



Bridge You and Nano

Exponential Business and Technologies Company

Pull-Off Strength for Coating Adhesion Evaluation

The bonding strength between coating and substrate, between coating layers, or within a coating layer are some of the most important considerations to improve a coating's lifetime and effectiveness. When designing coating on substrate systems, test methods that can evaluate adhesion strengths, material selections, and the effectiveness of cleaning processes are critical. Understanding the force limits that a coating system can withstand also informs on the conditions that can be set for safe operation of a product.

Within Ebatco's surface and interface analysis suite, pull-off strength testing with the Elcometer 510 Automatic Pull-Off Adhesion Tester provides a means to assess the "weakest link" in a coating system with minimal contribution from the other layers. This technique is widely used by paint and coating industries for quality control and for coating system development. To perform this test, an aluminum dolly is adhered to a coating surface with a strong adhesive, and after curing, the Elcometer actuator is attached to the dolly head. The dolly is then pulled either to a specified force or until failure of the coating system. Ebatco is equipped with a 20 mm diameter dolly which allows for an operating range of 2 – 25 MPa (300 – 3600 psi). The instrument is certified by Elcometer to have a gauge accuracy of $\pm 1\%$ of the full scale by their ISO/IEC 9001:2015 accredited lab.

A schematic of the test setup is shown in Figure 1, with labels for the substrate (A), coating layers (B – F), epoxy adhesive (Y), and aluminum dolly (Z). In addition to the pull-off strength values that are measured by the instrument, many national and international standards, including ISO 4624 and ASTM D4541, require the nature of the failure to be reported. For this, visual inspection of the failure surfaces is required and cohesive or adhesive failure codes are reported, according to the code system in Figure 1. If the failure occurs within a coating layer, this is referred to as cohesive failure, and it can be identified when the dolly and sample surfaces both have the same coating layer left on them. If a failure occurs at an interface, this is referred to as adhesive failure, and it can be identified when the dolly and sample surfaces have different coating layers left on them.

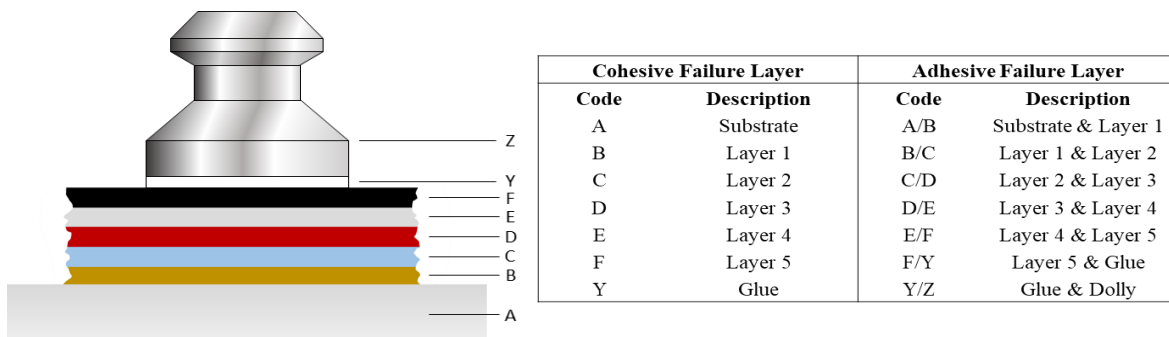


Figure 1. Schematic of test setup for pull-off adhesion strength (left) and ASTM D4541 system for reporting failure modes (right).



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To demonstrate the effectiveness of pull-off strength testing to identify the weakest link in a coating system, two samples were prepared for analysis. Coating 1 consists of an automotive primer (layer B) and paint (layer C) layered onto a steel substrate (A). Coating 2 has the same primer and paint layers, but with an additional clear coat layer (layer D) at the top surface. Figure 2 shows examples of dolly and coating surfaces after testing for each coating system. Table 1 provides the pull-off strength results from each test, and failure locations are indicated by a percentage for each layer or interface that failed; results that sum to < 100% indicate some of the failure occurred at the epoxy layer. Despite the addition of this harder, more durable clear coat layer, the pull-off strength for Coating 2 is only slightly higher than for Coating 1, and the failure occurs within the primer layer for both samples and for all tests. The low standard deviation, consistency in failure location, and minimal dependence on other coating layers make pull-off strength testing a valuable tool for coating development and coating quality control.

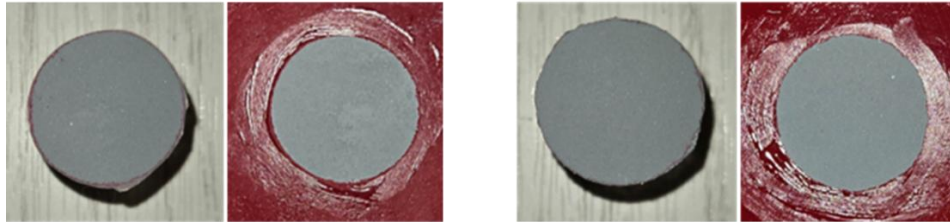


Figure 2. Images of post-test failure surfaces from Coating 1 (left) and Coating 2 (right)

Table 1. Pull-Off Strength Results

Specimen	Test	Pull Strength (MPa)	Failure Mode	ASTM D4541 Result
Coating A	1	5.97	Cohesive Failure in Primer	5.97 MPa, 100% B
	2	5.50	Cohesive Failure in Primer	5.50 MPa, 90% B
	3	5.87	Cohesive Failure in Primer	5.87 MPa, 100% B
	Average	5.78 ± 0.25	-	-
Coating B	1	5.90	Cohesive Failure in Primer	5.90 MPa, 90% B
	2	6.26	Cohesive Failure in Primer	6.26 MPa, 100% B
	3	6.25	Cohesive Failure in Primer	6.25 MPa, 100% B
	Average	6.14 ± 0.21	-	-

Pull-off adhesion testing is a technique within Ebatco's surface and interface analysis suite that provides insights into the weakest link within a coating system. Gaining quantitative pull-off strength, combined with visual inspection of the failure, can help to design a coating system to withstand particular end-use conditions and to maintain coating quality during production. Ebatco's ISO/IEC 17025 accredited lab services can provide controlled testing environments and will ensure the data quality you need for your product.