Adhesion Testing Methods

For coatings to perform satisfactorily, they must adhere to the substrates on which they are applied. A variety of recognized methods can be used to determine how well a coating is bonded to the substrate. Commonly used measuring techniques are performed with a knife or with a pull-off adhesion tester. After any test it is important to record if the bond failure was adhesive (failure at the coating / substrate interface) or cohesive (failure within the coating film or the substrate).

Knife Test

This simple test requires the use of a utility knife to pick at the coating. It establishes whether the adhesion of a coating to a substrate or to another coating (in multi-coat systems) is at a generally adequate level. Performance is based on both the degree of difficulty to remove the coating from the substrate and the size of removed coating.

Using the knife and cutting guide, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an “X”. At the vertex, the point of the knife is used to attempt to lift up the coating from the substrate or from the coating below.

This is a highly subjective test and its value depends upon the inspector’s experience. A coating which has a high degree of cohesive strength may appear to have worse adhesion than one which is brittle and hence fractures easily when probed. There is no known correlation to other adhesion test methods (pull-off, tape, etc.).

A standard method for the application and performance of this test is available in ASTM D6677.

Tape Test

On metal substrates, a more formal version of the knife test is the tape test. Pressure sensitive tape is applied and removed over cuts made in the coating. There are two variants of this test; the X-cut tape test and the cross hatch tape test.

The X-cut tape test is primarily intended for use at job sites. Using a sharp razor blade, scalpel, knife or other cutting device, two cuts are made into the coating with a 30 – 45 degree angle between legs and down to the substrate which intersects to form an “X”. A steel or other hard metal straightedge is used to ensure straight cuts. Tape is placed on the center of the intersection of the cuts and then removed rapidly. The X-cut area is then inspected for removal of coating from the substrate or previous coating and rated.

The cross hatch tape test is primarily intended for use in the laboratory on coatings less than 5 mils (125 microns) thick. It uses a cross-hatch pattern rather than the X pattern. A cutting guide or a special cross-hatch cutter with multiple preset blades is needed to make sure the incisions are properly spaced and parallel. After the tape has been applied and pulled off, the cut area is then inspected and rated.

A standard method for the application and performance of these tests is available in ASTM D3359.

Pull-Off Tests

A more quantitative test for adhesion is the pull-off test where a loading fixture, commonly called a dolly or stub, is affixed by an adhesive to a coating. By use of a portable pull-off adhesion tester, a load is increasingly applied to the surface until the dolly is pulled off. The force required to pull the dolly off or the force the dolly withstood, yields the tensile strength in pounds per square inch (psi) or mega Pascals (MPa). Failure will occur along the weakest plane within the system comprised of the dolly, adhesive, coating system, and substrate, and will be exposed by the fracture surface.

This test method maximizes tensile stress as compared to the shear stress applied by other methods, such as scrape or knife adhesion, and results may not be comparable. Further, pull-off strength measurements depend upon the instrument used in the test. Results obtained using different devices or results for the same coatings on substrates having different stiffness may not be comparable.

Testers operate using either mechanical (twist by hand), hydraulic (oil) or pneumatic (air) pressure. They are classified as being fixed aligned or self aligning depending upon their ability to ensure a vertical pull-off force. Best repeatability is obtained when the pull-off force acts perpendicular to the surface being tested.

The availability of a full range of pull off adhesion tester models facilitates the measurement of coating adhesion on almost any rigid substrate. For example, 20 mm dollies may be ideal for typical coating bond strengths on metal, plastic and wood, where as 50 mm dollies are more ideal for coatings on masonry substrates such as concrete. Many manufacturers also offer custom dolly sizes to address special measurement needs. For example, decreasing the dolly size from 20 mm to 10 mm, increases the pull off range of the gage by 4 times, allowing some manufacturers to accurately measure bond strengths over 12,000 psi. Keeping the dollies inexpensive eliminates the need for reusing dollies, greatly simplifying the preparation process,

with an additional benefit of allowing physical samples to be maintained for future reference or evidence of pull off test results.

A standard method for the application and performance of this test is available in ASTM D4541 and ISO 4624.

Scrape Tests

This test is typically performed in a laboratory and is limited to testing on smooth, flat panel surfaces. Adhesion is determined by pushing the coated panels beneath a rounded stylus or loop that is loaded in increasing amounts until the coating is removed from the substrate surface. A device called a balanced-beam scrape-adhesion tester is used.

A standard method for the application and performance of this test is available in ASTM D2197.

Other Tests

There are many other adhesion tests. Some of these involve the use of tensile test machines with paint applied to the substrate with a textile strip embedded in the paint (the tensile machine pulls substrate and cloth) or have the paint applied between two sheets of the substrate (tensile machine pulls on both substrate pieces). ASTM D2370 describes one such test of elongation, tensile strength, and stiffness of organic films when tested as free films. Organic coating adhesion to plastic substrates by mounting an aluminum stud and removing it with a tensile tester is covered in ASTM D5179.

ASTM D4145 describes a bending test for determining flexibility and adhesion of coatings on prepainted metallic substrates. These organic coatings are subjected to stresses when fabricated into products by roll forming, brake bending, or other deformation processes. These stresses can exceed the flexibility or adhesive strength of the coating resulting in fracture of the coating, exposing the substrate, or loss of adhesion to the substrate. This test is a means of evaluating the ability of a coating system to withstand the stresses of fabrication.

Formability and adhesion testing of factory applied zinc-rich primer/chromate complex coatings on steel is described in ASTM 4146. In this test, a coated specimen is biaxially stretched a given distance in an appropriate machine, adhesive tape is applied to the deformed area (dome) and then pulled off, and the amount of coating removed is compared with a photographic standard to determine the coating adhesion rating.

Adhesion is also a measurable result of some hardness tests made by pencil hardness, gravelometer, impact (falling dart, etc.) or mandrel bend. Coating chip-off should be recorded during these tests. Finally, loss of adhesion can be noted during some chemical resistance tests where the coating blisters, bubbles up or even falls off.