Adhesion

Abstract

Adhesion is of utmost importance for surface coatings to guarantee effective corrosion protection and resistance to physical damage. In practice, various testing methods are used to evaluate adhesion properties.

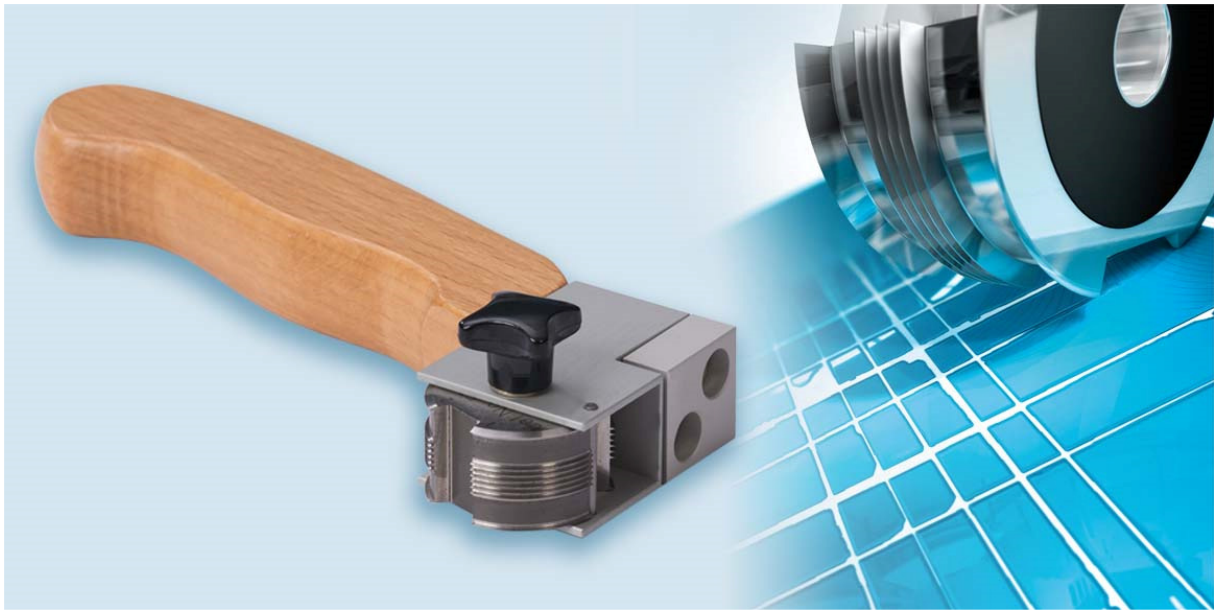

Table of Contents

1 Definition of adhesion

In addition to hardness and film thickness, adhesion is an important attribute of a coating. If it is not sufficient, coating functions will fail. For example, when a part is exposed to bending stress, and thus corrosion protection will no longer be guaranteed. Adhesion strength is the measure of the resistance of a coating to its mechanical separation from the substrate. [1]

In practice, various test methods are used to determine adhesion. The adhesion test is carried out during the manufacturing process on test panels coated in the process or on the object itself.

2 How the adhesion mechanism works

The adhesion strength of paints is the bond of the finished coating with the substrate and is influenced by the following factors (Fig. 1 and Fig. 2):

- Gravity
- Mechanical bonding intermolecular forces between substrate and coating (hydrogen bond, Van der Waal forces)
- Chemical bonding (Matz, Kollek)

Common to all models is that the effect of the forces only extends over very short distances. Basic requirement for the adhesion strength of paints. The wettability of the substrate through the paint depends on the surface tension of the substrate. The substrate is wettable, if the surface tension of the substrate is higher than that of the coating material.

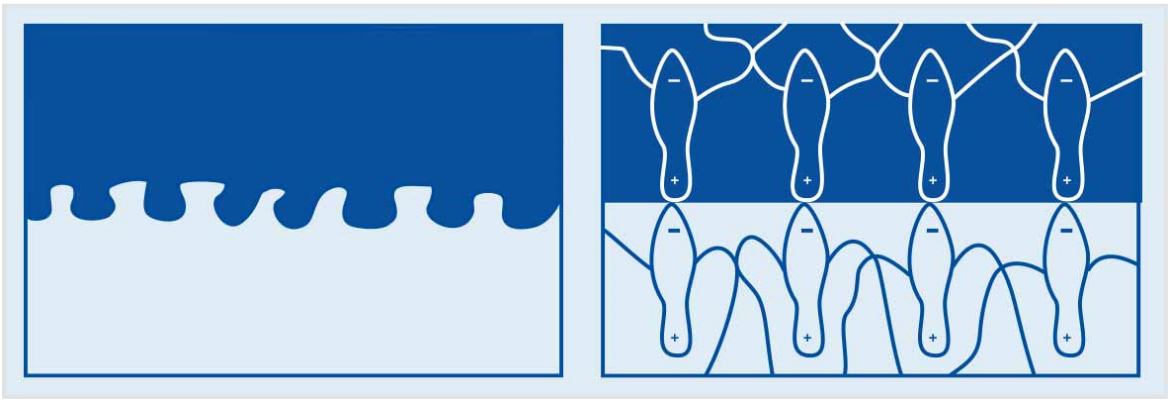

Fig. 1: Mechanical bonding

Dipol-Dipol / van der Waal interactions

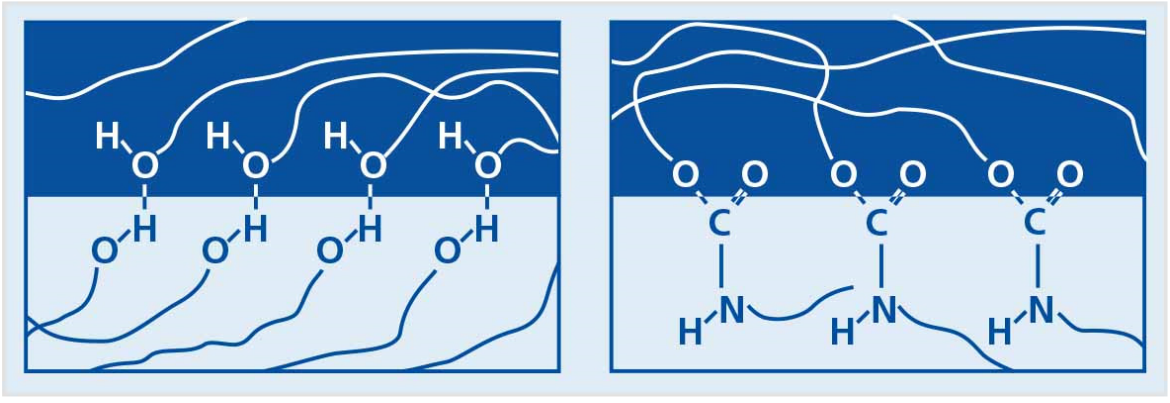

Fig. 2: Hydorgen bonding

Chemical bonding

3 Sample preparation

To achieve constant, repeatable and comparable results, it is necessary to maintain and document film thickness, pretreatment, drying (air, oven, IR, etc.), temperature, humidity and keep aging of the paint the same. DIN EN ISO 2409 explains sample preparation as well as measurement condition in detail. In addition, it recommends to document all parameters which are important to achieve comparable results [1]

4 Crosshatch test

4.1 Crosshatch testing according to DIN EN ISO and ASTM

The Cross-cut is performed by either using cutting tools with 1-edge (Fig. 3) or 6-edges (Fig.4). The procedure is to be carried out as follows:

Cut through the coating, 5 times vertically to the substrate at a defined distance with a sharp blade. Then 5 times horizontally over the previously made cut, so that a cross is created. Then brush in a diagonal direction with a soft hand brush and if defined apply an adhesive tape evenly over the cut within 5 min and pull it off in one go and within one second at a 60° angle (Fig. 5). It is important to ensure that the same adhesive tape is always used. [1,2,3,10]

The spacing of the cutting blade must be the same in both directions and is defined as follows:

- Up to 60 µm: 1 mm distance, for hard (e.g. metal and plastic) substrates
- Up to 60 µm: 2 mm distance, for soft (e.g. wood and plaster) substrates
- 61 µm to 120 µm: 2 mm distance for soft and hard substrates
- 121 µm to 250 µm: 3 mm distance for soft and hard substrates

Alternatively, the test can be carried out according to ASTM 3359 [3]. It should be noted that after 90 seconds +/- 30 seconds, the adhesive tape must be pulled off evenly at a 180° angle (Fig. 6).

Subsequently, the cut is visually evaluated at good lighting conditions and, if necessary, with a magnifying glass.

The cutting blades of the cross cutter are made of high-quality tool steel in order to ensure a repeatable qualitative measurement even on hard surfaces. The swiveling cutting head is easy to handle for optimum alignment on the test surface. The crosshatch set is supplied with all necessary accessories, which are needed for performing a qualitative crosscut.

Fig. 3: Crosshatch Kit, Single blade

Fig. 4: Crosshatch Kit, 6-edges

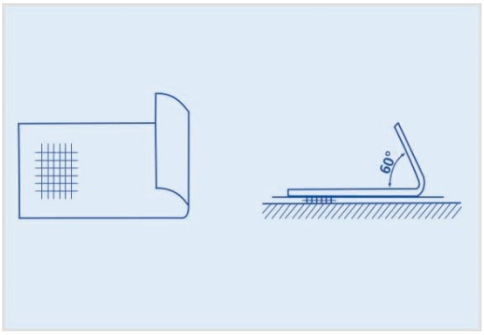

Fig. 5: DIN ISO Standard 60° angle

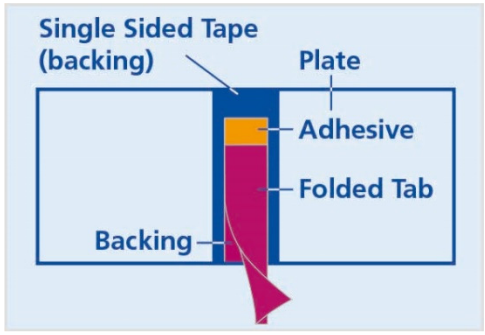

Fig. 6: ASTM Standard 180° angle

Practical tips:

- For cross cut tests it is important the that the cutting blades are sharp and on an even level on the substrate.
- When evaluating with an adhesive tape, the same manufacturer must be used, since adhesive tapes differ largely from different manufacturers in regards to adhesive strength and therefore influence the measurement results.

4.2 Evaluation of the cross-cut images

ISO Classification	ASTM Classification	Description
0	5B	The cutting edges are perfectly smooth No part of the coating has flaked off
1	4B	At the intersections of the grid line, small splinters of the paint have flaked off The chipped area is about 5% of the cuts
2	3B	The paint is chipped along the cutting edges and/or at the intersections of the grid line The chipped area ranges between 5% and 15% of the cuts
3	2B	The paint is partially or completely chipped lengthwise The chipped area is between 15% and 35%
4	1B	The paint is completely chipped along the cut edges in wide strips or even in individual sections The chipped area ranges between 35% and 65% of the cuts
5	0B	Any degree of chipped surfaces that can no longer be described with ISO 4 or ASTM 1B

Fig. 7: Evaluation of cross-cut images

5 Scratch hardness test

This test method is used to assess the adhesion strength of coating systems, such as paints and varnishes, on flat and smooth sample panels. The coating is applied with uniform layer thickness to several flat test panel with the same surface quality. After drying, the adhesion strength is determined by guiding the panels against a rounded pin or chisel that can be loaded with weights until the paint layer detaches from the substrate. [4,5]

The evaluation of the scratch hardness test is primarily carried out visually. The scratch hardness tests simulate loads in the laboratory to which a surface can be exposed in everyday life (Fig. 8, Fig. 9).

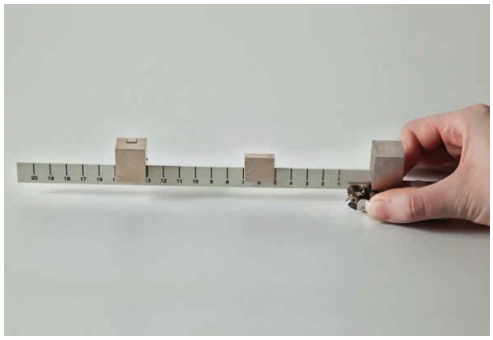

Fig. 8: Hoffman Scratch Hardness

Fig. 9: Tester Balanced Beam Adhesion/Mar

6 Pull-Off Test

The pull-off test determines the paint adhesion to a variety of substrates. The adhesion to the substrate, between several layers of paint and within a paint layer are assessed objectively and with minimal user influence. For the Pull-Off test, so-called dollies with a flat and clean contact surface are applied to the coating with a 2K adhesive glue (Fig. 10). Immediately after the curing of the glue, the test arrangement is analyzed with the adhesion tester

available as manual or automated version (Fig. 11). The test dollies must be aligned in such a way that the tensile force is applied evenly over the test surface without any bending. Subsequently, the tensile stress is applied at a speed not exceeding 1 MPa/s and is increased perpendicular to the plane of the coated substrate that the fracture occurs within 90 s after the start of the stress absorption. The tensile stress is measured when the adhesive bond breaks. [6,7,8,9]

6.1 Pull-Off Tester

The instrument offers a variety of advantages (Fig. 11). It is handy and easy to operate. It is powered by a rechargeable battery and therefore, ideal for laboratory and outdoor applications. The large and easy to read LCD display in PSI units and MPa is easy to understand. Due to the inexpensive one-way dollies the replacement cost is not very high. The self-aligning dollies enable measurements on smooth and uneven surfaces without distorting the measurement result. The hydraulic pump offers a safety valve, and the 2-component special adhesive glue can be used for a variety of coatings and layer thicknesses. Up to 200 measurements with definition of maximum tractive force, pull speed and test duration can be stored. Different punch sizes with diameters of 10, 14, 20 and 50 mm are available. The data transfer to the PC via USB interface makes operating the pull-off test method easy and safe.

6.2 Analysis of Pull-Off testing

The test report needs to document test conditions such as temperature, humidity, date and adhesive used. Information of the device with manufacturer and type number is as important as a description of the paint system (binder base and number of layers). The time and conditions between bonding, testing and the diameters of the test stamp used must be observed and always carried out in the same way when making comparisons. In addition, the point of fracture (in which layer) of the demolition must be given in %. (Fig. 12)

Practical tips:

- The compatibility of the adhesive with the paint material should be tested, in case of discoloration or dissolving, an alternative and compatible adhesive must be used.

Fig. 10: Dollies and Tools

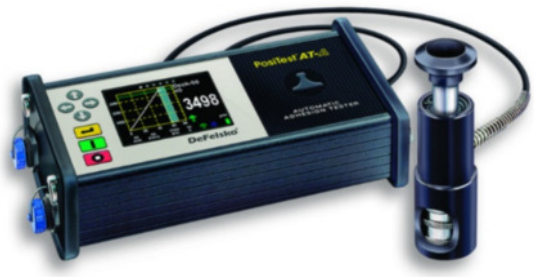

Fig. 11: Pull-OFF Tester

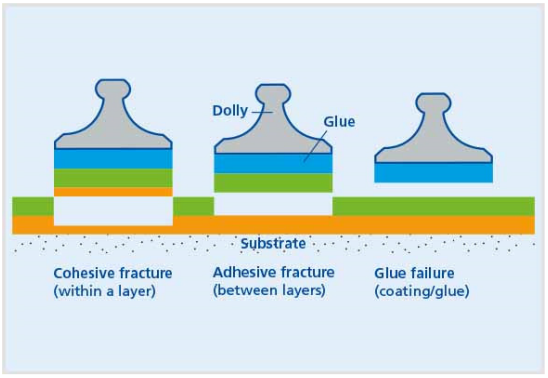

Fig. 12: Fracture

7 Precision of Test Methods

7.1 Precision of Cross-cut test according to DIN EN ISO 2409

The repeatability r and comparability R are both 95%. It should be noted that it must be the same person, substrate, time (specimen age and time of cross-cut) and environmental condition (temperature and humidity). [1,2,3,10]

- According to standard 1, the repeatability limit r is a cross-sectional characteristic value.
- According to standard 2, the reference limit R is cross-sectional characteristic values.

7.2 Precision of Scratch test according to ASTM D3002

In the scratch hardness test, the scoring tool is a consumable. This wears out quickly, especially with hard layers. To ensure consistent quality, the scoring tool should be checked regularly under the microscope. As a guideline: a diamond indentor holds approx. 100 - 200 measurements for hard coatings. [4,5]

7.3 Precision of Pull-Off test according to DIN EN ISO 4624

The devices are calibrated and certified to ± 1% accuracy with a NIST-traceable load cell and come with a calibration certificate that proves traceability to NIST. The self-aligning punches allow for accurate measurement. [6,7,8,9]

In the pull-off test, information must be provided on the mixing ratio, drying, paint chemistry, ambient temperature, humidity and layer thickness.

8 Summary

Paint adhesion determines how good the protective layer on a surface does its job. The associated quality criterion for the adhesion of the surface coating is referred to as adhesion strength. Different test methods are used to determine this property depending on the application or defined procedure. The result determines whether a coated parts will be accepted or rejected. [1]

The Crosshatch and the scratch hardness test are a fast method with acceptable precision as long as the user is experienced in performing the cut and conditions are reported.

The Pull-Off Test is more time-consuming but provides a more reliable and accurate result. The test is not as user dependent, the breaking point and weak point of the paint system is clearly definable and offers the user a high level of security.

9 Literature and Standards

[1] DIN EN ISO 2409 Cross-cut test
[2] DIN EN 927-3 Natural weathering test
[3] ASTM D3359 Measuring Adhesion by Tape Test
[4] ASTM D3002 Evaluation of Coatings Applied to Plastics
[5] ASTM D2197 Adhesion of Organic Coatings by Scrape Adhesion
[6] ASTM D5178 Mar Resistance of Organic Coatings
[7] DIN EN ISO 4624 Pull-off test for adhesion
[8] EN ISO 16276-1 Pull-off testing
[9] ASTM D4541 Pull-Off Strength of Coatings Using Portable Adhesion Testers
[10] ASTM D7234 Pull-Off Adhesion Strength of Coatings Portable Pull-Off Adhesion Testers