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Standard Guide for Use of Adhesive-Bonded Single Lap-Joint Specimen Test Results[1]

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INTRODUCTION

The true strength of an adhesive is a material property independent of the joint geometry, adherend properties, and load, and is a good starting point for determining an allowable design stress. Allowable stresses in shear and tension are needed to design safe, efficient, adhesively bonded joints and structures. The true shear strength, however, cannot be easily determined using single-lap specimens.

Many factors affect the apparent shear strength of an adhesive when measured with a small laboratory specimen, and in particular, with a single-lap specimen. For example, the failure of a typical single-lap specimen, is usually controlled by the tensile stress in the adhesive, and not by the shear stress. The factors that control the tensile stress in lap-joint specimen, and thus, the apparent shear strength are the size and shape of the specimen, the properties of the adherends, the presence of internal stresses or flaws, and the changes that take place in the specimen due to adhesive cure and the environment. Similarly these factors affect the apparent tensile strength of an adhesive in butt-joint test specimens.

Due to the effects of these factors, the apparent shear strength obtained through measurements on small laboratory specimens may vary widely from the true shear- or tensile-strength values needed to determine allowable shear and tension design stresses.

The objectives of this guide are: to develop an appreciation of the factors that influence strength and other stress measurements that are made with small laboratory test specimens; to foster the acceptable uses of the widely used thin-adherend single-lap-joint test; and, specifically, to prevent misuse of the test results.

1. Scope

1.1 This guide is directed toward the safe and appropriate use of strength values obtained from test methods using single-lap adhesive joint specimens.

1.2 The discussion focuses on shear strength as measured with small thin-adherend, single-lap specimens. Many factors, however, apply to shear modulus, tensile strength, and tensile modulus measured by small laboratory specimens in general. This discussion is limited to single-lap specimens and shear strength only for simplification.

2. Referenced Documents

2.1 *ASTM Standards:*

D 896 Test Method for Resistance of Adhesive Bonds to Chemical Reagents[2]

D 906 Test Method for Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading[2]

D 907 Terminology of Adhesives[2]

D 1002 Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)[2]

D 1144 Practice for Determining Strength Development of Adhesive Bonds[2]

D 1151 Test Method for Effect of Moisture and Temperature on Adhesive Bonds[2]

D 1183 Test Methods for Resistance of Adhesives to Cyclic Laboratory Aging Conditions[2]

D 1780 Practice for Conducting Creep Tests of Metal-to-Metal Adhesives[2]

D 2294 Test Method for Creep Properties of Adhesives in Shear by Tension Loading (Metal-to-Metal)[2]

D 2295 Test Method for Strength Properties of Adhesives in Shear by Tension Loading at Elevated Temperatures (Metal-to-Metal)[2]

D 2339 Test Method for Strength Properties of Adhesives in Two-Ply Wood Construction in Shear by Tension Loading[2]

[1] This guide is under the jurisdiction of ASTM Committee D14 on Adhesives and is the direct responsibility of Subcommittee D14.80 on Metal Bonding Adhesives.

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[2] *Annual Book of ASTM Standards*, Vol 15.06.

D 2919 Test Method for Determining Durability of Adhesive Joints Stressed in Shear by Tension Loading[2]

D 3163 Test Method for Determining Strength of Adhesively Bonded Rigid Plastic Lap-Shear Joints in Shear by Tension Loading[2]

D 3164 Test Method for Determining the Strength of Adhesively Bonded Plastic Lap-Shear Sandwich Joints in Shear by Tension Loading[2]

D 3165 Test Method for Strength Properties of Adhesives in Shear by Tension Loading of Single-Lap-Joint Laminated Assemblies[2]

D 3166 Test Method for Fatigue Properties of Adhesives in Shear by Tension Loading (Metal/Metal)[2]

D 3434 Practice for Multiple-Cycle Accelerated Aging Test (Automatic Boil Test) for Exterior Wet Use Wood Adhesives[2]

D 3528 Test Method for Strength Properties of Double Lap Shear Adhesive Joints by Tension Loading[2]

D 3632 Practice for Accelerated Aging of Adhesive Joints by the Oxygen-Pressure Method[2]

D 3983 Test Method for Measuring Strength and Shear Modulus of Nonrigid Adhesives by the Thick Adherend Tensile Lap Specimen[2]

D 4027 Test Method for Measuring Shear Properties of Structural Adhesives by the Modified-Rail Test[2]

D 4562 Test Method for Shear Strength of Adhesives Using Pin-and-Collar Specimen[2]

D 5868 Test Method for Lap Shear Adhesion for Fiber Reinforced Plastic (FRP) Bonding[2]

E 6 Terminology Relating to Methods of Mechanical Testing[3]

E 229 Test Method for Shear Strength and Shear Modulus of Structural Adhesives[2]

3. Terminology

3.1 *Definitions:*

3.1.1 The following terms are defined in accordance with Terminologies D 907 and E 6.

3.2 *creep*—the time-dependent increase in strain in a solid resulting from force.

3.3 *shear strength*— the maximum shear stress which a material is capable of sustaining. Shear strength is calculated from the maximum load during a shear or torsion test and is based on the original dimensions of the cross section of the specimen. (See *apparent* and *true shear strength*).

3.4 *strain*—the unit change due to force, in the size or shape of a body referred to its original size or shape. Strain is a nondimensional quantity, but is frequently expressed in inches per inch, centimeters per centimeter, etc. (Refer to Terminology E 6 for specific notes.)

3.4.1 *linear (tensile or compressive) strain*—the change per unit length due to force in an original linear dimension.

3.4.2 *shear strain*— the tangent of the angular change, due to force, between two lines originally perpendicular to each other through a point in a body.

3.5 *stress*—the intensity at a point in a body of the internal forces or components of force that act on a given plane through the point. Stress is expressed as force per unit of area (pounds-force per square inch, newtons per square millimetre, etc.).

NOTE 1—As used in tension, compression, or shear tests prescribed in product specifications, stress is calculated on the basis of the original dimensions of the cross section of the specimen.

3.5.1 *normal stress*— the stress component perpendicular to the plane on which the forces act. Normal stress may be either:

3.5.1.1 *compressive stress*—normal stress due to forces directed toward the plane on which they act, or

3.5.1.2 *tensile stress*— normal stress due to forces directed away from the plane on which they act.

3.5.2 *Discussion*—In single-lap specimen testing, the plane on which the forces act is the bondline. Tensile stress is sometimes used interchangeably, although incorrectly, with peel or cleavage stress. Peel and cleavage involve complex tensile, compressive, and shear stress distributions, not just tensile stress.

3.5.3 *shear stress*— The stress component tangential to the plane on which the forces act.

3.6 *Definitions of Terms Specific to This Standard:*

3.6.1 *allowable design stress*—a stress to which a material can be subjected under service conditions with low probability of mechanical failure within the design lifetime.

3.6.1.1 *Discussion*—Allowable design stress is obtained usually by multiplying the true shear strength of the material (or close approximation thereof) by various adjustment factors for manufacturing quality control, load and environmental effects, and safety.

3.6.2 *apparent shear strength*—(in testing a single-lap specimen) the nominal shear stress at failure without regard for the effects of geometric and material effects on the nominal shear stress. Often called the *lap-shear* or *tensile-shear strength*.

3.6.3 *average stress*—(in adhesive testing) the stress calculated by simple elastic theory as the load applied to the joint divided by the bond area without taking into account the effects on the stress produced by geometric discontinuities such as holes, fillets, grooves, inclusions, etc.

3.6.3.1 *Discussion*—The average shear and tensile stresses are denoted by τ_{avg} and σ_{avg} respectively. (See 5.3.1.1.) (*Average stress* is the same as the preferred but less common term, *nominal stress*, as defined in Terminology E 6.)

3.6.4 *cleavage stress*—(in adhesive testing) a term used to describe the complex distribution of normal and shear stresses present in an adhesive when a prying force is applied at one end of a joint between two rigid adherends.

3.6.5 *peel stress*—(in adhesive testing) a term used to describe the complex distribution of normal and shear stresses present in an adhesive when a flexible adherend is stripped from a rigid adherend or another flexible adherend.

3.6.6 *single-lap specimen*—(in adhesive testing) a specimen made by bonding the overlapped edges of two sheets or strips of material, or by grooving a laminated assembly, as shown in Test Methods D 2339 and D 3165. In testing, a single-lap specimen is usually loaded in tension at the ends.

[3] *Annual Book of ASTM Standards*, Vol 03.01.

NOTE 2—In the past this specimen has been referred to commonly as the tensile-shear- or the lap-shear-specimen. These names imply that this is a shear dominated joint, and that the measured strength is the shear strength of the adhesive. This is not true for most uses of such specimens. (An exception would be where the adhesive being evaluated is so low in strength as not to induce any bending in the adherends.) It is recommended that, henceforth, this specimen be referred to as a single-lap specimen.

3.6.7 *stress concentration*—a localized area of higher than average stress near a geometric discontinuity in a joint or member (such as a notch, hole, void, or crack); or near a material discontinuity (such as a bonded joint or weld) when the joint or member is under load.

3.6.7.1 *Discussion*—In adhesive testing, the most common and important discontinuities are the ends of the bonded adherends and the interfaces between the adhesive and adherends.

3.6.8 *stress concentration factor*—the ratio of the stress at a point in a stress concentration to the average stress.

3.6.9 *thick adherend*—(in adhesive testing) an adherend used in a single-lap specimen that does not bend significantly when a load is applied, resulting in relatively lower tension/normal stress at the ends of the overlap; and, more uniform normal and shear stress distributions in the adhesive compared to a joint made with thin adherends and placed under the same load.

3.6.9.1 *Discussion*—A thick adherend for a typical epoxy adhesive and steel joint is at least 0.25 in. (6.36 mm) thick when the overlap is 0.50 in. (12.7 mm), based on finite element analysis and mechanical tests **(1 and 2)**.[4] Objective criteria for determining whether or not an adherend is thick are given in Test Method D 3983.

3.6.10 *thin adherend*—(in adhesive testing) an adherend used in a single-lap specimen that bends significantly, causing significant tension/normal stresses in the adhesive at the ends of the overlap and nonuniform shear and normal stress distributions in the adhesive when a load is applied.

3.6.10.1 *Discussion*—The bending of the adherends, the tension-normal stresses, and the nonuniform stress distributions are continuous functions of the adhesive modulus and thickness, the adherend modulus, and the joint overlap length as described more fully in Test Method D 3983. An adherend thickness to overlap length ratio of less than 1:5 is a reasonable approximation of a thin adherend for epoxy-steel joints **(1 and 2)**.

3.6.11 *true shear strength*—the maximum uniform shear stress which a material is capable of sustaining in the absence of all normal stresses.

4. Significance and Use

4.1 Single-lap specimens are economical, practical, and easy to make. They are the most widely used specimens for development, evaluation, and comparative studies involving adhesives and bonded products, including manufacturing quality control.

4.2 Special specimens and test methods have been developed that yield accurate estimates of the true shear strength of adhesives. These methods eliminate or minimize many of the deficiencies of the thin-adherend single-lap specimens, but are more difficult to make and test. (See Test Methods D 3983, D 4027, D 4562, and E 229.)

4.3 The misuse of strength values obtained from such Test Methods or Practices as D 906, D 1002, D 1144, D 1151, D 1183, D 1780, D 2294, D 2295, D 2339, D 3163, D 3164, D 3165, D 3434, D 3528, D 3632, and D 5868, as allowable design-stress values for structural joints could lead to product failure, property damage, and human injury.

5. Considerations for the Analysis of Small Single-Lap Specimen Test Results

5.1 The true shear strength of an adhesive can be determined only if normal stresses are entirely absent. These conditions can be approached under special conditions, but not in single-lap specimens made with the thin adherends normally used in manufacturing and in most standard test specimens. In most cases the tensile stress in the adhesive controls joint failure. As a consequence the single-lap specimen strength is unrelated to, and an unreliable measure of, the true shear strength of an adhesive **(1 and 2)**.

5.2 Changes in adhesive volume during cure, the size of the joint, the modulus of the adherends, and temperature or moisture shifts after cure, all affect the magnitude of the stresses imposed on an adhesive in service. The thermal conductivity and permeability of the adherends affect the extent of thermal or moisture softening and the rate of chemical degradation of the adhesive in service. Therefore, in addition to the problems stated in 5.1, the average stress at failure of small single-lap specimens after a given exposure is an unreliable measure of an adhesive's environmental resistance in any other joint, especially a much larger structural joint.

5.3 *Factors Affecting Apparent Shear Strength*:

5.3.1 Specimen geometry, material properties, and load are factors affecting *apparent shear strength*. The shear and normal stresses at any point in a single-lap specimen are described mathematically in the classic linear-elastic analysis of Goland and Reissner **(3)**. Modern finite element analysis has proven the Goland and Reissner analysis to be accurate except at the very ends of the overlap **(1)**. Both the Goland and Reissner and finite element analyses show that both the normal and shear stress concentration factors increase toward the ends of the overlap (Fig. 1). Usually the tensile stress concentration is higher and is the dominant factor in failure. This means that peak stresses, and in particular the peak tensile stresses cause failure, not the average shear stress across the bonded area. Thus the strength of a single-lap specimen, or the apparent shear strength of the adhesive, is simply the average shear stress that happens to exist in the joint when the stress concentrations reach a critical level and the joint fails. It is not the true shear strength of the adhesive.

5.3.2 In addition to the problem of determining the true shear strength of the adhesive with a single-lap specimen, both shear- and tensile-stress concentrations are controlled by the following geometric-, material-, and load-parameters, as shown by Goland and Reissner **(3)**:

[4] The boldface numbers in parentheses refer to the list of references at the end of this guide.