Designation: F1269 – 13 (Reapproved 2018)

Standard Test Methods for Destructive Shear Testing of Ball Bonds[1]

This standard is issued under the fixed designation F1269; 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 These test methods cover tests to determine the shear strength of a series of ball bonds made by either thermosonic or thermal compression techniques using either gold or copper wires.

NOTE 1—Common usage at the present time considers the term "ball bond'' to include the enlarged spheriodal or nailhead portion of the wire, (produced by the flameoff/spark [EFO] and first bonding operation in the thermosonic [or thermal compression] process), and the ball bond-bonding pad interfacial-attachment area or weld interface.

1.2 These test methods cover ball bonds made with small diameter (from 18 to 76-µm (0.0007 to 0.003-in.)) gold or copper wire of the type used in integrated circuits and hybrid microelectronic assemblies, system on a chip, and so forth.

1.3 These test methods can be used only when the ball height and diameter are large enough and adjacent interfering structures are far enough away to allow suitable placement and clearance (above the bonding pad and between adjacent bonds) of the shear test ram.

1.4 These test methods are destructive. They are appropriate for use in process development or, with a proper sampling plan, for process control or quality assurance.

1.5 The values stated in SI units are to be regarded as the standard. The values given in parentheses are for information only.

1.6 *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, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.7 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

F458 Practice for Nondestructive Pull Testing of Wire Bonds

F459 Test Methods for Measuring Pull Strength of Microelectronic Wire Bonds

2.2 *NIST Documents:*[3]

NBS Handbook 105-1 Specification and Tolerances for Reference Standards and Field Standards, Weights and Measures

IOLM Class M2-Circular 547-1 Precision Laboratory Standards of Mass and Laboratory Weights

2.3 *Military Standard:*[4]

MIL-STD 883, Method 2010

3. Terminology

3.1 *Definitions of Terms Specific to This Standard:*

3.1.1 *ball lift*—a separation of the ball bond at the bonding pad interface with little or no residual (less than 25 % of the bond deformation area) ball metallization remaining on the bonding pad (that remains essentially intact). In the case of gold ball bonds on aluminum pad metallization, a ball lift is defined as a separation of the ball bond at the bonding pad interface with little or no intermetallic formation either present or remaining (area of intermetallic less than 25 % of the bond deformation area).

3.1.1.1 *Discussion*—Intermetallic refers to the aluminum gold alloy formed at the ball bond pad metallization interfacial area where a gold ball bond is attached to an aluminum pad metallization. If the wire/ball is of copper, then the aluminum intermetallic is normally much thinner and may not be optically observable.

3.1.2 *ball shear (weld interface separation)*— an appreciable intermetallic (in the case of the aluminum-gold system) and ball metallization, or both, (in the case of the gold-to-gold

[1] These test methods are under the jurisdiction of ASTM Committee F01 on Electronics and is the direct responsibility of Subcommittee F01.03 on Metallic Materials, Wire Bonding, and Flip Chip.

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[2] 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.

[3] Available from the National Technical Information Service, 5285 Port Royal Rd., Springfield, VA 22161.

[4] Available from Standardization Documents Order Desk, Bldg. 4 Section D, 700 Robbins Ave., Philadelphia, PA 19111-5094, Attn: NPODS.

system) remains on the bonding pad (area of remaining metal or intermetallic greater than 25 % of the bond deformation area).

3.1.3 *bonding pad lift (substrate metallization removal)*—a separation between the bonding pad and the underlying substrate. The interface between the ball bond and the residual pad metallization attached to the ball remains intact.

3.1.4 *cratering*—bonding pad lifts taking a portion of the underlying substrate material with it. Residual pad and substrate material are attached to the ball. The interface between the ball and this residual material remains intact.

3.1.4.1 *Discussion*—It should be noted that cratering can be caused by several factors including the ball bonding operation, the post-bonding processing, and even the act of shear testing itself. If cratering occurs, chemically etch off the ball bonds and bond pads of untested units and microscopically check for cratering. Cratering caused prior to the shear test operation is unacceptable.

Various aspects of the failure mode definitions are illustrated in Fig. 1.

4. Summary of Test Methods

4.1 The microelectronic device with the ball bond (wire bond (see Practice F458 and Test Methods F459)) to be tested is held firmly in an appropriate fixture. A shearing ram is positioned parallel to the substrate and approximately 25 µm (1 mil) above the substrate metallization (except for the case of fine pitch bond bonds and pads, where the ram height can be lower, depending on the pitch, final ball height,[5] and so forth. A typical shearing configuration is shown in Fig. 2. The ram is then moved into the ball until the ball separates from the substrate. The force applied to the ram, in order to cause the failure of the ball bond, is recorded. The mode of failure (for example, ball lift, weld-interface separation, cratering, etc.) is observed and recorded.

NOTE 2—Bonds made with larger or smaller diameter wire may require that the ram be placed further above the substrate, or lower, but in all cases the ram should be located below the ball's horizontal centerline. The distance below the center should be at least half the distance between the center line and the substrate.

NOTE 3—Besides ball separation from the substrate, other modes of failure are possible and will be described in Section 6.

5. Significance and Use

5.1 Failure of microelectronic devices is often due to the failure of an interconnection bond. The most common type of interconnection bond is the thermosonic gold or copper wire bond. A very important element of this interconnection is the first bond or ball bond. These test methods can assist in maintaining control of the process for making ball bonds. They can be used to distinguish between weak and nonadherent ball bonds, of both, and bonds that are acceptably strong.

5.2 These test methods are appropriate for on-line use in process control, for process development, for purchase specifications, and for research in support of improved yield and reliability. Since the ball shearing method tests only the first bond in a microelectronic wire bond interconnection system, it must be used in a complementary fashion[5,6] with the wire bond pull test.[3]

6. Inferences

6.1 The most common interference is wire shear in which the ball is sheared too high or offline. Only a minor fragment of the ball is attached to the wire. The major portion of the ball remains on the pad with the bond-pad weld interface region intact. Wire shear is illustrated in Fig. 1, View B.

6.2 Many of the common interference modes (such as wire shear) are caused by improper positioning of the ram during the ball shear operation as shown in Fig. 3. Rams that are too high (Fig. 3, View B) or angled upward (Fig. 3, View D) result in lower than normal shear strength values. Rams that are angled downward (Fig. 3, View C and Fig. 4) or positioned too low (Fig. 3, View A) will strike the bonding pad and the substrate, or both, (chip) and cause inordinately high shear strength as well as potentially damage the shearing ram.

6.3 Shearing gold ball bonds on gold metallization pads or substrates can lead to friction rewelding as illustrated in Fig. 4. As a strongly welded gold bond is sheared, the ball tends to tip away from the ram and contact the substrate as it moves. The ball smears against the pad metallization and rewelds itself often several times before it finally clears the metallization.

6.4 In bonding systems in which excessive intermetallic growth has formed around the ball bond, the shearing ram may contact the intermetallic rather than the ball bond and thus the shear readings can be in error (that is, weak ball bond shear is masked by the shear strength of the strong intermetallic wreath surrounding it.

6.5 When the bond pad pitch becomes too small to practically shear test (which appears to be around ≤30 µm pitch with current equipment) then the only alternative is to use the destructive bond pull test, Test Methods F459, and accept that resultant value, even if the ball lifts or pulls up the bond pad, assuming that value is acceptable by pull test criteria.

7. Apparatus

7.1 *Ball Bond Shearing Machine*—Apparatus for measuring the ball bond shear strength are required with the following components:

7.1.1 *Shearing Ram*—Various shearing tools or rams have been recommended in the technical literature, but the ones that appear the most effective have a flat chisel shape with a shearing edge dimension equal to approximately 1 to 2-ball diameters as shown in Fig. 5. For 25.4-µm (1-mil) diameter wire this dimension would be approximately 0.152 mm (6 mils).

[5] Charles, Jr., H. K. and Clatterbaugh, G. V., "Ball Bond Shearing—A Complement to the Wire Bond Pull Test," *International Journal of Hybrid Microelectronics*, Vol 6, No. 1, 1983, p. 171.

[6] Harman, G. G. "The Microelectronic Ball-Bond Shear Test—A Critical Review and Comprehensive Guide to its Use'', *International Journal of Hybrid Microelectronics*, Vol 6, No. 1, 1983, p. 127; also Harman, G. G., *Wire Bonding in Microelectronics*, Third Edition, McGraw Hill, 2010, pp. 110-118.

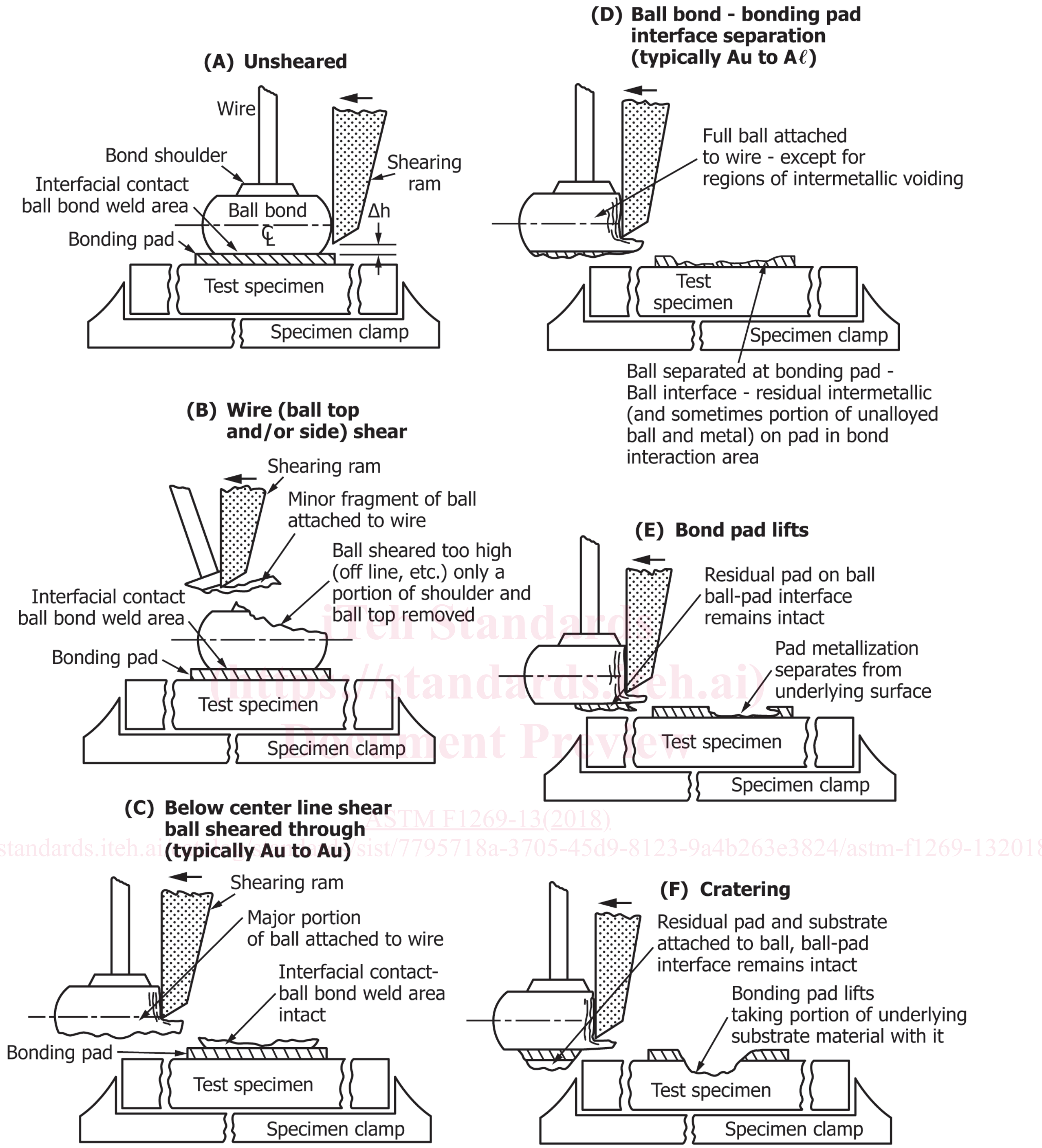


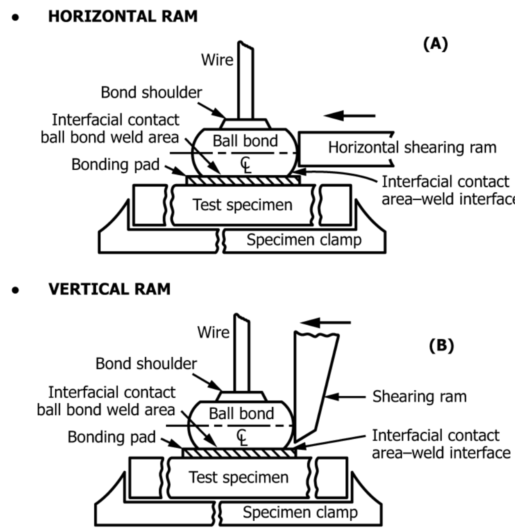
FIG. 1 Ball Shear Failure Modes

7.1.2 *Shearing and Gaging Mechanism*—Mechanism for applying a measured vertical (or horizontal) force to the shearing is needed. The mechanism shall incorporate a means for recording maximum force applied and shall be capable of applying the shear force at a uniform rate of ram motion. Force application rate can be variable (either continuously or in fixed steps) to accommodate different shearing conditions and configurations, or both. In no case should the ram speed exceed 6.0 mm/s.

NOTE 4—It has been shown that the shear force is independent of force application rate in the range from 0.25 to 6.0 mm/s.

NOTE 5—Electronic-strain gage-force reading mechanisms are the industry standard; however, the dynamometer type mechanisms known as" gram gages'' may be used satisfactorily providing careful calibration test procedures are employed.

7.1.2.1 The range of the force reading gage/sensor shall be selected so that the maximum scale reading will be no greater than three times the expected average ball bond shear strength.



NOTE 1—Schematic diagrams of the ball shear test. (A) Horizontal sample and horizontal ram. (B) Horizontal sample and vertical ram.

FIG. 2 Ball Shear Test Configurations

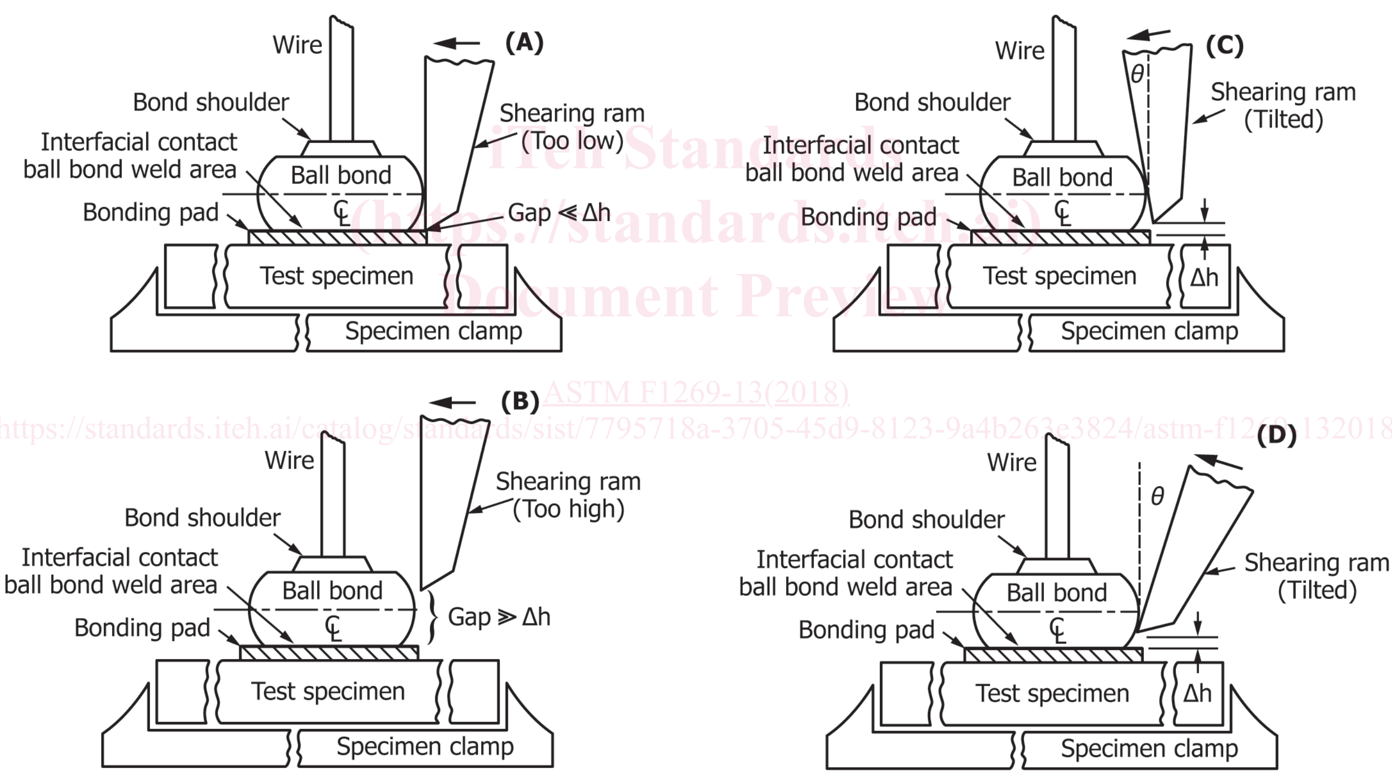


FIG. 3 Ball Shear Interferences

Anticipated force ranges for the various wire sizes and materials covered by these test methods are summarized[6] in Fig. 6.

NOTE 6—The maximum scale range of the electronic strain gage with digital readout may be larger than three times the expected average shear strength providing the accuracy specified in 10.7.6 is maintained over the entire range of the load cell.

7.1.3 *Microscope and Light Source*—Zoom microscope with a light source for viewing the device under test is needed. The minimum magnification shall be at least 60×.

7.1.4 *Device Holder*—A clamping mechanism for rigidly holding the device under test in either a horizontal or vertical position depending upon shear tester configuration is required (see 7.2).

7.1.5 *Calibration Masses*—At least five masses (weights) with mass values known to an accuracy of 0.5 % (or better, such as NBS Class T or IOLM Class M2 (NBS Handbook 105-1 and Circular 547. IOLM) [3]) sized to cover the shearing and gaging mechanism range of force measurements and