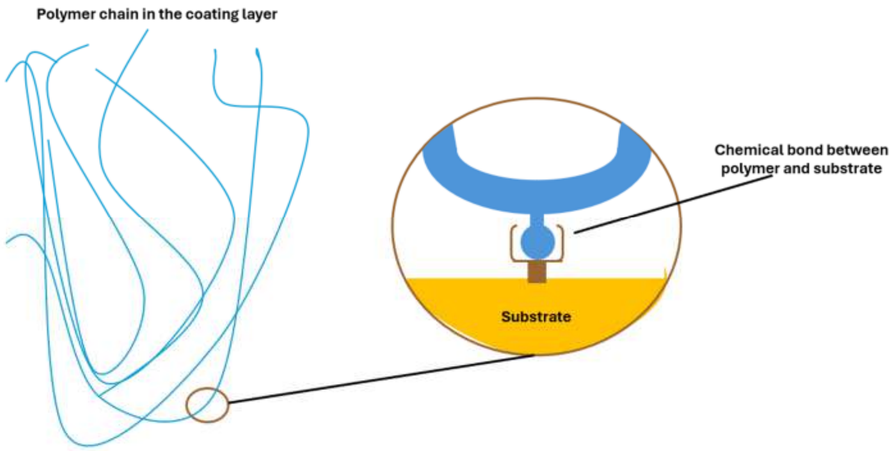
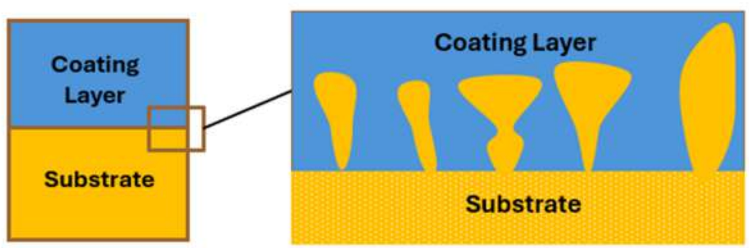


- **Mechanical theory**: This theory suggests that adhesion occurs when a coating's molecules flow into the nook and crannies of a surface. If one is having problems with a coating sticking to a surface, it is common practice to "rough up" the surface to give it "tooth." Although the above description seems obvious, the rouging-up mechanism creates additional surface area as the smooth surface. This additional surface allows for more Van de Waals contact points.



Testing for Acceptable Adhesion

It is not possible to *fully understand* how surfaces interact, and which adhesion theory dominates as two surfaces come together. What is essential is to test for proper adhesion. Assessing the adhesion of thin films, such as those routinely found in prepainted metal, is one of the most challenging aspects in the coil coatings industry. There is no one tool or instrument that can easily make a simple measurement, so multiple tests need to be considered to determine if adequate adhesion exists with a prepainted product.

The following table describes tests that are commonly used to assess adhesion of prepainted metal. The table is divided into four quadrants: Stressed and unstressed, and unexposed and exposed to environmental stress factors.

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	Unexposed	**Exposed** (to water, heat, UV, thermal shock, etc.)
Stressed	**T-Bend** (ASTM D4145)—slow deformation	Same test, but with added water soak, boiling water, dry heat, or any other source of environmental stress
	Impact (ASTM D2794)—rapid deformation	
	Biaxially stretched dome—slow deformation (Olson, Erichsen; ASTM D7093, ISO 20482)	
Unstressed	**Cross-hatch & X-cut** (ASTM D3359)	
	Knife Adhesion (ASTM D6677)	
	Nickel Adhesion (no ASTM method)	
	Scrape Adhesion (ASTM D2197)	

The above terms are defined as follows:

Stressed—Testing a sample after the object has been deformed (T-bend, Impact, etc.).

Unstressed—Testing a sample in its flat, undeformed state. The coated sample has not been exposed to any form of stress, such as roll forming.

Unexposed—Testing a sample, whether stressed or unstressed, before exposure of the sample to any environmental exposure (water, heat, UV radiation, etc.). Unexposed testing typically occurs shortly after the sample has been made in laboratory conditions, or samples from a coil line during routine production. Retain samples are often tested in an unexposed condition.

Exposed—Testing a sample, whether stressed or unstressed, after exposure to environmental exposure. Common examples of exposure include soaking the sample in water for a particular time and temperature, or exposure to boiling water for a certain time, or after weathering the sample in an accelerated or real-time fashion.

Unstressed Testing

ASTM D3359 Standard Test Methods for Rating Adhesion by Tape Test
The cross-hatch test involves a scribe and tape, where the cutting tool or knife cuts parallel lines in the coating to the substrate. (An alternate method described in D3359 is to make a simple X cut in the coating.) The distance between the lines can be varied depending upon the thickness of the coatings and the requirements of the coating. Although a knife may be used to produce cross-hatch cuts, tools are also available.

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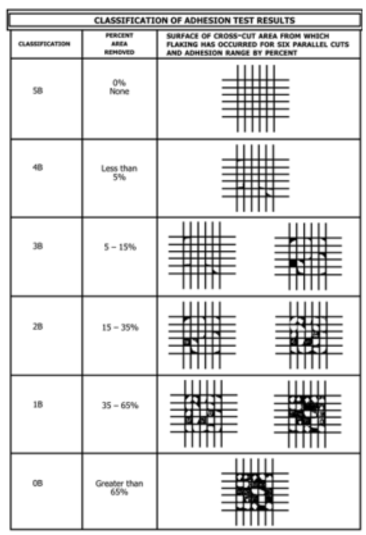
Source: Byk Instruments

The narrower the line spacing, the more stress that is imparted on the coating during the scribing process. After the set of parallel lines are made, a second set of cuts orthogonal to the first are made creating squares. As the knife cuts through the paint, it can cause delamination and chipping. Pressure-sensitive tape is firmly pressed on the scribe area. The tape is then removed, and the cuts and squares are examined for chipping or delamination. The damage is judged against pictures of damage in the ASTM protocol. This test gives a qualitative assessment of adhesion, but it is not very quantitative.



CLASSIFICATION OF ADHESION TEST RESULTS		
CLASSIFICATION	PERCENT AREA REMOVED	SURFACE OF CROSS-CUT AREA FROM WHICH FLAKING HAS OCCURRED FOR SIX PARALLEL CUTS AND ADHESION RANGE BY PERCENT
5B	0% None	
4B	Less than 5%	
3B	5 – 15%	
2B	15 – 35%	
1B	35 – 65%	
0B	Greater than 65%	

Source: ASTM International

The following three test methods all attempt to assess adhesion in a similar fashion:

- **ASTM D2197 Standard Test Method for Adhesion of Organic Coatings by Scrape Ahesion**
- **ASTM D6677 Standard Test Method for Evaluating Adhesion by Knife**
- **Nickel Adhesion, which has no ASTM test method associated with it**

In each of the above tests, a sharp object (a knife, or a tool, such as a hardened steel rod) is pressed against the organic coating and scrapes the coatings. D2197 utilizes equipment of

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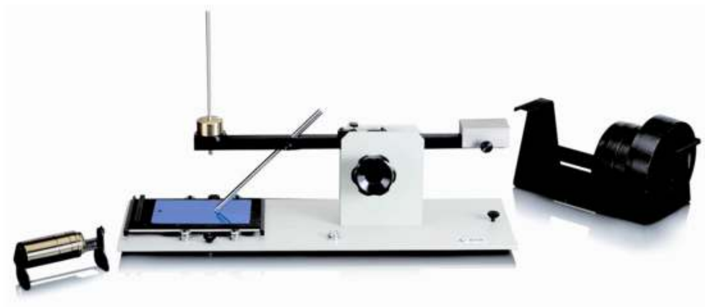
varying designs, but each allows the load on the stylus to be adjusted by adding or removing weight. The devices may use a hardened rod, or a hardened steel loop.



Source: Byk Instruments

In the case of knife adhesion and nickel adhesion, the operator simply makes an observation about the degree of adhesion. D6677 and the Nickel adhesion test are subjective. The force exerted on the coating is not specified, and neither is the rate at which the scraping is done. The nickel test uses a U.S. 5¢ coin. New coins will have a sharper edge than an old coin, so the condition of the coin is a significant variable.

Unstressed testing, after Exposure to an Environmental Condition
Each of the four tests mentioned may be appropriate when testing products that have been exposed to some environmental conditions. In the laboratory, for example, the knife adhesion of a coating might be used immediately after removing a panel from a humidity cabinet. Since coatings are somewhat permeable, the water vapor from the cabinet, to some degree, is absorbed by the coating, which might degrade the adhesion. Using a knife for a quick check immediately after the panel is removed is a convenient way to observe failures. This is typically called "wet adhesion."

Stressed Testing
There are three common tests used in the industry that fall into the category of stressed testing:

1. T-bend test—ASTM D4145 Standard Test Method for Coating Flexibility of Prepainted Sheet
2. Impact test—ASTM D2794 Standard Test Method for Resistance of Organic Coatings to the Effects of Rapid Deformation (Impact)
3. Biaxially stretched dome—ASTM D7093 Standard Test Method for Formability of Thin Film Organic Coatings on Steel Over a Biaxially Stretched Dome

The t-bend and the impact tests are routinely run on material being produced on a coil coating line. Both tests attempt to duplicate the stress involved in the fabrication process of prepainted coils. The T-bend test is similar to the roll forming fabrication process. Roll forming shapes the prepainted metal as it passes through several forming rolls.

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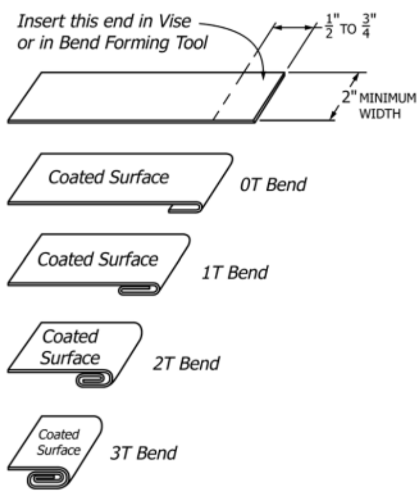
Source: The Fabricator

The metal, therefore, is shaped slowly into the final part, and the T-bend test is also a slow deformation test method, and ASTM D4145 describes the test method in detail.

After each bend is made, it is a common practice to observe if any cracking has taken place. It is also common practice to tape each bend (i.e., apply pressure sensitive tape to the T-bend, pull the tape off quickly). The tape is then inspected to determine if the coating has been removed.



Source: ASTM

The following equipment is commonly used to produce the above bends.

Source: Birmingham Heavy Duty Brake

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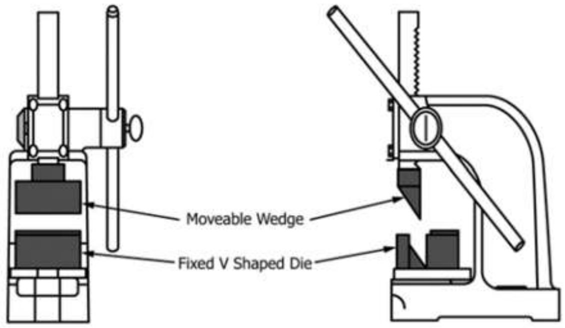
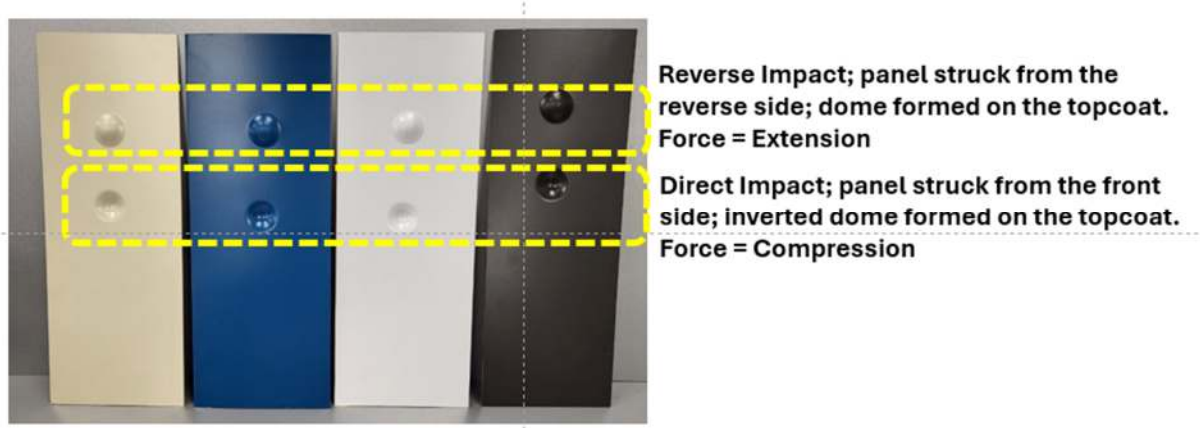


V-bend brake

Source: ASTM

In addition to roll forming parts, certain building products, especially roofing products, are formed in a stamping press. This method of fabrication involves rapid deformation of the pre-painted metal. ASTM D2794 describes an impact testing protocol, where a falling weight strikes a rod, deforming the metal. The most common test in the coil coating industry is to strike the panel from the backside, forming a dimple on the front side of the panel. Like the T-bend test, it is common to tape the dimples to test for adhesion loss.

Source: BYK Instruments



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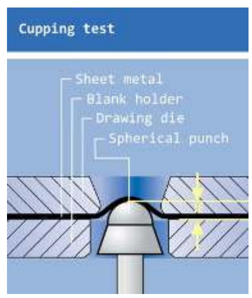
The last of the three tests to discuss is ASTM D7093 Standard Test Method for Formability of Thin Film Organic Coatings on Steel Over a Biaxially Stretched Dome, a test designed to simulate the effects of a part that undergoes a drawing operation. This is seldom done with prepainted metal, and it requires specialized equipment to perform the test.



Source: Erichsen

Testing Adhesion after Exposure to Environmental Conditions
Since prepainted metal lasts for decades, it will be exposed to a number of conditions that may affect the adhesion of the coating to the substrate. Additionally, on-site roll forming is not uncommon, especially for creating seamless standing seam roofing panels and aluminum accessories such as gutters and downspouts. These on-site processes can take place under extreme conditions (e.g., very cold winter weather, fabrication during very humid or rainy weather, etc.).

The most common test used to anticipate the effect of exposure is a simple boiling water test. Any of the tests discussed may be run by either immersing the coated panel in boiling water, and then running a crosshatch test, or impact test, or T-bend test. Depending on the environmental conditions being considered, it is also common to first run these tests, followed by a boiling water test. In all cases, the part being tested is taped to determine if adhesion has been lost. Of course, there are many other approaches that one may take, such as exposing a material after performing a T-bend test to "dry heat," where the bent panel is placed in an oven (usually <200°F), to observe if adhesion loss is apparent after taping. For products designed for on-site fabrication, it would make sense to place the panel in a freezer, where upon removing the panel immediately testing it using an impact test. There is no prescribed set of conditions to anticipate all the environmental exposures that a prepainted metal product may experience.

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The purpose of this tool kit has been to demonstrate the complexity of understanding and assessing adhesion. The literature on this topic is extensive. This tool kit, however, avoids much of the theory and focuses on the practical aspects that the industry faces when it comes to producing products with long lifetimes.

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