Designation: D5573 – 99 (Reapproved 2012)

Standard Practice for Classifying Failure Modes in Fiber-Reinforced-Plastic (FRP) Joints[1]

This standard is issued under the fixed designation D5573; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the method of classifying, identifying, and characterizing the failure modes in adhesively bonded fiber-reinforced-plastic (FRP) joints. The FRP used in developing this practice consists of glass fibers in a thermoset-polyester-resin matrix, commonly referred to as sheet-molding compound, or SMC.

1.2 One objective of this practice is to present comprehensive definitions of possible failure modes to serve as a guide for contracts, drawings, product specifications, and product performance.

NOTE 1—Figures 2 through 11 referred to in the practice are contained in the ASTM adjunct, Color Photographs of Failure Modes.[2]
Fig. 2—Side-by Side Comparison of Failure Modes
Fig. 3—Adhesive Failure
Fig. 4—Cohesive Failure
Fig. 5—Thin-Layer Cohesive Failure
Fig. 6—Fiber-Tear Failure
Fig. 7—Light-Fiber-Tear Failure
Fig. 8—Stock-Break Failure
Fig. 9—Mixed Failure—40 % Fiber-Tear Failure, 60 % Light-Fiber-Tear Fiber
Fig. 10—Mixed Failure—32 % Adhesive Failure, 68 % Fiber-Tear Failure
Fig. 11—Mixed Failure—20 % Adhesive Failure, 60 % Light-Fiber-Tear Failure, 20 % Fiber-Tear Failure
NOTE 2—This practice may be used to describe the failure modes generated from testing, using procedures such as Test Methods D3163, D3164, D3165, D3807, D5041, D5868, and SAE J1525.

1.3 The values stated in SI units are to be regarded as the standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*[3]
D907 Terminology of Adhesives
D3163 Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading
D3164 Test Method for Strength Properties of Adhesively Bonded Plastic Lap-Shear Sandwich Joints in Shear by Tension Loading
D3165 Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies
D3807 Test Method for Strength Properties of Adhesives in Cleavage Peel by Tension Loading (Engineering Plastics-to-Engineering Plastics)
D5041 Test Method for Fracture Strength in Cleavage of Adhesives in Bonded Joints
D5868 Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding
2.2 *SAE Standard:*
SAE J1525 SAE Recommended Practice—Lap Shear Test for Automotive-Type Adhesives for Fiber Reinforced Plastic (FRP) Bonding[4]
2.3 *ASTM Adjuncts:*
Color Photographs of Failure Modes[2]

3. Terminology

3.1 *Definitions:*
3.1.1 Definitions may not appear outside of this practice unless the following delimiting phrase is included: "*relating to testing FRP bonded joints and ASTM Practice D5573.*"
3.2 *Definitions of Terms Specific to This Standard:*
3.2.1 *failure-mode classification, n—relating to testing FRP bonded joints*, a classification that includes the seven classes of failure modes identified here: (1) adhesive failure, (2) cohesive failure, (3) thin-layer cohesive failure, (4) fiber-tear failure, (5)

[1] This practice is under the jurisdiction of ASTM Committee D14 on Adhesives and is the direct responsibility of Subcommittee D14.40 on Adhesives for Plastics.
Current edition approved Oct. 1, 2012. Published October 2012. Originally approved in 1994. Last previous edition approved in 2005 as D5573 – 99 (2005). DOI: 10.1520/D5573-99R12.
[2] Available from ASTM International Headquarters. Order Adjunct No. ADJD5573. Original adjunct produced in 1993.
[3] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.
[4] Available from SAE International (SAE), 400 Commonwealth Dr., Warrendale, PA 15096-0001, http://aerospace.sae.org.

light-fiber-tear failure, (6) stock-break failure, and (7) mixed failure (see 3.2.1.2 through 3.2.1.10).

3.2.1.1 *Discussion*—Failure of a tested specimen is seldom confined to a single mode, but rather is a combination of two or more of the first six modes, such combination designated as *mixed failure*. Whenever possible, *mixed failure* should always be reported citing the class of failure present and the percent of each class.

3.2.1.2 *adhesive failure, ADH (or A), n*—rupture of the adhesively bonded joint, such that the separation appears to be at the adhesive-adherend interface. (Sometimes referred to as *interfacial failure*.) (See Fig. 1, Fig. 2, and Fig. 3.)

3.2.1.3 *Discussion*—After failure, the FRP and adhesive surfaces may have a shiny appearance and there is no evidence that any adhesive or FRP, or both, have transferred to the other surface.

3.2.1.4 *cohesive failure, COH (or C), n*—rupture of an adhesively bonded joint, such that the separation is within the adhesive. (See Fig. 1, Fig. 2, and Fig. 4.)

3.2.1.5 *Discussion*—This term has also been used to describe a failure within the FRP substrate. This usage is being discouraged.

3.2.1.6 *thin-layer cohesive failure, TLC, n*—failure similar to *cohesive failure,* except that the failure is very close to the adhesive-substrate interface, characterized by a "light dusting" of adhesive on one substrate surface and a thick layer of adhesive left on the other. (Sometimes referred to as *interphase failure*.) (See Fig. 1, Fig. 2, and Fig. 5.)

3.2.1.7 *fiber-tear failure, FT, n*—in an adhesively bonded joint, failure occurring exclusively within the FRP matrix, characterized by the appearance of reinforcing fibers on both ruptured surfaces. (See Fig. 1, Fig. 2, and Fig. 6.)

3.2.1.8 *interphase failure, n*—see *thin-layer cohesive failure*.

3.2.1.9 *interfacial failure, n*—See *adhesive failure*.

3.2.1.10 *light-fiber-tear failure, LFT, n*—failure occurring within the FRP substrate, near the surface, characterized by a thin layer of the FRP resin matrix visible on the adhesive, with few or no glass fibers transferred from the substrate to the adhesive. (See Fig. 1, Fig. 2, and Fig. 7.)

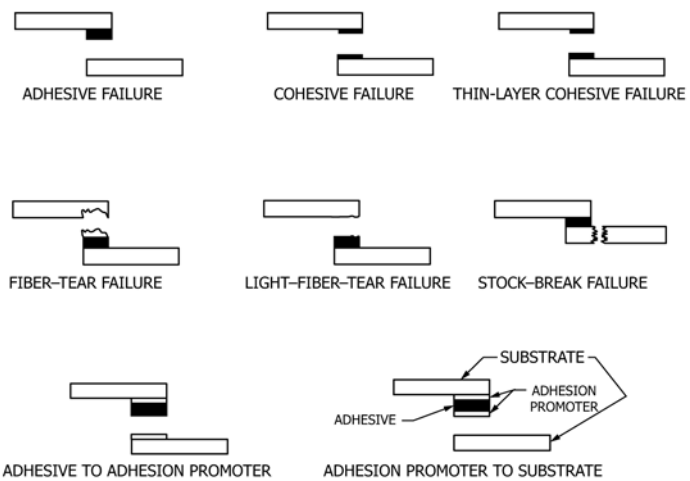

FIG. 1 Sketches Representing Failure Modes

3.2.1.11 *stock-break failure, SB, n*—a break of the FRP substrate outside the adhesively bonded-joint region, often occurring near it. (See Fig. 1, Fig. 2, and Fig. 8.)

3.2.1.12 *mixed failure, n*—any combination of two or more of the six classes of failure mode defined in 3.2.1.2, 3.2.1.4, 3.2.1.6, 3.2.1.7, 3.2.1.10, and 3.2.1.11. (See Fig. 1, Fig. 2, Fig. 9, Fig. 10, and Fig. 11.)

3.3 *Abbreviations:*

3.3.1 *ADH (or A)*—adhesive failure.

3.3.2 *COH (or C)*—cohesive failure.

3.3.3 *TLC*—thin-layer cohesive failure.

3.3.4 *FRP*—fiber-reinforced plastic.

3.3.5 *FT*—fiber-tear failure.

3.3.6 *LFT*—light-fiber-tear failure.

3.3.7 *SB*—stock-break failure.

4. Significance and Use

4.1 This practice provides a simple means of classifying failure modes for adhesively bonded FRP joints.

4.2 Each failure mode classification is based solely on a visual observation of the failure surface without the aid of a microscope or other means to magnify the surface.

4.3 Except for the line-drawing representations given, this practice does not contain descriptions of failure modes possible when using adhesion promoters. However, similar analogies to the failure modes described herein can be made.

4.4 This practice does not address the acceptability of any specific failure mode.

5. Interferences

5.1 When classifying the failure modes of FRP adhesively bonded joints, it is essential that the analysis be conducted on specimens tested by only one test method. There is no guarantee that the failure modes of FRP adhesively bonded joints will be the same when tested by different test methods.

6. Test Specimens

6.1 Prepare test specimens in accordance with the specified test method to be used in evaluating the adhesively bonded FRP joint. (Refer to 2.1.)

7. Procedure

7.1 Condition and test specimens as specified in the selected test method.

7.2 Classify the failure mode for each specimen by using the photographic standards shown in Figs. 2 through 11.

7.2.1 For examples exhibiting more than one failure mode, determine the percentages of each. (See Fig. 7, Fig. 8, and Fig. 9.)

7.2.2 For increased accuracy, use a grid drawn on a clear film placed over failure surface. Count squares of each type of failure mode and calculate percentage.

NOTE 3—For photographs in the adjunct, percentages were calculated using a 5 by 5 square grid, resulting in the accuracy of ±4 %.

8. Report

8.1 Report the following information:

8.1.1 Test method used, and

8.1.2 *Failure Mode Classification*—This should include percentages when more than one failure mode occurs.

NOTE 4—Include all pertinent data in accordance with the test method used.

9. Precision and Bias

9.1 This practice yields essentially qualitative comparison data to classify failure modes of bonded assemblies. Precision, as normally expressed for quantitative measurement test methods is not directly applicable.

10. Keywords

10.1 adhesive bond; failure mode; fiber-reinforced plastic; FRP; practice