JEDEC STANDARD

Wire Bond Pull Test Methods

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WIRE BOND PULL TEST METHODS

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WIRE BOND PULL TEST METHODS

(From JEDEC Board Ballot JCB-22-47, formulated under the cognizance of the JC-14.1 Subcommittee on Silicon Devices Reliability Qualification and Monitoring.)

1 Scope

This test method provides a means for determining the strength and failure mode of a wire bonded to, and the corresponding interconnects on, a die or package bonding surface and may be performed on pre-encapsulation or post-encapsulation devices. This test method may be performed on gold alloy, copper alloy, and silver alloy thermosonic (ball and stitch) bonds made of wire ranging in diameter from 15 µm to 76 µm (0.6 mils to 3.0 mils); and on gold alloy, copper alloy, and aluminum alloy ultrasonic (wedge) bonds made of wire ranging in diameter from 18 µm to 600 µm (0.7 mils to 24.0 mils).

This wire bond pull test method is destructive. It is appropriate for use in process development, process control, and/or quality assurance.

This test method allows for two distinct methods of pulling wires:

1) One method incorporates the use of a hook that is placed under the wire and is then pulled.
2) One method requires that after the wire be cut, a clamp is placed on the wire connected to the bond to be tested, and this clamp is used to pull the wire.

This test method defines three pull tests. The Wire Pull Test (WPT) is appropriate for all bonded wires. The Bond Pull Test (BPT) and Stitch Pull Test (SPT) are appropriate for thermosonically bonded wires.

This test method can also be used on the following four applications of thermosonic and ultrasonic bonds, though each requires special considerations when performing the test method:

a) Pulling aluminum wires and aluminum ribbons that are bonded with multiple ultrasonic bonds. See 5.3.1.1.1 for special considerations. Multiloop wires and ribbons are used in some high-power device packages.
b) Pulling wires of reverse bonds which are also known as “stitch on ball”. These types of bonds can include gold stitch on gold ball, copper stitch on copper ball, and copper stitch on gold ball. See A.1 in Annex A for additional information.
c) Pulling a thermosonically bonded wire that has a security bond or security loop placed on top of the stitch bond in order to provide additional strength. See A.2 for additional information.
d) Pulling thermosonic wire bonds on stacked dice when wires and/or bonds are not accessible to allow for proper pull testing. See 5.3.1.1.3 for special considerations.

2 Normative References

JESD47, *Stress-Test-Driven Qualification of Integrated Circuits*

Also see Annex H (informative) References.

3 Terms and Definitions

For the purposes of this standard, the following terms and definitions apply:

bond, wire: The adhesion or welding of a wire (typically gold, aluminum, copper, or silver) to a bonding surface using a thermosonic or ultrasonic wire bonding process.

ball bond: The first bond during the thermosonic (ball) bonding process, in which the end of a small diameter wire (typically gold, copper, or silver) is bonded to a die bonding surface (typically an aluminum alloy die pad metallization).

NOTE The ball bond includes the enlarged spherical or nail-head portion of the wire that is provided by the electronic flame-off), the underlying bonding pad, and the metallurgical weld interface between the ball bond and the bonding pad.

stitch bond: The second bond during the thermosonic (ball) bonding process, in which the wire is typically bonded to the package bonding surface (e.g., leadframe, substrate, post, etc.).

NOTE 1 A stitch bond may also be referred to as a crescent bond.

NOTE 2 For some unique constructions (e.g., reverse bond), the second bond may be formed on top of a bump. See also “reverse bond” and “bump”).

wedge bond: The attachment of a wire (typically aluminum, copper, or gold) or an aluminum ribbon to a die bonding surface (typically aluminum pad metallization) or the package bonding surface (usually a plated leadframe post or finger) using an ultrasonic bonding process.

bonding surface: Surface to which the wire is bonded, which may be any one of the following: 1) the die pad metallization or die surface metallization (e.g., MOSFET), 2) the package surface metallization (e.g., leadframe, substrate, post), 3) a bump (see also “reverse bond” and “bump”), or 4) a bonded stitch on die pad/flag or package surface metallization (see also “security bond” and “security loop”).

bonding process, thermosonic: A bonding process in which two members are joined through the combined application of heat, pressure, and an ultrasonic oscillatory lateral motion.

bonding process, ultrasonic: A bonding process in which two members are joined through the combined application of pressure and an ultrasonic oscillatory lateral motion.

bonding wire: A wire that is bonded to a chip bonding surface in order to electrically connect the chip to any other point within the device package.

3 Terms and Definitions (cont'd)

ribbon (wire): A flat wire (non-round).

NOTE Throughout this test method the term "wire" covers both wire and ribbon (wire).

aluminum wire: A aluminum alloy wire in which the aluminum content is typically 98% or greater.

copper wire: A copper alloy wire in which the copper content is typically 99%, but also includes copper wire with a very thin coating of palladium or gold and palladium.

gold wire: A gold alloy wire in which the gold content is typically 99% or greater.

silver wire: A silver alloy wire in which the silver content is typically greater than 85% for integrated circuits (ICs) and greater than 75% for light emitting diodes (LEDs).

midspan: A location on the bonded wire that is approximately one half of the horizontal distance between the two bonds. (See Figure 1)

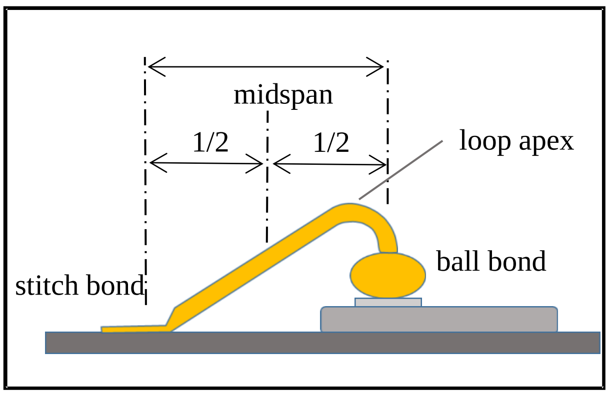


Figure 1 – Definition of Midspan

outlier product: Product that meets manufacturer specifications and user requirements but exhibits anomalous characteristics with respect to a normal population (an example of which is depicted by the histogram in Figure 2) and may be subject to a higher-than-normal level of failures in the user's application.

NOTE 1 For purposes of this document, all Wire Bond Pull Tests have only a minimum pull value requirement and no upper limit, thus the upper specification limit (USL) is not applicable.

NOTE 2 See also JESD50, "Special Requirements for Maverick Product Elimination and Outlier Management".

3 Terms and Definitions (cont'd)

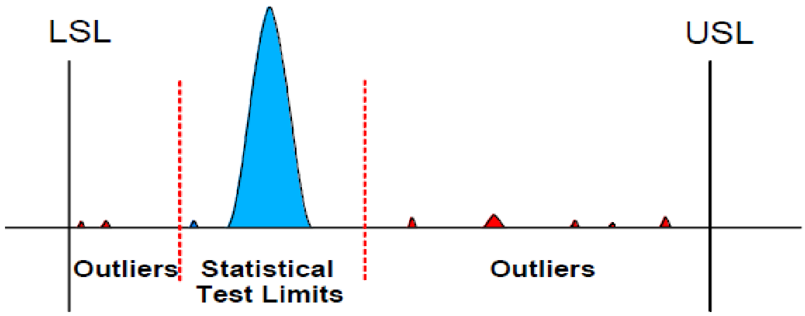


Figure 2 – Depiction of Eight Outliers, Seven of Which are Outlier Products

reverse bond: A thermosonic bond for which the ball is placed on the package bonding surface and the stitch is placed on a bump on the die. This is also known as "stitch on ball".

bump: A thermosonic ball bond from which the wire has been removed. It can be used as the underlying ball bond for reverse bonds on which the stitch (2nd bond) for the reverse bond is placed, or the ball bond placed on a stitch bond to form a security bond.

security bond: The placing of a bump (see also "bump") on top of a stitch bond to improve the mechanical strength of a stitch bond to withstand the shearing stress between the encapsulation material and the bonding surface.

NOTE Security bonds are commonly used in surface mount LED (light emitting diode) packages which use non-filled encapsulants for the lens material that have higher coefficients of thermal expansion than silica filled encapsulants, and thus exhort higher shear stresses on the stitch bond.

security loop: A security bond from which the wire has not been removed and the wire for the security loop is attached to the same bonding surface as a stitch bond.

wire bond pull, destructive: A process in which an instrument pulls on a thermosonic or ultrasonic bonded wire until failure.

wire bond pull, non-destructive: A process in which an instrument pulls on a thermosonic or ultrasonic bonded wire with a specified load that is below the minimum destructive pull value, such that no permanent damage or degradation is expected to be imparted on the wire.

wire bond pull force (destructive): The force required to cause any of the following to occur: the bonded wire to break; one of the bonds to separate from a bonding surface; or one of the bonding surfaces to separate from the die, leadframe, or substrate.

4 Apparatus and Material

The apparatus and materials required for wire bond pull testing shall be as follows:

4.1 Inspection Equipment

An optical microscope system or scanning electron microscope with a minimum of 70X magnification is required to support the optical assessment of the resulting failure mode, such as whether the wire break was ductile or brittle or if the bond lifted from pad or leadframe/substrate with or without residues on pad or leadframe/substrate).However, a higher magnification may be necessary for verifying Failure Codes 1, 2, 3, 6, 7, 8, and 9 (see 5.5 for a detailed discussion of Failure Codes).

4.2 Workholder

The fixture used to hold the device, known as the "workholder" shall prevent any movement of the device during wire bond pull testing and shall allow positioning the hook for optimum force application to the wire.

4.3 Wire Bond Pull Equipment

The apparatus shall consist of suitable equipment for applying a pulling force to the bonding wire as required per this test method until failure occurs within the wire, wire bond, or wire bonding surface. The equipment shall be capable of applying force at a constant rate. The equipment shall indicate the applied force in SI and/or English units and be calibrated over the full range of the expected values for the specific wire being pulled with an accuracy of ±5 percent of the intended breaking load or ±2.9 mN (±0.3 gf), whichever is the greater tolerance. The required range of force values will vary by wire material and wire cross-section.

The pull tester manufacturer's recommended pulling tool travel speed for the wire material being tested should be used. To verify that the pull speed for a test was in an acceptable range, the output of the loadcell shall be reviewed to ensure that the strain rate was consistent throughout the test.

4.4 Pulling Hook

The pulling hook should be made of a strong, rigid material that will not deform during pull testing. The diameter of the wire used to make the hook utilized to apply force to the interconnect wire shall be large enough and its final shape shall be such to ensure that the force applied by the hook distributes the pull force through the wire to the bonds and does not cut through the wire. Table 1 provides the minimum diameter for the pulling hook to ensure the above requirement.

Table 1 – Guidance for the Minimum Diameter of the Pulling Hook

Wire diameter	Hook diameter
≤ 50 microns (2 mils)	Minimum of 2.0x wire diameter
> 50 microns (2 mils) to ≤ 125 microns (5 mils)	Minimum of 1.5x wire diameter
> 125 microns (5 mils)	Minimum of 1.0x wire diameter

For ribbon wire, use the equivalent round wire diameter which gives the same cross-sectional area as the ribbon wire being tested. The flat portion of the hook (horizontal) should be > 1.25x the equivalent diameter of the ribbon wire being tested.

4.4 Pulling Hook (cont'd)

The hook shall be smooth (no sharp edges) and free of defects and contamination which could compromise the test results or damage the wire being pulled.

4.5 Bond Pull Clamp

For the clamp pull tests, the clamp used shall be able to apply enough force to the wire being pulled to hold it firmly such that it will not slip during the test. The clamp shall be large enough to firmly hold the diameter of the wire or width and thickness of the ribbon to be pulled such that it does not move when being pulled. The external shape and dimensions of the clamp shall be optimized to allow for it to clamp onto the wire to be pulled, but also minimize the chance of it touching and possibly damaging other wires on the device that are intended to be pull tested.

5 Procedure

5.1 Calibration

Before performing the wire bond pull test, it must be determined that the equipment has been calibrated in accordance with manufacturer's specifications and is presently in calibration. Recalibration is required if the equipment is moved to another location.

5.2 Visual Examination of Bonds to be Tested after Decapsulation

In addition to being a manufacturing process monitor, this test method can also be used to assess bonds of encapsulated devices after soldering operations or after reliability stress testing. To do this, the encapsulation material needs to be removed in a manner that does not significantly degrade the wire, the bond, the bonding interface, or the bonding surface. Bond pull force values are often lower for bonds that have been decapsulated, and therefore cannot be compared to values for similar, unencapsulated bonds. If the decapsulation process is well controlled and repeatable, which is the case for gold wire, then this test method can be used for lot-to-lot comparison; however, it may be hard to consistently control the decapsulation process for copper and silver wires to ensure the accuracy of the results. For copper (Cu) and silver (Ag) wires, the effectiveness of etch has been seen to vary due to the encapsulation material and the level of reliability stress testing performed on the samples. See Annex B for additional information regarding the decapsulation process of devices with Cu and Ag wire bonds.

Bonds must also be examined to ensure that enough encapsulation material has been removed to allow for suitable placement of the pull hook.

5.2.1 Bond Pad Examination and Acceptability Criteria for Both Aluminum and Copper Bond Pad Metallization

If performing wire bond pull testing on a device which has been opened using wet chemical and/or dry etch techniques, the bond pads shall be examined to initially ensure that there is no absence of metallization on the bonding surface area due to chemical etching, and then ensure that wire bonds are attached to the bonding surface. Bonds on aluminum or copper bond pads with significant chemical attack or absence of metallization shall not be used for wire bond pull testing.

5.2.1 Bond Pad Examination and Acceptability Criteria (cont'd)

It is possible that wire bonds on bonding surfaces without degradation from chemical attack may not be attached to the bonding surface due to other causes (e.g., package stress), however, in these cases wire bonds are considered valid and shall be included in the pull data as a zero (0) pull force value.

5.2.2 Examination and Acceptability Criteria for Cu and Ag Wire and Connections (All Bonds)

When performing wire bond pull testing on a device with copper or silver wires, the connection of the bond and wire shall be examined after decapsulation, both before or after the pull test to ensure that there is no significant loss of metal or other damage due to decapsulation process that might affect the results of the pull test. The pull result can be excluded for a copper bond or a copper wire with significant chemical attack or other damage due to the decapsulation process. Annex B provides additional information to assess what level of damage is acceptable.

5.3 Performing the Wire Bond Pull Test

Multiple wire bond pull tests are described in this document:

- wire pull (hook used to pull wire so that both bonds are stressed),
- ball pull (hook or clamp used to stress mainly the ball bond),
- stitch pull (hook or clamp used to stress mainly the stitch bond), and
- pull of wedge bonds (clamp or hook used to stress either one or both bonds).

Each of the pull tests and their variations are described below.

NOTE Not all bond pull tests give repeatable and/or reproducible results, as results may be affected by the geometry of the device and the device decapsulation results (if decapsulation is required). The determination of which wires and bonds are to be pulled within a device and by which pull test is determined by the qualification document that references this test method and should ensure that the pulling of all types of bonds is adequately addressed.

5.3.1 Hook Pull Method

The wire bond pull equipment shall pass all self-diagnostic tests before beginning the test. The wire bond pull equipment and test area shall be free of excessive vibration or movement. Examine the pull hook to ensure that the correct hook is used and to verify it is in good condition and is not bent or damaged (nicks, sharp edges, etc.). Check the pull hook to verify it is in the up position.

Adjust the workholder to match the device being tested. Position the device so that the bond to be pulled is located below the pull hook. Lower the pull hook or raise the device depending upon the wire bond pull equipment being used, so the hook is below the wire to be pulled but will not contact the surface of the die or package substrate/leadframe (Figure 3). If there is not enough space under the wire for the hook, a clamp may be used to perform the wire pull test. See 5.3.2 for details.

5.3.1 Hook Pull Method (cont'd)

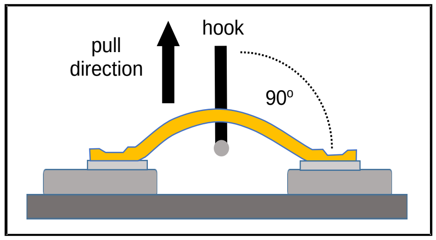


Figure 3 – Place Hook Under Wire

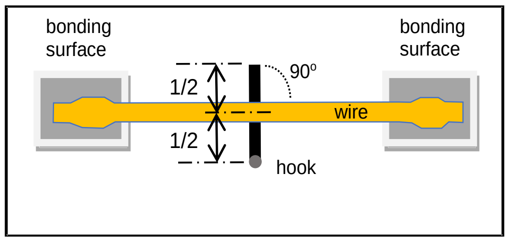


Figure 4 – Orientation of Hook with Respect to the Wire (Viewed from Above)

Position the hook with respect to the bonded wire to be tested so that it is perpendicular to the length of the wire when observed from above (see Figure 4), or if constrained by space, as close to perpendicular as possible. Position the pull hook under the wire so the wire is approximately in the middle of the hook; not too close to the end of the hook so that the wire might slip off, or too close to the inside of the hook such that the upper part of the hook does not allow for free movement of the wire. The hook should not contact the wire prior to the start of the test. Once in place, the hook shall be pull upward, perpendicular to the bonding surface whenever possible.

If the spacing between wires is less than the length of the hook, such that the hook cannot be inserted next to the wire to be pulled without contacting a wire, then use one of the following approaches to insert the hook may be used:

1) The recommended approach is to use a pull tester that has the capability to rotate the hook assembly. This capability rotates the hook to be parallel to the wires, lowers the hook below the wire loop, and then rotates it back such that the hook is orthogonal to the wire. Care must be taken to not contact the wire when it is rotated to the orthogonal position.
2) If the pull tester does not have the capability to rotate the hook assembly, the device itself may be rotated until the hook is parallel to the wires, the hook is then lowered below the wires, and then finally the device is rotated back so that the hook is orthogonal to the wire to be pulled without disturbing either adjacent wire.

The correct location for placing the hook along the length of the wire as prescribed by the type of pull test to be performed. Below are the three pull tests defined in this test method and their respective hook locations:

1) Wire Pull Test (WPT), see 5.3.1.1 - Hook pull near the mid-span of the wire
2) Ball Pull Test (BPT), see 5.3.1.2 - Hook pull near the neck of the thermosonic ball bond
3) Stitch Pull Test (SPT), see 5.3.1.3 - Hook pull near the thermosonic stitch bond

5.3.1 Hook Pull Method (cont'd)

Final hook placement shall be accomplished under observation at 15x minimum magnification. A microscope with a zoom capability may be used for indexing the hook.

If the hook contacts an adjacent wire during set-up or during the pulling operation, that adjacent wire shall not be used for pull testing. If the touched wire was required to have been pulled, then a Failure Code of 0 (See 5.5) should be applied to that wire and another wire be chosen for pull testing.

5.3.1.1 Wire Pull Test (WPT) – Hook Pull Near the Midspan of the Wire

This test may be used on thermosonic bonded gold, copper, and silver wire; on ultrasonic bonded gold, copper, silver, and aluminum wire; and aluminum ultrasonic ribbon. This method is similar to Mil Std 883, Method 2011, Condition D.

For this test the hook shall be placed approximately at the midspan of the length of the wire that is not deformed by the formation of the bonds. See Figures 5a through 5f for variations in hook placement for different types of wire bonds. Each of the diagrams in Figure 5 shows a space between two lines for the approximate placement of the hook. This test method cannot provide an exact location for the placement of the hook due to differences in wire length and shape for each bonded wire. Whenever possible, it is recommended that each wire to be pulled be reviewed and a specific location be identified to minimize variability in the results if multiple samples of the same device are to be pull tested.

5.3.1.1 Wire Pull Test (WPT) (cont'd)

The hook shall be in a fixed position that restricts motion along a straight line between each bond, so that it will not rise to the highest point which could result in a test for only one bond (e.g., as for a ball bond).

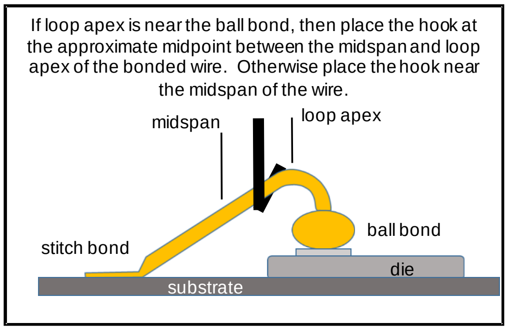


Figure 5a – Thermosonic (die to substrate)

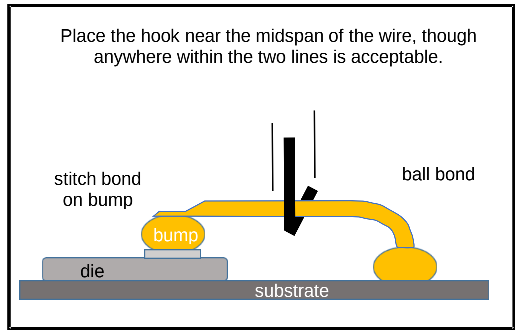


Figure 5b – Thermosonic (reverse)

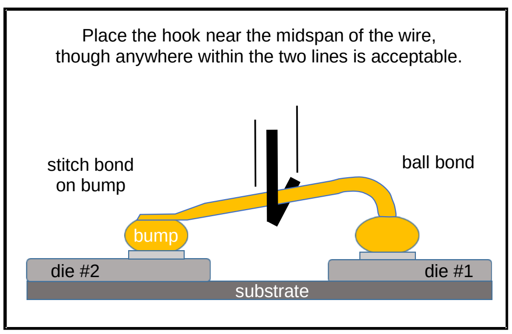


Figure 5c – Thermosonic (Die to Die)

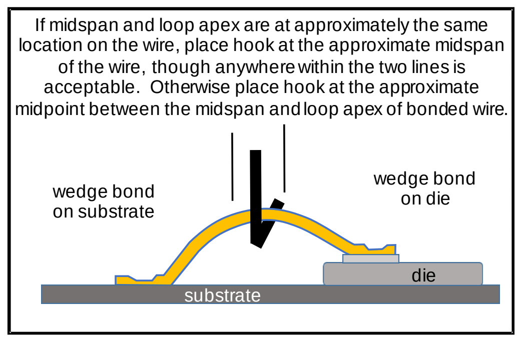


Figure 5d – Ultrasonic (die to substrate)

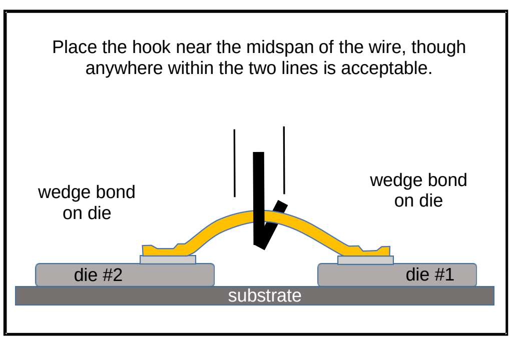


Figure 5e – Ultrasonic (die to die)

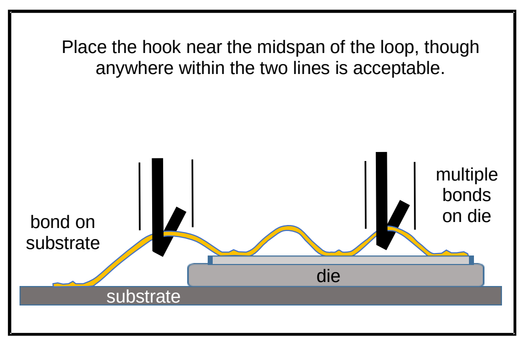


Figure 5f – Ultrasonic multi-loop wire/ribbon

NOTE If this method is to be used on wires post encapsulation, the full length of the wire must be free of material. The decision to ensure that all encapsulation material is removed from the bonds will depend on whether there is a concern for failure at either of the bonds.

Figure 5 – Hook Placement for Wire Pull Test (WPT) for Different Types of Wire Bonds

5.3.1.1.1 Special Considerations for Pulling a Bonded Ribbon or Wire with Multiple Loops

When performing (mid-span) wire pull testing on a bonded ribbon or wire with multiple loops see the requirements below for the number of loops to be pulled. If the bonded ribbon or wire has:

- 2 loops – Pull only one of the loops (as the middle bond will be weakened by the initial pull which could artificially lower the pull force for the 2^{nd} loop).
- 3 or 4 loops – Pull the outer two loops.
- 5 or more loops – Pull the outer two loops. Optionally, additional loops may be pulled as long as neither bond for the loop has been previously subjected to pull testing (i.e., neither loop on each side of the loop to be pulled has been pull tested).

5.3.1.1.2 Special Considerations for Pulling Wires and Ribbons with Low Loop Height

Wires with low loop height may prevent access of the hook for wire pull testing. Figure 6 shows a module with multiple die and the ultrasonic bonds shown have low bond angles and thus an overall low loop height.

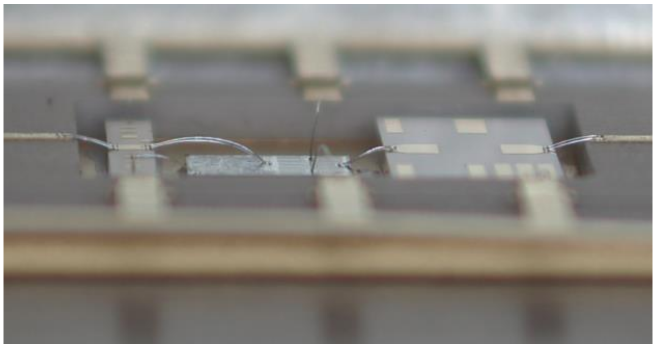


Figure 6 – Wires with Low Bond Angles

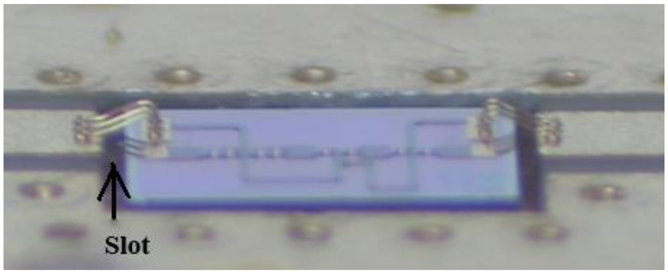


Figure 7 – Device with Slots to Allow for Hook Placement

A test coupon with either slots (Figure 7) or attached metallized ceramic chips may be used to replicate the wire loop profile and permit access of the hook to the wire to be tested. These wires are to be bonded at the same time the production devices are bonded using the same setup, operator, and schedule. The test coupon wires are to be pull tested in lieu of the inaccessible wires on the production device. Failures on the test coupon shall be considered as failures to production device and appropriate action is to be taken in accordance with the applicable specification.

5.3.1.1.3 Special Considerations for Pulling Wires on Stacked Die

Stacking configurations for packages with multiple dice can pose challenges in wire pull testing as not all wires or bonds will be exposed to allow for proper pull testing. For some die stacks, not all wires will be accessible by a hook or clamp once fully assembled. For other die stacks, some of the bonds may not be able to freely move during the pull test (e.g., are encapsulated by die adhesive material).

To enable wire pull testing for process monitoring, special test vehicles of partially assembled product should be used to allow for the pulling of wires and bonds that are not accessible once all dice are bonded. The test vehicle shall be bonded at the same time the production devices are bonded using the same processes, procedures, and controls.

When developing the test vehicle build plan, ensure that the wires chosen for pull testing cover the extremes found within the package. For example, pulling wires with the lowest and highest loop profile or pulling the top and bottom wires in a stack to sample the extremes for bonding preheat.

Figure 8 shows a stack of 8 dice, with four dice stacked like shingles going to the right, and then four dice stacked going to the left. The wires shown for the lower four dice cannot be pulled by a hook as the upper four dice create interference with the pull test. The bond on the fourth die in the stack has the additional issue that it is within the die attach film and thus would not be free to move during wire pulling test. Therefore, it is recommended that to assess the integrity of the wire bonds on the four lower dice, a test vehicle with just the bottom four dice be used for wire pull testing and actual product be used for pull testing of the wire bonds on the top four dice.

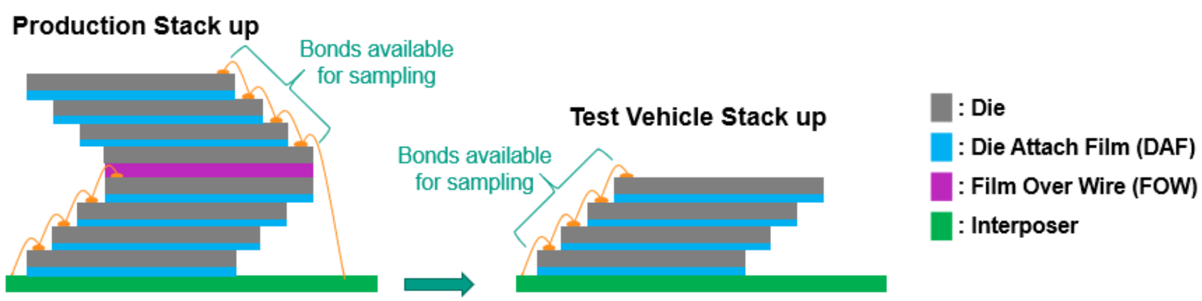


Figure 8 – Reverse "Shingle" Stack

5.3.1.1.3 Special Considerations for Pulling Wires on Stacked Die(cont'd)

Figure 9 shows a vertical stack of five dice of the same size. The ball bonds for the lower four dice are fully immersed in the die attach film of the die above it. Pulling these wires would not provide a realistic assessment of the bond strength as the film would alter the pull force value. It is also not feasible to build test vehicles ranging from 1 die, 2 die, and up to the total number of dice in the production stack. Therefore, the recommendation for pull testing of a vertical stack is as follows:

1) Build a test vehicle along with production product that consists of just the bottom die of the stack and pull the wires on that die.
2) Pull the wires of the top die of a fully assembled stack.

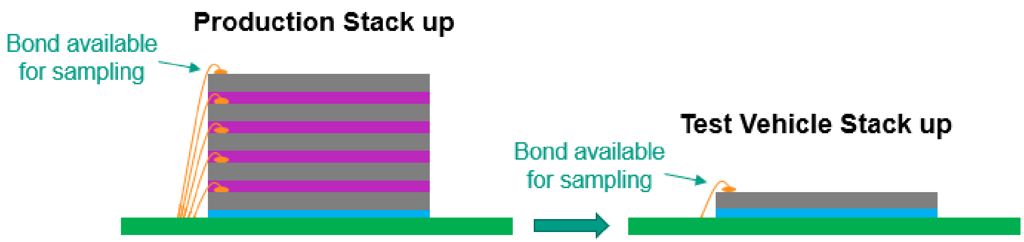


Figure 9 – Vertical Stack of Dice of the Same Size

5.3.1.2 Ball Pull Test (BPT) – Hook Pull Near the Neck of the Thermosonic Ball Bond

This test may be used for process development and product qualification on thermosonic ball bonds of gold, copper, and silver wire. This method is similar to the hook placement requirement in some industry qualification standards.

For this test the hook shall be placed as close to the ball bond as possible or within the range shown in the images below. See Figures 10a through 10c for hook placement for different types of wire bonds. Each of the diagrams in Figure 10 shows a space between two lines for the approximate placement of the hook. This test method cannot provide an exact location for the placement of the hook due to differences in wire length and shape for each bonded wire. Whenever possible, it is recommended that each ball bond to be pulled be reviewed and a specific location be identified to minimize variability in the results if multiple samples of the same device are to be pull tested.

The hook shall be in a fixed position that restricts motion away from the ball bond (the point of interest), since moving away from the point of interest could result in a test that is more of the wire and less of the ball bond.

5.3.1.2 Ball Pull Test (BPT) (cont'd)

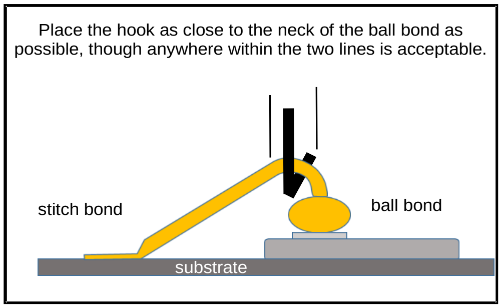


Figure 10a - Thermosonic (Die to Substrate)

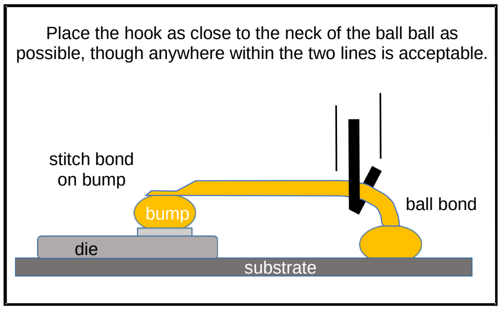


Figure 10b – Thermosonic (reverse)

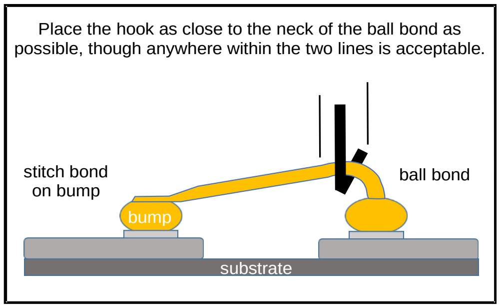


Figure 10c –Thermosonic (Die to Die)

NOTE If this method is to be used on ball bonds post encapsulation, all material must be removed from the ball bond and the full length of the wire must be free of material. The decision to ensure that all encapsulation material is removed from the stitch bond will depend on whether there is a concern for failure at the stitch bond.

Figure 10 – Hook Placement for Ball Pull Test (BPT) for Different Types of Wire Bonds

5.3.1.3 Stitch Pull Test (SPT) – Hook Pull Near the Thermosonic Stitch Bond

This test may be used on thermosonic stitch bonds of gold, copper, and silver wire. This method is similar to the hook placement requirement in some industry qualification standards.

For this test the hook shall be placed as close to the stitch bond as possible or within the range shown in the images below. See Figures 11a through 11c for hook placement for different types of wire bonds. Each of the diagrams in Figure 11 shows a space between two lines for the approximate placement of the hook. This test method cannot provide an exact location for the placement of the hook due to differences in wire length and shape for each bonded wire. Whenever possible, it is recommended that each stitch bond to be pulled be reviewed and a specific location be identified to minimize variability in the results if multiple samples of the same device are to be pull tested.

The hook shall be in a fixed position that restricts motion away from the stitch bond (the point of interest), since moving away from the point of interest could result in a test that is more of the wire and less of the stitch bond.

5.3.1.3 Stitch Pull Test (SPT) (cont'd)

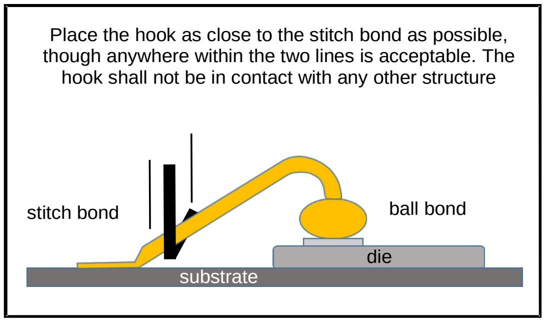


Figure 11a – Thermosonic (Die to Substrate)

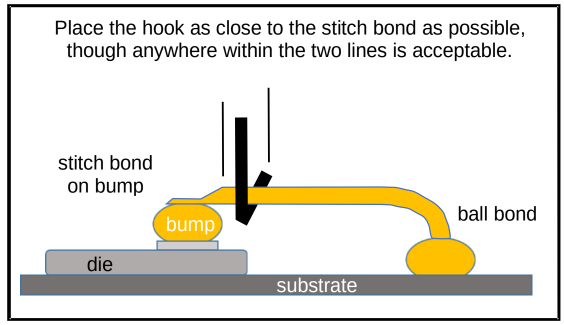


Figure 11b – Thermosonic (reverse)

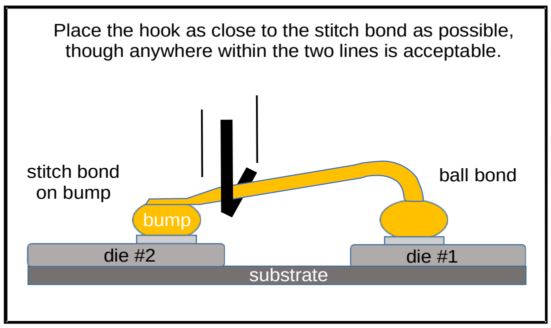


Figure 11c –Thermosonic (Die to Die)

NOTE If this method is to be used on stitch bonds post encapsulation, all material must be removed from the stitch bond and the full length of the wire must be free of material. The decision to ensure that all encapsulation material is removed from the ball bond will depend on whether there is a concern for failure at the ball bond.

Figure 11 – Hook placement for Stitch Pull Test (SPT) for different types of wire bonds

5.3.2 Clamp Pull Method of Single Bond (Cut Wire)

This test method is best suited for performing process development, design of experiments, and verifying hook pull results. This test method is not recommended for production control since it requires manually cutting the wires to be pulled, which is not required for the hook pull method.

The wire bond pull equipment shall pass all self-diagnostic tests before beginning the test. The wire bond pull equipment and test area shall be free of excessive vibration or movement. Examine the clamping tool to verify it is in good condition and is not damaged.

Adjust the workholder to match the device being tested. Cut the wire to be pulled at its mid-span. If the wire is too short to allow for each end to be properly pulled, cut the wire close to one bond in order to allow pull testing of the opposite bond. The wire should be long enough to ensure that the clamp can be firmly attached without contacting the neckdown region of the wire above the bond so that a wire break fail mode (Code 5) is still possible. Care must be taken when cutting the wire to avoid damaging the rest of the wire and the bond to be tested. See Figure 12a and Figure 12b for examples of acceptable and unacceptable clamp placement.

5.3.2 Clamp Pull Method of Single Bond (Cut Wire) (cont'd)

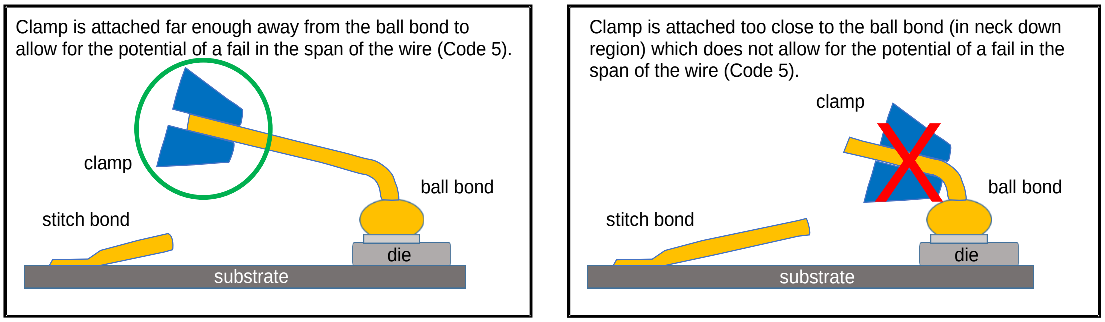


Figure 12a – Acceptable placement of clamp on wire   Figure 12b – Unacceptable placement of clamp on

Figure 12 – Examples of Acceptable and Unacceptable Placement of Clamp on Wire

Position the device so that the wire to be pulled is located below the clamping tool. Lower the clamping tool or raise the device depending upon the wire bond pull equipment being used, so the clamp is just above the wire to be pulled. Position the clamp onto the wire to be tested and then orient the sample or clamp to allow for the pulling of the wire in the direction prescribed in 5.3.2.1 or 5.3.2.2 based on the type of bond being pulled. Pull the wire in the prescribed direction.

5.3.2.1 Ball Pull Clamp Test (BPCT) – Clamp Pull of Thermosonic Ball Bond

This test condition may be used on gold, copper, and silver wire thermosonic ball bonds. For pulling thermosonic ball bonds, the direction of pull shall be straight up from the ball bond (90° with respect to bonding surface) as shown in Figure 13.

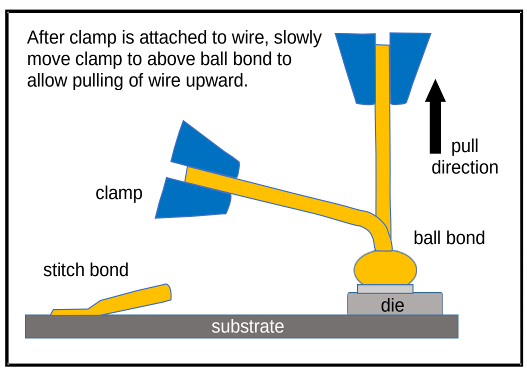


Figure 13 – Clamp Placement for Ball Pull Test

5.3.2.2 Stitch Pull Clamp Test (SPCT) – Clamp Pull of Thermosonic Stitch Bond

This test condition may be used on gold, copper, and silver wire thermosonic stitch bonds. For pulling thermosonic stitch bonds the direction of pull shall be straight up from the stitch bond (90° with respect to bonding surface) as shown in Figure 14.

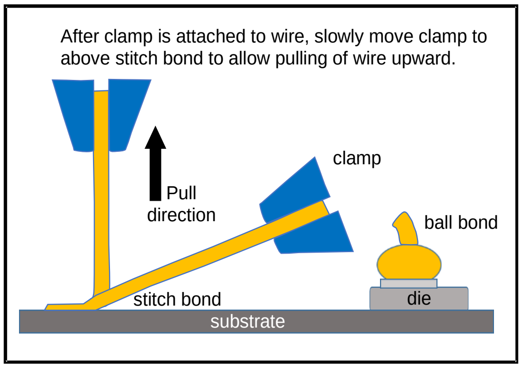


Figure 14 – Clamp Placement for Stitch Pull Test

5.4 Examination of Pulled Wire Bonds

All bonds shall be pulled in a predefined and documented sequence so that later visual examination can determine which, if any, pull values should be eliminated due to an improper pull. The point of failure shall be examined at a minimum of 70X magnification and assigned a Failure Code per 5.5.

Pulled bonds that exhibit bond pad cratering (Failure Code 1) shall be investigated further to determine whether the cracking and/or cratering is due to a preexisting condition in the silicon and/or metallization under the bond pad prior to the bonding operation or if it was due to the act of bonding. A cratering failure resulting from the bonding process shall be considered a valid failure of the wire and shall be included in the pull data. However, if investigation determines that the cratering failure was the result of a preexisting condition in the silicon and/or metallization under the bond pad then the failure is invalid for this test method and the wire shall not be included with the pull data. Note that in the latter case, even though the wire is not included in the pull data, the preexisting condition must be addressed.

5.5 Wire Bond Pull Failure Codes

Table 2 states the general descriptions for each of the Failure Codes, independent of the type of wire bond. Tables 3 through 9 provide detailed descriptions for the seven different types of wire bonds: standard thermosonic (Table 3), reverse thermosonic (Table 4), die to die thermosonic (Table 5), standard ultrasonic (Table 6), die to die ultrasonic (Table 7), substrate to substrate ultrasonic (Table 8), and multi-loop ultrasonic wire/ribbon (Table 9).

The numbering schema is consistent across all type of bonds.

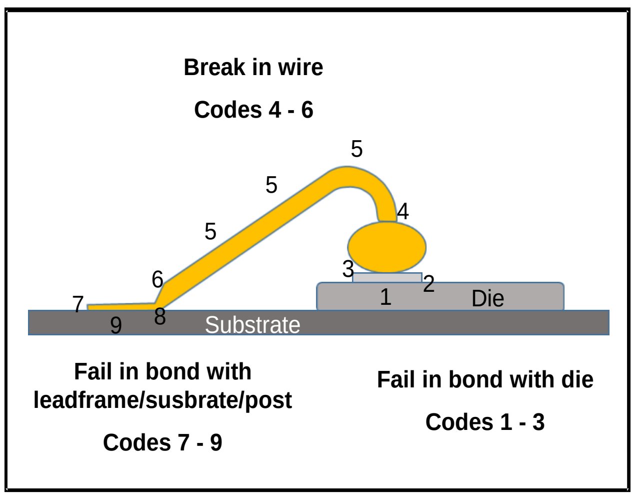
- Codes 1 to 3 are for failures associated with the bond made to the die, with Code 1 for a fracture in the die under the bond (e.g., cratering) and numerically progressing up through the bonding metallurgy to the bond with the die with Code 3 for lifted bonds.
- Codes 4 to 6 are for wire breaks and progress through the wire from breaks in the work hardened portion next to the first bond to breaks next to the second bond.
- Codes 7 to 9 are for failures associated with the bond made with the substrate/leadframe/post, progressing from a bond lift to a fracture in the substrate.

The Failure Codes used by this test method are different from those in Mil-Std 883, Method 2011. Annex C provides a comparison of the Failure Codes in this test method versus the Codes in Mil-Std 883, Method 2011.

See Table 11 in Annex D for graphic illustrations of the Failure Codes.

Table 2 – General Description of Wire Bond Pull Failure Codes for All Bond Types

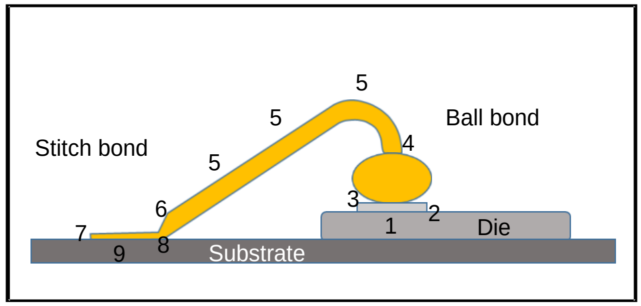
Code	Description of Failure Code
0 (zero)	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die (includes cratering).
2	Lifted die metallization or failure within die metallization.
3	Lift of bond from die metallization.
4	Break in wire in the neckdown region of the first bond.
5	Break in the span of the wire.
6	Break in wire in the neckdown region of the second bond.
7	Lift of bond from substrate/leadframe/post metallization.
8	Lifted substrate/leadframe/post metallization.
9	Fracture or lift of substrate/leadframe/post metallization.



5.5 Wire Bond Pull Failure Codes (cont'd)

Table 3 – Detailed Pull Failure Codes for Standard Thermosonically Bonded Wires

Code	Failure Codes – standard thermosonic bonds
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to ball bond).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other die bond pad metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of ball bond from die metallization (separation between ball bond and die pad metallization).
4	Break in wire in the neckdown region above the ball bond in the heat affected zone (length equal to 2x wire diameter above ball).
5	Break in the span of the wire (from 2x wire diameter above the ball bond to just above the stitch bond).
6	Break in wire in the neckdown region of the stitch bond (portion of the wire deformed by the capillary, but not bonded to the substrate/leadframe/post).
7	Lift of stitch bond from substrate/leadframe/post metallization (some to no remnant of stitch on substrate/leadframe/post).
8	Lifted substrate/leadframe/post metallization (partial to complete lifting of copper land on substrate or of plated metal on leadframe/post).
9	Fracture or lift of substrate/leadframe/post (portion of substrate material remains attached to stitch bond).

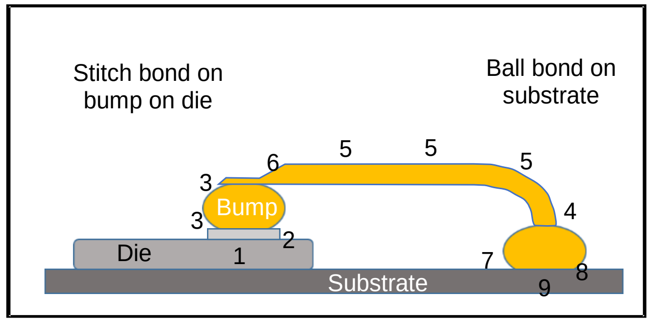


Fail Codes Thermosonic (Standard)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 4 – Detailed Pull Failure Codes for Reverse Thermosonically Bonded Wires

Code	Failure Codes –reverse thermosonic bonds (ball on substrate, stitch [on bump] on die)
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to ball bond on die).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other die bond pad metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of stitch bond from bump (underlying ball bond) (some to no remnant of stitch on ball bond) or lift of bump (underlying ball bond) from die bonding pad (stitch still attached to bump).
4	Break in wire in the neckdown region above the ball bond in the heat affected zone (length equal to 2x wire diameter above ball).
5	Break in the span of the wire (from 2x wire diameter above the ball bond to just above the stitch bond).
6	Break in wire in the neckdown region of the stitch bond (portion of the wire deformed by the capillary, but not bonded to bump).
7	Lift of ball bond from substrate/leadframe/post metallization (separation between ball bond and substrate/leadframe/post pad metallization).
8	Lifted substrate/leadframe/post metallization (partial to complete lifting of copper land on substrate or of plated metal on leadframe/post).
9	Fracture or lift of substrate/leadframe/post (portion of substrate material remains attached to ball bond).

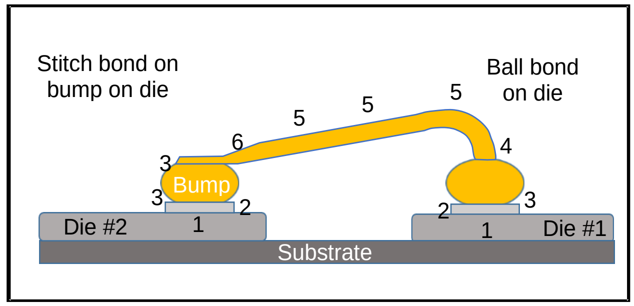


Fail Codes –Thermosonic (Reverse)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 5 – Detailed Pull Failure Codes for Die to Die Thermosonically Bonded Wires

Code	Failure Codes – die to die thermosonic bonds
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to ball bond).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of ball bond or bump from die metallization (separation between ball bond and die pad metallization, some to no intermetallic formed), or lift of stitch bond from bump (underlying ball bond.
4	Break in wire in the neckdown region above the ball bond in the heat affected zone (length equal to 2x wire diameter above ball).
5	Break in the span of the wire (from 2x wire diameter above the ball bond to just above the stitch bond).
6	Break in wire in the neckdown region of the stitch bond (portion of the wire deformed by the capillary, but not bonded to bump).
7	Not applicable
8	Not applicable.
9	Not applicable.

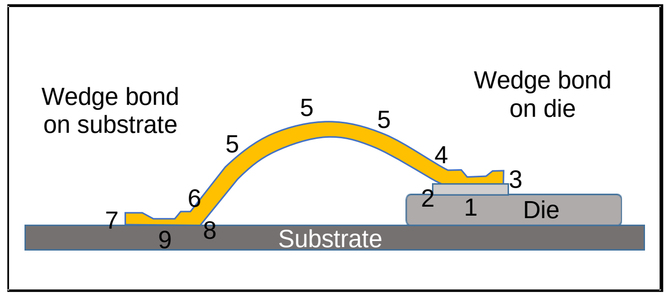


Fail codes – Thermosonic (Die to Die)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 6 – Detailed Pull Failure Codes for Standard Ultrasonically Bonded Wires

Code	Failure Codes – standard ultrasonic bonds
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to wedge bond).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of wedge bond from die metallization (separation between wedge bond and die pad metallization).
4	Break in wire in the neckdown region of the wire at the wedge bond on the die (portion of the wire deformed by the bonding tool, but not bonded to the die, and up to 2x wire diameter away from the wedge bond).
5	Break in the span of the wire (more than 2x wire diameter away from either wedge bond).
6	Break in wire in the neckdown region of the wire at the wedge bond on the substrate/leadframe/post (portion of the wire deformed by the bonding tool, but not bonded to the substrate/leadframe/post, and up to 2x wire diameter away from the wedge bond).
7	Lift of wedge bond from substrate/leadframe/post metallization (little to no remnant of stitch on substrate/leadframe/post).
8	Lifted substrate/leadframe/post metallization (partial to complete lifting of copper land on substrate or of plated metal on leadframe/post).
9	Fracture or lift of substrate/leadframe/post (portion of substrate material remains attached to wedge bond).

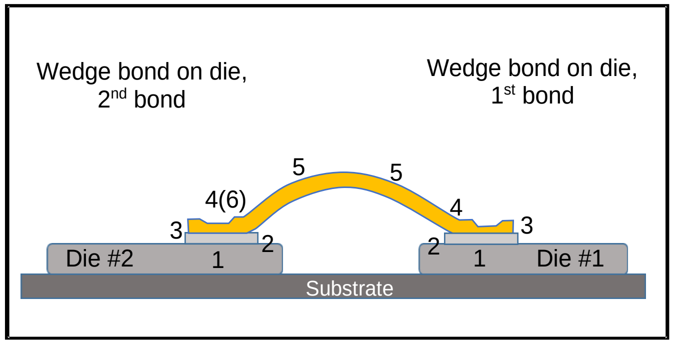


Fail codes – Ultrasonic (Standard)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 7 – Detailed Pull Failure Codes for Die to Die Ultrasonically Bonded Wires

Code	Failure Codes – die to die ultrasonic bonds
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to wedge bond).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of wedge bond from die metallization (separation between wedge bond and die pad metallization).
4	Break in the wire in the neckdown region at the wedge bond on the die (portion of the wire deformed by the bonding tool, but not bonded to the die, and up to 2x wire diameter away from the wedge bond).
5	Break in the span of the wire (more than 2x wire diameter away from either wedge bond).
6	Not applicable (Optional: If able to track which bond was made 1st and 2nd, Code 4 may be used for a break in the neckdown region of the wire at the wedge bond above the 1st die bonded (portion of the wire deformed by the bonding tool, but not bonded to the die, and up to 2x wire diameter away from the wedge bond) and Code 6 is for a similar break above the 2nd die bonded.).
7	Not applicable.
8	Not applicable.
9	Not applicable.

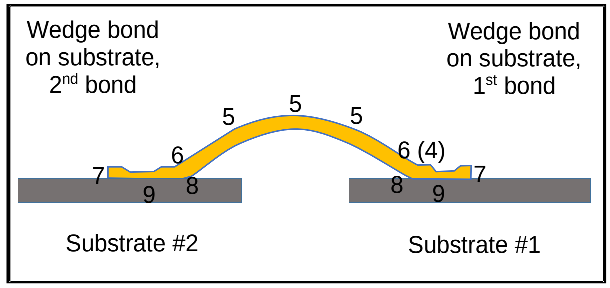


Fail codes – Ultrasonic (Die to Die)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 8 – Detailed Pull Failure Codes for Substrate to Substrate Ultrasonically Bonded Wires

Code	Failure Codes – substrate to substrate ultrasonic bonds
0	Operator error or wire damaged/missing prior to test.
1	Not applicable.
2	Not applicable.
3	Not applicable.
4	Not applicable (Optional: If able to track which bond was made 1st and 2nd, Code 4 may be used for a break in the wire in the neckdown region at the wedge bond above the 1st substrate/leadframe/post bonded (portion of the wire deformed by the bonding tool, but not bonded to the substrate/leadframe/post, and up to 2x wire diameter away from the wedge bond) and Code 6 is for a similar break above the 2nd substrate/leadframe/post bonded).
5	Break in the span of the wire (more than 2x wire diameter away from either wedge bond).
6	Break in the wire in the neckdown region at the wedge bond on the substrate/leadframe/post (portion of the wire deformed by the bonding tool, but not bonded to the substrate/leadframe/post, and up to 2x wire diameter away from the wedge bond).
7	Lift of wedge bond from substrate/leadframe/post metallization (little to no remnant of stitch on substrate/leadframe/post).
8	Lifted substrate/leadframe/post metallization (partial to complete lifting of copper land on substrate or of plated metal on leadframe/post).
9	Fracture or lift of substrate/leadframe/post (portion of substrate material remains attached to wedge bond).

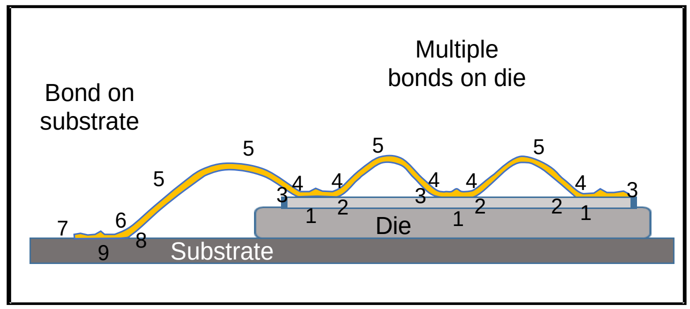


Fail codes – Ultrasonic
(Substrate to Substrate)

5.5 Wire Bond Pull Failure Codes (cont'd)

Table 9 – Detailed Pull Failure Codes for Multi-Loop Ultrasonically Bonded Wires / Ribbons

Code	Failure Codes – multi-loop ultrasonic wire/ribbon bonds
0	Operator error or wire damaged/missing prior to test.
1	Fracture or chip-out of die including cratering (portion of dielectric material and possibly other layers remains attached to wedge bond).
2	Lifted die metallization (partial or complete lifting of aluminum, copper, NiPdAu, or other metallization plating) or failure within the metallization of the die bonding pad.
3	Lift of wedge bond from die metallization (separation between wedge bond and die pad metallization).
4	Break in the wire in the neckdown region at the wedge bond on the die (portion of the wire/ribbon deformed by the bonding tool, but not bonded to the substrate/ leadframe/post, up to 2x wire dia. away from the wedge bond or up to 2x ribbon thickness away from the wedge bond).
5	Break in the span of the wire (more than 2x wire diameter or 2x ribbon thickness away from either wedge bond).
6	Break in the wire in the neckdown region at the wedge bond on the substrate/ leadframe/post (portion of the wire/ribbon deformed by the bonding tool, but not bonded to the substrate/leadframe/post, and up to 2x wire diameter away from the wedge bond or up to 2x ribbon thickness away from the wedge bond).
7	Lift of wedge bond from substrate/ leadframe/post metallization (little to no remnant of stitch on substrate/ leadframe/post).
8	Lifted substrate/leadframe/post (partial to complete lifting of plated metal on leadframe/post copper land or on substrate)
9	Fracture or lift of substrate/leadframe/post (portion of substrate material remains attached to wedge bond).



Fail Codes - Ultrasonic Multi-loop Wire/Ribbon

5.5.1 Defining Code 6 vs. 7 for Thermosonic Stitch Bonds

D.1 and D.2 in Annex D contain images of copper and gold bonded wires that have been pull tested and their Failure Codes have been classified as Code 6 and Code 7 respectively. These images can be used as visual aids to help users in assigning the correct Failure Code. For thermosonic stitch bonds, identifying the location where the neckdown ends and where the stitch bond begins (metallurgical connection between wire and bonding surface) can be very difficult as it varies greatly based on several factors, such as wire material, bonding surface, capillary design, bonding parameters, etc. For this reason, the interface between Failure Codes 6 and 7 can be thought of as a zone, and the device manufacturer may need to provide guidance to the pull tester on the location of this interface for the wires to be pulled.

Figure 15 is an SEM image of a stitch bond made with Au wire prior to encapsulation. The single, straight dashed line shows where the neck down region of the stitch bond begins; and the grouping of arched dashed lines show the zone where the metallurgical bond might begin. For additional discussion regarding the variability within this zone of where the metallurgical bond may begin, see D.3 in Annex D which contains optical and SEM images of stitch bonds of various materials on different bonding surfaces.

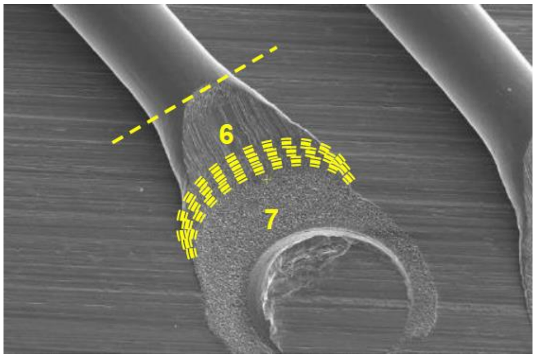


Figure 15 – Location of Breaks in the Stitch Neckdown Region vs. in the Stitch Bond

5.5.2 Discussion on the Significance of Failure Codes

The Failure Codes for pull testing define where the break occurred due to the force applied and thus indicate the location of the weakest point in that bonded wire. The structure made when a wire is bonded represents an area within the package of a discontinuity in material and/or structure. Throughout the lifespan of a device, a bond is expected to be subjected to more stress than the wire, be it electrical stress from electromigration or thermomechanical stress from CTE mismatch of materials around the area of the bond. Therefore, to ensure the long-term reliability of the device, the initial pull strength of the bonds should be higher than that of the wire itself.

With the assumption that the bond is stronger than the wire, it is therefore expected that during a pull test the break should occur in the bulk wire (Code 5) or in the neckdown region of the wire (Codes 4 and 6). However, a break within either of the two bonds (Codes 1, 2, 3 or 7, 8, 9) would suggest that a sub-optimal bond had been made. Assuming the bond is stronger than the wire, Failure Code 5 is acceptable if the pull force is above the specified minimum acceptable pull force value.

5.5.2 Discussion on the Significance of Failure Codes (cont'd)

However, even if the pull force is above the specified minimum acceptable pull force value, an investigation should be initiated to determine if the pull results should be considered a true failure when both conditions a) and b) are present:

a) The Failure Code is either 1, 2, 3, 4, 6, 7, 8, or 9.

b) The pull force is above the allowed minimum pull force, but the value is below the statistical test limits of forces for this lot compared to baseline data (see the definition of outlier product).

During the investigation of an outlier pull value, the Failure Code should be taken into consideration as follows:

- For Failure Codes 4 and 6 the root cause for an outlier pull value would be limited to an issue with the wire material and the bonding process (capillary, tool settings, etc.).
- For Failure Codes 1, 2, 3, 7, 8, and 9 the condition of the bonding surface must also be included along with a possible issue with the wire material and the bonding process in the evaluation for implementing appropriate correction actions.

NOTE An outlier value could also be due to an issue of how the pull test was performed.

Annex E provides additional guidance regarding minimum pull force specification values and process control requirements.

5.6 Wire Bond Pull Data to be Recorded

Data shall be maintained for each wire bond pulled. The data shall identify;

- information for product tested:
  - wire material (gold, aluminum, or copper),
  - wire diameter or ribbon dimensions along with equivalent "wire diameter" (see 5.6.1),
  - method of bonding (thermosonic or ultrasonic),
  - materials of bonding surfaces,
  - unencapsulated or decapsulated,
  - pre-stress or post-stress, and
  - type of pull test – hook location (wire pull, ball pull, or stitch pull);
- specific bonding wire pulled, if required (e.g., corner wires or specific wires per bonding diagram);
- the pull force value; and
- the wire bond pull Failure Code as defined in 5.5.

The following are optional data that may be recorded;

- specific wire information (e.g., wire manufacturer and name, Pd coated Cu wire, 4N gold, etc.),
- device/package,
- wire bonder ID,
- pull test operator,
- pull tester ID,
- time and date, and
- general notes (any anomalies that may have occurred during the test).

5.6.1 Determining Equivalent Wire Diameter for Ribbon Bonds

The minimum pull force requirement for a ribbon is determined by finding a wire diameter with the same cross-sectional area as that of the ribbon.

For example, a ribbon to be pull tested is 750 um wide by 150 um thick, thus its cross-sectional area is 112,500 um^2. To find the wire diameter with an equivalent cross-sectional area the following equation would be used:

$$d = 2(A/\pi)^{½}$$

Where A is the area of the wire and is equal to πr^2; where r is the radius of the wire and is equal to ½ d (diameter of wire). Using 112,500 um^2 as the area, the equivalent wire diameter for the 750x 150 um ribbon would be calculated as follows:

$$d = 2(112{,}500/\pi)^{½} \cong 380 \text{ um (15 mils).}$$

5.6.2 Effective Pull Force Versus the Actual Force on a Bond

When pulling wires that have very low bond angles (< 30°) on both bonds, see F.1 in Annex F to determine if the wire pull force values should be other than those specified in Table 7-1 of JESD47.

It is important that the pull direction be as close to perpendicular to the plane of the bonding surfaces as possible for the following reasons:

1) The force at each bond will begin to diverge as the angle of pull increases (see F.2).
2) A change in the angle of the pull force could alter the failure mode.

6 Summary

The following details shall be specified in the applicable procurement documents:

a) sample size: number of devices tested and number of wire or bonds per device under test if different from that stated in JESD47;
b) location of bonds to be pulled if different from that stated in JESD47;
c) minimum accepted pull force value if different from that stated in JESD47;
d) minimum accepted process capability data (Cpk);
e) acceptability and/or non-acceptability of any Failure Codes if different from that stated in JESD47;
f) sample preconditioning and/or any stressing prior to pull testing; and
g) velocity of the hook or any other change to the pull parameters from that prescribed by the pull test manufacturer.

Annex A (Informative) Guidance for Performing Pull Testing on Stacked Bonds (Reverse, Security and Others)

A.1 Reverse Bonds (a.k.a. "Stitch on Ball")

Figure 16 and Figure 17 show close up images of reverse bonds, which are also referred to as "stitch on ball".

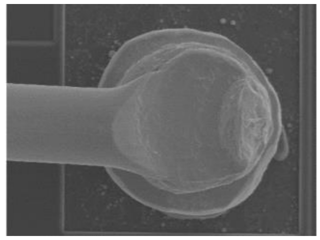


Figure 16 – Top View Image of Reverse Bond

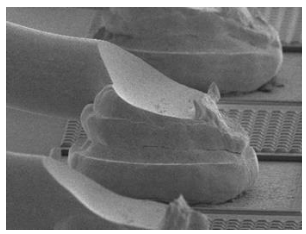


Figure 17 – Side View Image of Reverse Bond

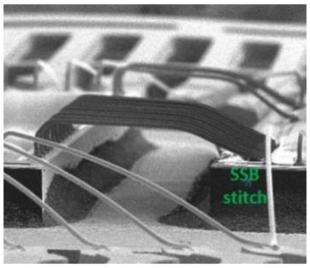
Reverse bonds are used for making an electrical connection for the following package configurations:

1) between die in a multiple chip module;
2) between die and substrate (organic or metal) in very thin packages; or
3) between stacked dice.

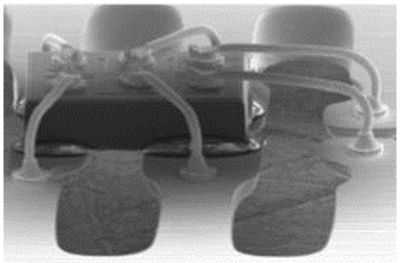
Annex A Guidance for Performing Pull Testing on Stacked Bonds (cont'd)

Figure 18 comprises four images that illustrate the kinds of electrical connections made with reverse bonds.

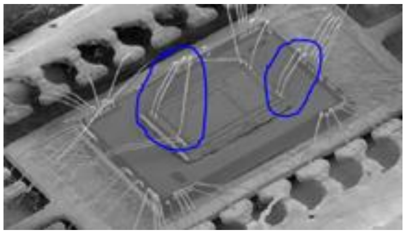
- a) shows "die to die" bonding with the bump (a ball bond with the wire removed) being first formed on the right die and then the second wire has the ball formed on the left die and its stitch is placed on top of the bump on the right die.
- b) shows "leadframe to die" bonding, which allows for a very low-profile package.
- In c) the wires circled in blue are examples of die-to-die bonding between the stacked dice.
- d) also shows die to die bonding between the stacked dice.



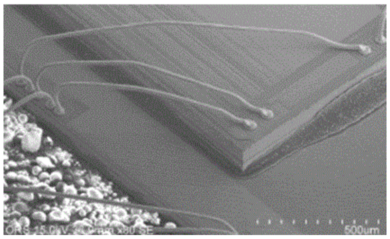
a)



b)



c)



d)

Figure 18 – Examples of Different Electrical Connections Made with Reverse Bonds

The wire pull test method can be used for evaluating the pull strength of the bonded wire for process development and for production. The ball pull and stitch pull tests may be performed as part of process development.

A.2 Security Bonds

The bump of a “Security” bond (Figure 19) or the ball bond of a “Security Loop” (Figure 20) may be placed on top of a stitch bond to improve the mechanical strength of the stitch bond. The intention of using a security bond is to help the stitch bond withstand forces from encapsulation materials caused by thermal mismatches between the encapsulation material and the substrate/leadframe to which the stitch bond is attached.

It is recommended that pull testing (WPT, SPT, or BPT) of the initially bonded wire (without the addition of the security bond) should be performed during process development; but pull testing of the initially bonded wire before the security bond is attached is not required for production. At a minimum for production, wire pull testing of the initially bonded wire after the security bond is attached is required for each assembly lot.

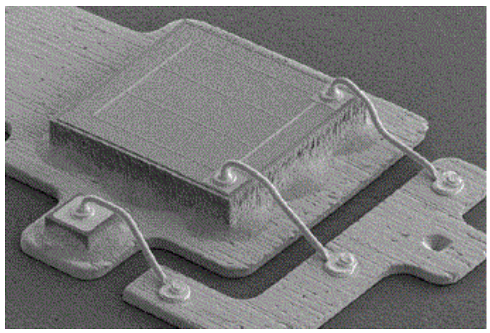


Figure 19 – The Bump of a Security Bond

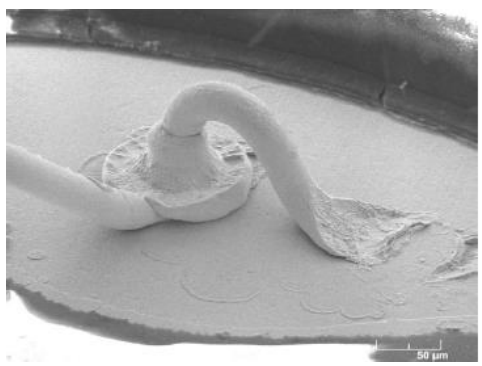


Figure 20 – The Ball Bond of a Security Loop

A.3 Other Stacked Bonds

Figure 21 shows a bonding scheme used in a stacked die package in which reverse bonds connect the bottom die to the substrate. The connection of the top die to the bottom die is also with reverse bonds, but the ball bond for the 2^{nd} reverse bond is placed on top of the stitch of the 1^{st} reverse bond, such that there is a ball bond on top of a stitch bond that is on top of a bump.

Similar to security bonds, it is recommended that pull testing (WPT, SPT, or BPT) should be performed on the initially bonded wire (without the addition of any later bonds) during process development; but is not required for production. However, for production, pull testing of the initially bonded wire after the addition of the bond(s) is attached is required for each assembly lot. Pull testing of the 2^{nd} wire in this stacked bond construction should be performed for process development and on all production assembly lots. However, if for production, the lower reverse bond was pull tested, the upper reverse bond should not be tested as the first pull will have weakened the shared bond.

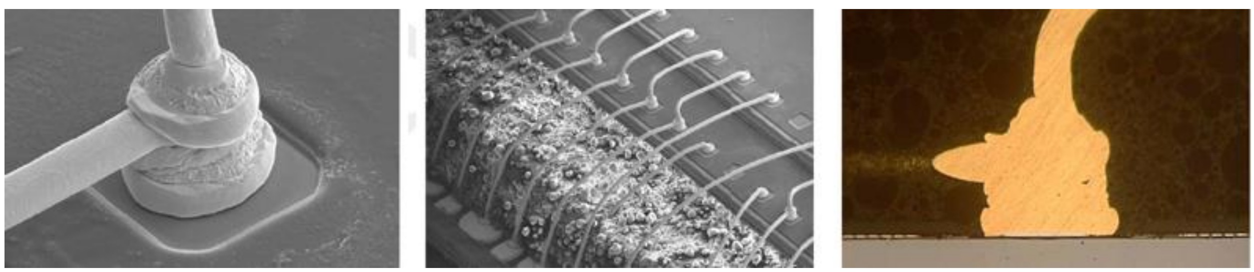


Figure 21 – Example of Another Type of Stacked Bonds

Annex B (Informative) Guidance for Performing Decapsulation on Devices Prior to Bond Pull Testing

Besides being used as a process monitor, wire bond pull testing is also used to assess the integrity of bonds after encapsulation and after stress testing. It can be used on samples that have been subjected to solder attach simulation (preconditioning), to thermal cycling stress, and to any other stress test. Some qualification standards require bond testing after qualification stresses.

B.1 Warning Regarding Ultrasonic Cleaning of Exposed Wire Bonds

Warning: If wire pull testing is to be performed on decapsulated devices, regardless of the decapsulation technique used, ultrasonic cleaning should not be used once the neckdown regions of the bonds have been exposed, as it may alter the pull force results and possibly change where the break occurs (Failure Code).

B.2 Concerns with Decapsulation Processes for Devices with Copper and Silver Wire Bonds

The procedures described below were developed for Cu wire, and initial studies have shown that the techniques described will also be beneficial in developing safe decapsulation procedures for packages with silver wire bonds as well, though the etching solutions (acid or plasma) for packages with silver wires will likely need to be different from those developed for Cu wires. As the range of alloying of Ag wire varies greatly (from 88% to 99% Ag) the etching recipe developed for one Ag alloy wire may not work for a different composition of Ag alloy wire.

With the transition to small diameter copper wire bonds (1.3mils and less), some of the etchants that have been successfully used to decapsulate packages with gold wire bonds have been shown to attack copper wire bonds. In some cases, this attack has been so severe that the bonds can no longer be pulled or sheared. Figure 22 shows some images of copper wire bonds severely damaged by the etching process.

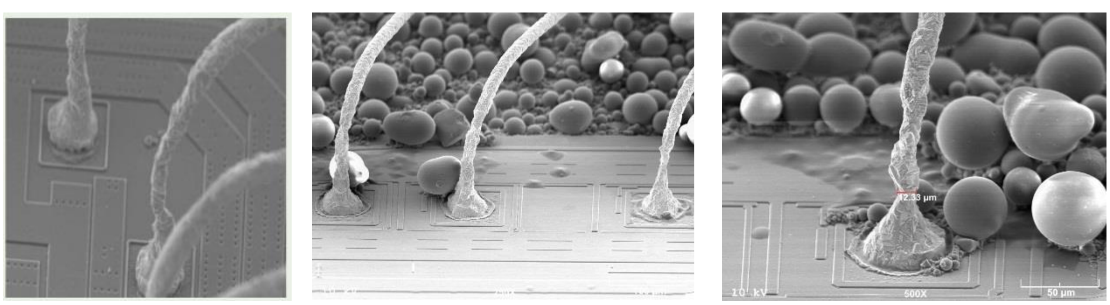
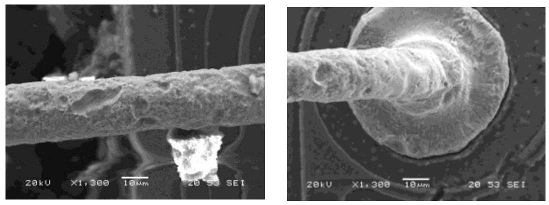


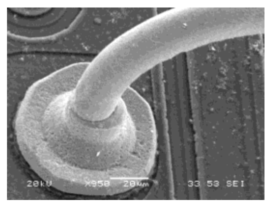
Figure 22 – Images of Copper Ball Bonds Showing Severe Damage from Etching Process

B.2 Concerns with Decapsulation Processes (cont'd)

Most chemical etchants used for devices with gold wire bonds were designed to minimize the damage to the aluminum bond pad; however, copper can be easily attacked by some of these etchants. New etching chemistries have been successfully introduced to minimize this issue.



Original Etchant



New Etchant

Figure 23 – Comparison Images Showing Degree of Cu Attack Due to Two Different Etchants

With the original etchant, the ball contact area was still intact, and testing could still be performed, however, there was a small loss in strength. For this product a new etchant was able to minimize the damage to the copper wire bond.

Several factors can affect the amount of damage the etching process will inflict upon copper wire bonds. These include;

- molding compound chemistry,
- type of copper wire (bare Cu wire versus palladium coated copper wire),
- etchant chemistry used (type of chemical – wet, or type of plasma – dry), and
- sample history (high temperature stresses (e.g., HTS, HTOL, etc.) can influence the etching rate of mold compounds which can alter the effectiveness of the etching processes).

Copper bonding wires that show some sign of having been attacked by the etchant (slight reduction of wire diameter) may still provide acceptable wire bond pull results. Therefore, at this time the members of the working group that generated this annex cannot recommend any visual inspection criteria for determining "good" and "bad" bonds for the purpose of performing wire bond pull testing. It is noted that SEM images do tend to provide a better indication of what may be "bad" than do optical images.

One method that may be used for determining if a wire is over etched is to compare the wire pull results of the etched devices to the results of an unencapsulated sample of the same product. If the pull value is significantly less than the typical value for wire pull of unencapsulated product or the variability in the results is significantly larger, then it is very likely that the wire and/or bond has been damaged due to the etching process. If this does occur, then this 'over etched' sample should not be used for wire bond pull testing.

B.2 Concerns with Decapsulation Processes (cont'd)

For those devices that are more susceptible to etchants, a two-step decapsulation process may be used. Either laser or mechanical milling may be performed initially to remove most of the encapsulant. A mechanical milling process could be used to remove all encapsulant material to just above the wires. Laser ablation will not damage the copper wires so it can be used to expose the wires themselves. However, the laser will damage the die surface, so to prevent damage of the bond pads, some amount of encapsulant must remain on the top of the die surface.

The laser or mechanical milling is followed by a chemical decapsulation procedure to remove the remaining encapsulating material from around the copper wire spans, the ball or wedge bonds, and the bonding surfaces. The purpose of the two-step process is to limit the exposure time to the chemical etchant as much as possible, and thus minimize the level of damage to the copper wire and ball bonds during the decapsulation procedure.

Laser ablation of the molding compound is an effective method of removing the encapsulant without damaging the copper wire. Figure 24 shows an image of a copper wire stitch bond fully decapsulated using laser ablation with no visible damage to the stitch bond. However, laser ablation cannot remove material that is underneath the wire (Figure 25), and it will damage the die surface, thus severely affecting the ability to perform this test method properly.

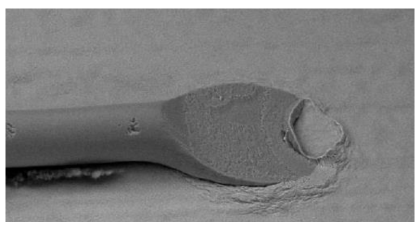


Figure 24 – Copper Wire Stitch Bond Fully Decapsulated using Laser Ablation

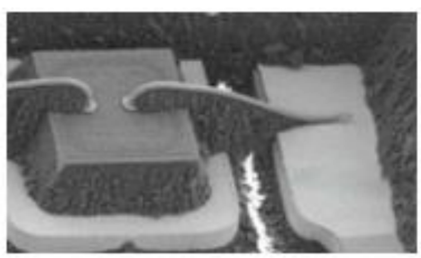


Figure 25 – Laser Ablation Damage

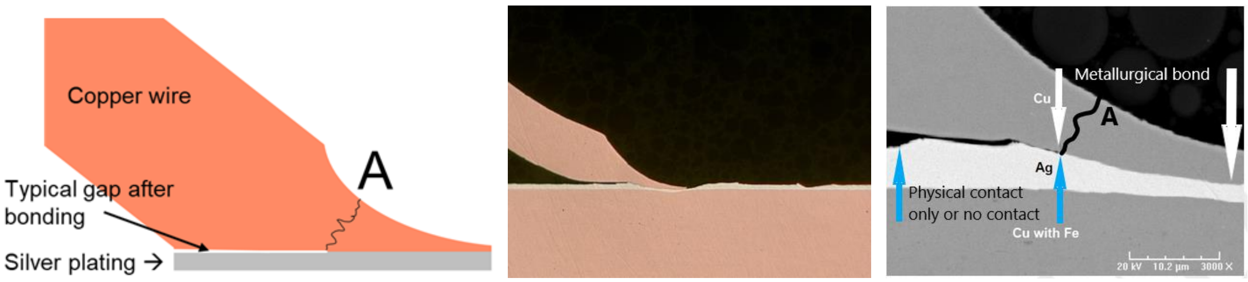
Microwave Induced Plasma (MIP) is another technique that has been shown to produce good results in decapsulating packages while not significantly degrading Cu and Ag wires, when the choice of plasma and process conditions have been optimized for the wire material. The technique typically alternates between a plasma etching step that attacks the organic material and an ultrasonic cleaning step to remove the remaining silica filler particles, so that the next etching step is more efficient. The multi-step etching and cleaning process allows for short etching times, which also minimizes the attack of the Cu or Ag wire.

B.3 Concern with Undercutting Bonds due to the Over Etching of the Silver Plating on Leadframes

Improper decapsulation methods may cause chemical dissolution of the silver plating on the leadframe. If the Ag dissolution is severe, it could undercut the silver plating under stitch bonds on the leadframe which can cause low pull force values. Though undercutting is mostly a concern for stitch bonds, it is possible that severe undercutting could reduce the pull force of the ball bond for reverse bonds. Silver is not the only plated finish that may be susceptible to over etching, as plated Cu finishes are as similarly susceptible but are not as commonly used as Ag. Over etching is not a significant concern for NiPdAu and NiAu finishes, however, if such a finish is on a Cu land on an organic substrate and a portion of the Cu is exposed, it could be attacked by the etching solution.

Samples with dissolved silver plating adjacent to the stitch bond should not be used for pull testing.

When pulling a typical decapsulated stitch bond (no undercutting), the bond commonly breaks at the position where the stitch makes a metallurgical bond with the plated silver, which in turn produces high pull force values. In Figure 26, the drawn image shows the break occurring at point A, where the metallurgical bond begins, and coincides with the edge of the capillary used to make the bond. The optical image is a cross section of a typical Cu wire stitch bond on a silver-plated copper alloy leadframe. The SEM image shows the location of metallurgical bond versus where there may only be physical contact between the Cu wire and the plated silver or where there is no contact at all.



Drawing **Optical image** **SEM image**

Figure 26 – Drawn, Optical and SEM Images of Break Where Metallurgical Bond Begins

However, if some of the silver plating underneath the stitch bond is dissolved by the decapsulation process (i.e., undercutting), the resulting pull force values during pull testing may be lower based on the amount of undercutting. When undercutting occurs, the stitch will break at the position where the undercutting ends, which corresponds to point B in Figure 27. At this new point the stitch bond is thinner due to the capillary imprint that formed the stitch bond, thus resulting in lower pull values. If undercutting occurs, the pull force value obtained is not a true representation of the bond's strength, and thus should not be used for pull testing.

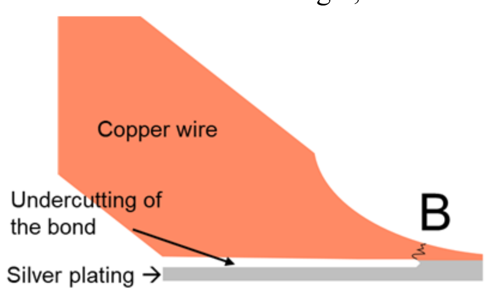


Figure 27 – Undercutting of Stitch Bond Due to Excessive Etching of Silver Plating

B.3 Concern with Undercutting Bonds due to the Over Etching (cont'd)

Decapsulation methods that can generate an undercutting situation include wet chemical decapsulation, plasma supported decapsulation using a temperature that is too high, and plasma supported decapsulation using a non-optimized composition of reaction gases.

Before performing bond pull testing on a decapsulated device, the visible surface of the leadframe should be inspected for any preparation artifacts, especially areas that are free of silver where silver is expected to be. In Figure 28 almost all of the Ag plating has been removed by the decapsulation process as the underlying copper alloy is visible throughout the image. In Figure 29 the amount of Ag dissolution is much less than in Figure 28, as the plated silver is still visible in the area around the stitch bonds, but some of the Cu alloy leadframe is visible at the edges.

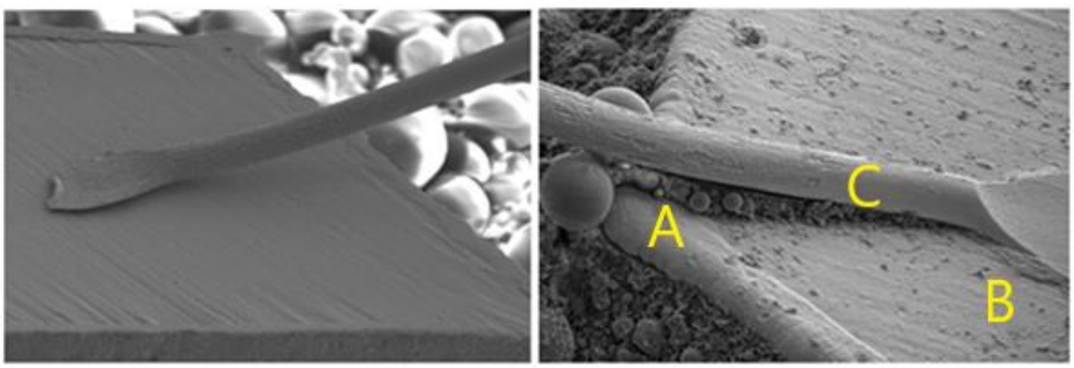
Figure 28 – Ag Plating Removed by the Decapsulation Process, Underlying Cu is Visible

Figure 29 – Plated Ag Visible in the Area Around the Stitch Bonds, Cu only Visible at Edges

B.3.1 Techniques for Assessing if Excessive Etching of Ag Plating has Occurred

Determining optically whether excessive etching of the silver plating has occurred may not be easy, and it is more difficult to determine if undercutting has occurred by just using optical methods. The following techniques are provided as aids in assessing whether excessive etching has occurred and thus the affected bonds are not recommended to be used for pull testing.

1) If available, compare the pull test results with those from previous testing of the same product (decapsulated or even unencapsulated). Undercutting of the Ag plate is likely to have occurred if the pull force values are lower and/or the distribution of the Failure Codes has changed to a higher amount of stitch bond lifts.
2) Visually inspect the remnants of any pulled bonds that have failed due to lifted stitch bonds. Look for evidence of variation of the silver plate around and under where the stitch bond had been.
3) Only pull a portion of the bonds on a sample. After pull testing has occurred pot the device and cross section through several of the remaining stitch bonds to assess of undercutting of the Ag plate has occurred.
4) Inspect the stitch bond for evidence that might suggest over-etching. Images in Figure 30 are examples. Letters A, B and C have been added to identify where to look for these signs. The text below states the visual differences in appearance for each location which might suggest if over-etching has occurred.



a) Over etched, Ag plate fully removed **b) Not over etched, Ag plate intact**

c) Optical image of Ag plate intact

Figure 30 – Assessing if Excessive Etching of Ag Plating has Occurred

A. Some encapsulation material is still present under the wire. If all of the encapsulation material is removed and there is no residue of encapsulation material, this could indicate that over-etching has occurred. If some of the material still remains under the wire, that remaining material should not affect the pull force value.

B.3.1 Techniques for Assessing if Excessive Etching of Ag Plating has Occurred (cont'd)

B. There is some evidence of silver splash around the edges of the stitch bond. The stitch bond in Figure 30 a) appears to be just sitting on top of the leadframe and there is no evidence of silver splash; these are signs that that over-etching may have occurred.

C. (For Cu and Ag wire) The surface of the stitch bond and the wire just above the stitch bond is smooth. These two locations in Figure 30 b) are smooth, but in Figure 30 a) they are rough. The stitch bond are typically the last portion to be exposed in the etching process, thus if these locations are not smooth, the stitch bond may have been over-etched. Figure 30 c) is an optical image of Figure 30 b), and in the optical image the smoothness of the stitch bond and the wire above the stitch bond is quite evident compared to the surface further up the wire.

B.4 Concern with Decapsulating Packages with Stitch Bonds on Multiple Planes

When a device that has stitch bonds that are on different planes within the package, there may be a concern of possibly undercutting the stitch bonds at the higher planes as the chemical decapsulation process continues to expose bonds on the lower planes. One possible method to address this concern is to expose each plane in multiple steps, starting with the highest plane. The decapsulation chemical reaction should be stopped once the wires with stitch bonds at the highest plane have been fully exposed. After the wires with stitch bonds at the highest plane have been pulled, then the wires with stitch bonds on the next plane can be fully decapsulated and pulled. This process is continued for wires with stitch bonds at each remaining lower plane needing to be pulled.

Another option is to split the samples to be pulled and decapsulate a subset to each plane of interest and only pull wires on the sample that have stitch bonds on the plane of interest.

This technique also applies to ultrasonic wedge bonds in which the bonds are on multiple levels (more than 2) within the package.

This concern may also apply to devices with multiple planes of ball bonds and the bond pad metallurgy of the upper most ball bonds, thus similar precautions to prevent undercutting may be used.

B.5 Concern with Not Removing all Encapsulation Material Around the Bonded Wire Prior to Pull Testing

If encapsulation material remains above or around a bond and even under a wire to be pull tested, it can alter the pull force value as some of the force will be directed to the wire/encapsulant interface instead of the bond. For this reason, it is recommended that all encapsulation material be removed from around the bond and underneath the wire.

For bonds with very low bond angles, such as stitch bonds and ultrasonic wedge bonds, a very small amount of encapsulation material under the wire is acceptable. For these types of bonds the etching process needs to be optimized to remove all of the encapsulation material, but not etch the plated Ag or other plated finish right next to or under the bond.

B.5 Concern with Not Removing all Encapsulation Material (cont'd)

Figure 31 shows examples of very low angle bonds and what could be considered to be reasonable amounts of remaining encapsulation material that should not have an effect on the resulting wire pull force value.

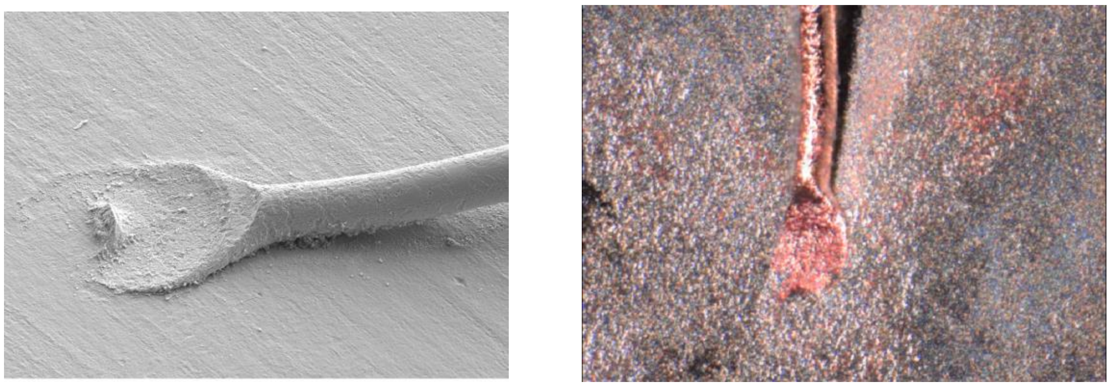


Figure 31 – SEM and Optical Image Examples of a Reasonable Amount of Remaining Encapsulant Material for Pull Testing of Very Low Angle Bonds

Annex C (Informative) Correlation Between Pull Failure Codes in this Document Versus Pull Failure Codes in Mil-Std 883 Method 2011.9

This annex provides information on how to compare pull test data results taken using the Failure Codes defined in this test method versus data obtained using the Failure Codes defined in Mil-Std 883, Method 2011.9.

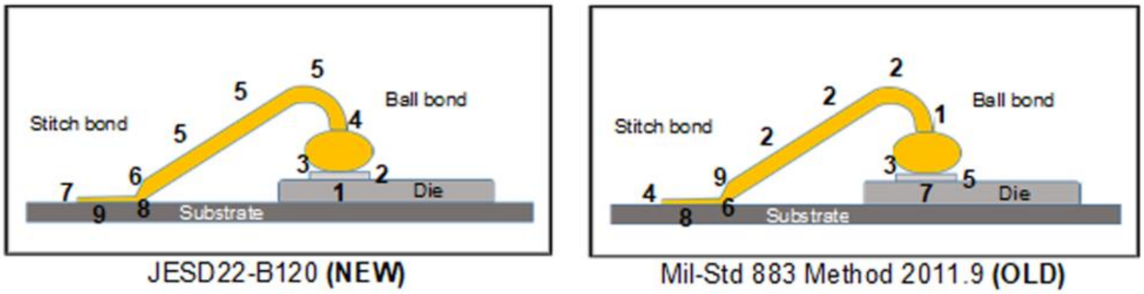


Figure 32 – Pull Failure Code Locations for JESD22-B120 and Mil-Std 883 Method 2011.9

Table 10 - Conversion from (New) JESD22-B120 Pull Codes to (Old) Mil-STD 883 Method 2011.9

Failure Code **-** per **JESD22-B120**	Failure Code **-** per **Mil-Std 883 Method 2011.9**	**Description of Failure Code**
0 (zero)	0 (zero)	Operator error or wire damaged/missing prior to test.
1	7	Fracture or chip-out of die (includes cratering).
2	5	Lifted die metallization or failure within die metallization.
3	3	Lift of bond from die metallization.
4	1	Break in wire in the neckdown region of the first bond.
5	2	Break in the span of the wire.
6	9	Break in wire in the neckdown region of the second bond.
7	4	Lift of bond from substrate/leadframe/post metallization.
8	6	Lifted substrate/leadframe/post metallization.
9	8	Fracture or lift of substrate/leadframe/post.

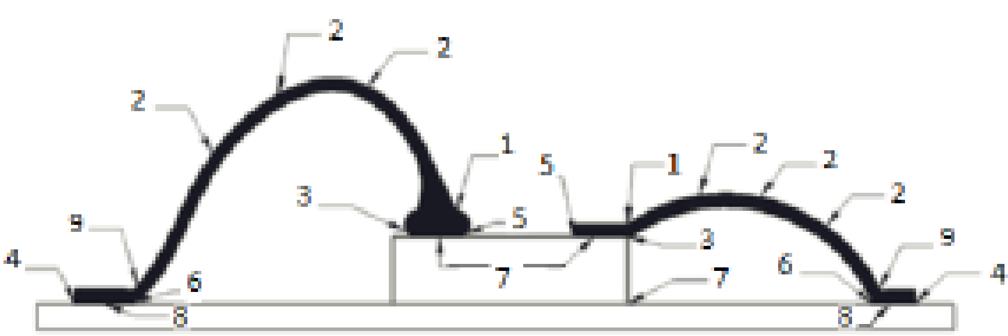
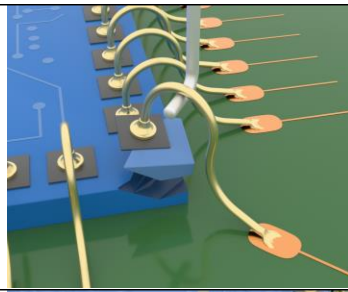
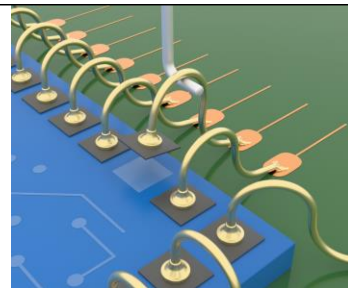
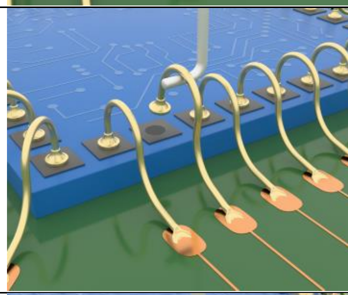
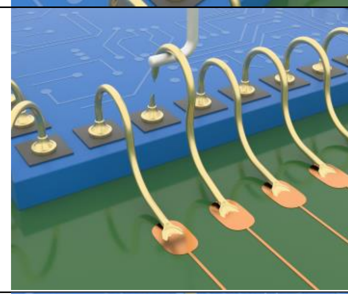
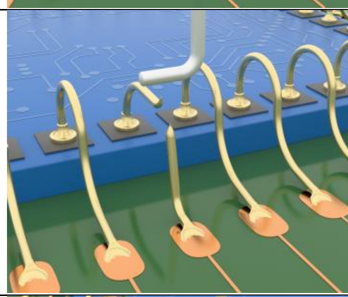
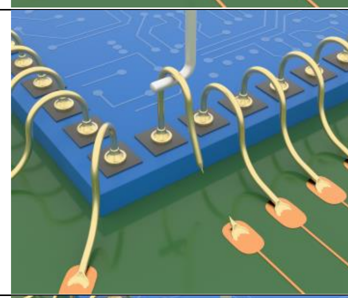
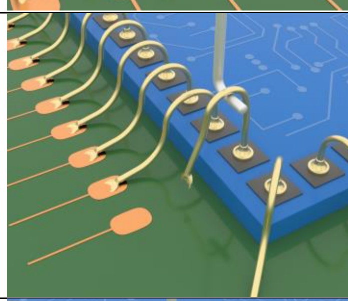
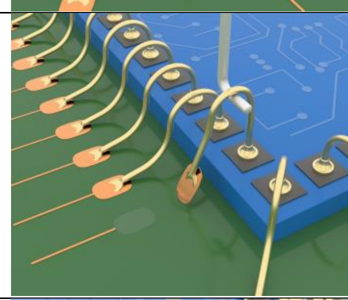
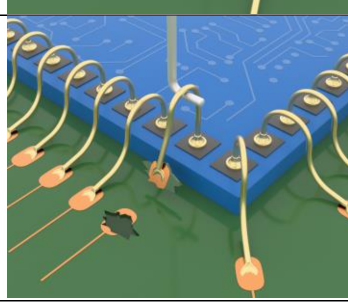
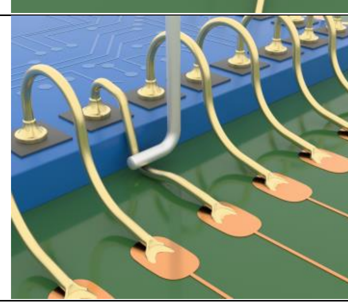


Figure 33 – For Reference Only: Failure Code Diagram from Mil-STD 883 Method 2011.9

Annex D (Informative) Images to Aide in Determining Appropriate Failure Code

Table 11 – Failure Code Illustrations

Failure Code 1 Fracture or chip-out of die (includes cratering)		**Failure Code 2** Lifted die metallization or failure within die metallization	
Failure Code 3 Lift of bond from die metallization		**Failure Code 4** Break in wire in the neckdown region of the first bond	
Failure Code 5 Break in the span of the wire		**Failure Code 6** Break in wire in the neckdown region of the second bond	
Failure Code 7 Lift of bond from substrate/ leadframe/post metallization		**Failure Code 8** Lifted substrate/ leadframe/post metallization	
Failure Code 9 Fracture or lift of substrate/ leadframe/post		**Failure Code 0** Operator error or wire damaged/ missing prior to test (One example shown)	

Images provided courtesy of Nordson Dage.

D.1 Fail in Deformed Portion of Wire Above Thermosonic Stitch Bond – Code 6

Definition per 5.5, Table 3: Code 6 - Break in wire in the neckdown region of the stitch bond (portion of the wire deformed by the capillary, but not bonded to the substrate/leadframe/post)

Figure 34 shows a gold stitch bond (pre-encapsulation) before and after wire pull testing. The break occurred within the neckdown region of a gold stitch bond.

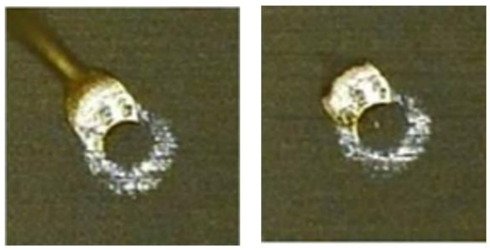


Figure 34 – Gold Stitch Bond (Pre-encapsulation) Before and After Wire Pull Testing

Figure 35 shows several copper stitch bonds after pull testing for which the break occurred within the neckdown region.

Figure 35 – Examples of Break Occurring Within the Neckdown Region

Figure 36 shows several copper stitch bonds (pre-encapsulation) before and after wire pull testing. The break occurred within the neckdown region of each copper stitch bond.

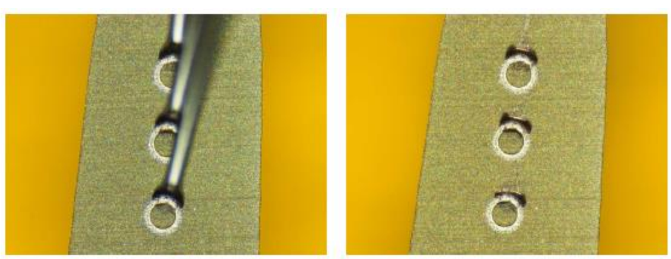


Figure 36 – Copper Stich Bonds Before and After Wire Pull Testing

D.1 Fail in Deformed Portion of Wire Above Thermosonic Stitch Bond – Code 6 (cont'd)

Figure 37 is an SEM image showing a break within the neckdown region of a gold stitch bond, post-encapsulation, even though the bond in this image was not pull tested. If this were a pull test break, it would be Code 6.

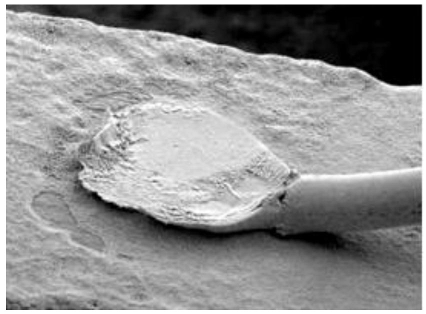


Figure 37 – SEM Image of a Break Within the Neckdown Region of a Gold Stitch Bond

D.2 Fail in Thermosonic Stitch Bond – Code 7

Definition per 5.5, Table 3: Code 7 **-** Lift of stitch bond from substrate/leadframe/post metallization (some to no remnant of stitch on substrate/leadframe/post)

Figure 38 shows several gold stitch bonds (pre-encapsulation) after wire pull testing. The break occurred within the gold stitch bond for both bonds. A remnant of the stitch bond is visible for each.

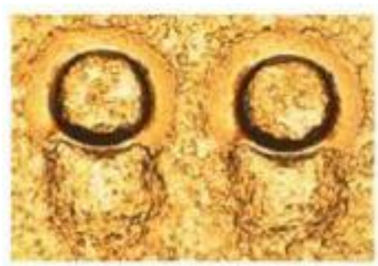


Figure 38 – Break Occurring Within Gold Stitch Bonds

Figure 39 shows a progression of breaks in copper stitch bonds from a break in the neckdown region to a break with very little remnant left on the leadframe. The Failure Code assigned is shown above each image.

Figure 39 – Break Occurring Within Neckdown Region of Copper Stich Bonds

D.2 Fail in Thermosonic Stitch Bond – Code 7 (cont'd)

Figure 40 shows SEM images; from left to right: the remnant of a Cu stitch bond after pull testing (pre-encapsulation, where the break occurred in the stitch bond and thus Code 7 was applied), a break within the stitch bond for a gold wire, post-encapsulation (if this were a pull test break, it would be Code 7), and the remnant of a break (Code 7) within the stitch bond for a gold wire, post-encapsulation.

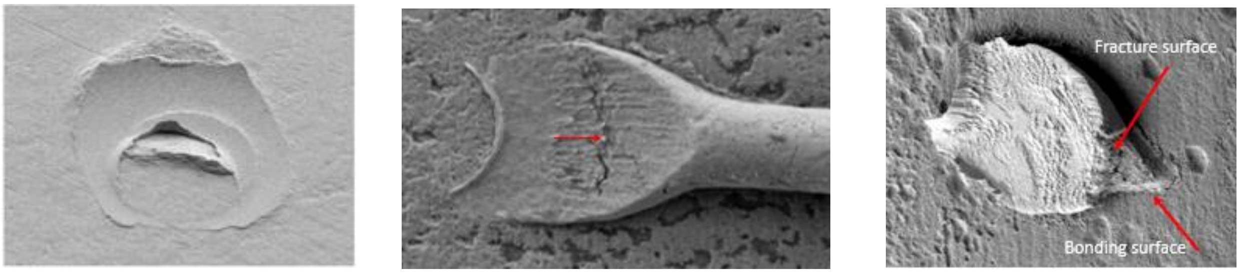


Figure 40 – SEM Images of Where the Breaks are Designated Code 7

D.3 Additional Guidance for Breaks in Thermosonic Stitch Bonds – Code 6 vs. Code 7

The shape of a stitch bond and the bonding interface varies based on several factors, including capillary shape, bonding force, wire material, bonding surface, and finish on the bonding surface. Below are optical and SEM images of different stitch bonds and cross-sections of bonds to help show the variability in the location of the interface "zone" (as described in 5.5.1) that defines the boundary between the end of the neckdown region (Code 6) and the beginning of the metallurgically bonded stitch bond (Code 7).

Figure 41 shows a stitch bond made with Au wire on a Ni/Au plated Cu land on an organic substrate.

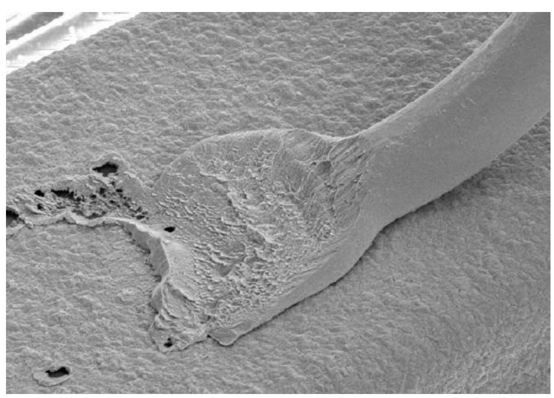


Figure 41 – Gold Stich Bond on a Ni/Au Plated Cu Land on an Organic Substrate

D.3 Additional Guidance for Breaks in Thermosonic Stitch Bonds (cont'd)

Figure 42 is an optical image (left) of a cross section of a similar bond from the same construction analysis report of the stitch bond shown in Figure 40, and an SEM of that same cross section (right) at a higher magnification. A red line has been drawn in both images to show where the metallurgical bond between the stitch bond and the plated land of the substrate ends and where the deformed wire not metallurgically attached to the land begins. To the right of the red line, notice that gaps begin to appear between the gold wire and the gold- and nickel-plated finish on the Cu land.

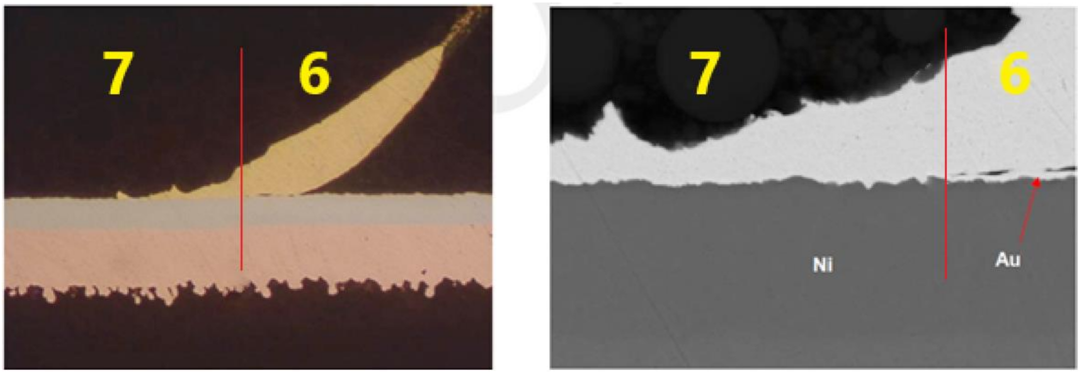


Figure 42 – Images from Construction Analysis Report of Gold Stitch Bond

Figure 43 shows several stitch bonds made with Pd coated Cu wire on a Ag plated Cu alloy leadframe.

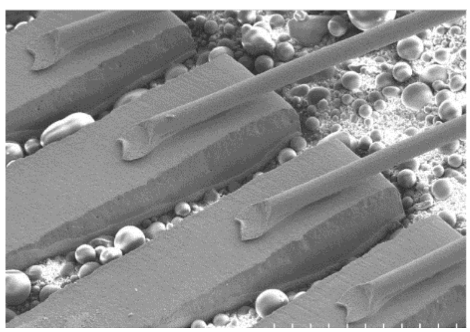


Figure 43 – Stitch Bonds Made with Pd Coated Cu Wire on a Ag Plated Cu Alloy Leadframe

D.3 Additional Guidance for Breaks in Thermosonic Stitch Bonds (cont'd)

Figure 44 is an SEM image (left) of a cross section of a similar bond from the same construction analysis report of the stitch bond shown in Figure 43, and a higher magnification SEM image (right) of that same cross section. A red line has been drawn in both images to show where the metallurgical bond between the stitch bond and the Ag plated leadframe ends and where the deformed wire not metallurgically attached to the plated leadframe begins. In looking at the cross sections it is evident that the Ag finish on the leadframe is pushed out (called splash) from underneath of the stitch bond by the ultrasonic scrubbing action of wire bonder. Even though a portion of the deformed wire in the neckdown region (to the right of the red line) sits on top of this Ag splash, it does not form a metallurgical bond with the Ag finish as the bonder capillary would not be able to provide enough downward force to create a metallurgical bond.

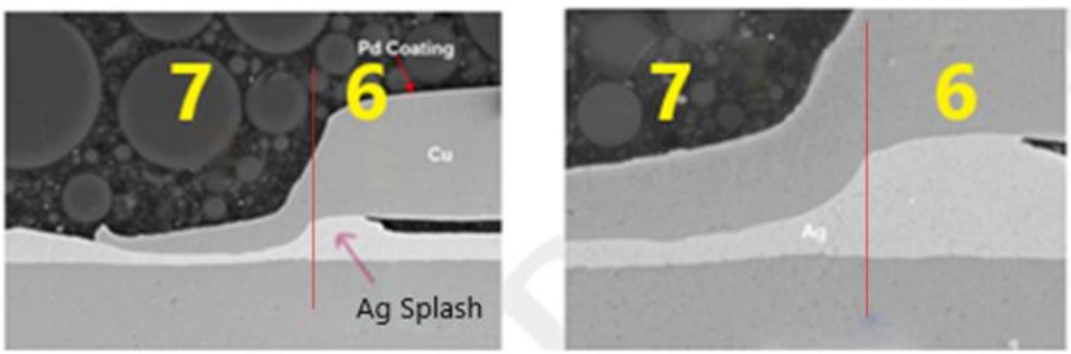


Figure 44 – Ag Splash

Figure 45 is an optical image (left) of a cross section of a Cu wire on NiPdAu pre-plated Cu leadframe, and an SEM image (right) of that same cross section at a higher magnification. A red line has been drawn in both images to show where the metallurgical bond between the stitch bond and the plated leadframe ends and where the deformed wire not metallurgically attached to the leadframe begins. To the left of the red line, notice that gaps begin to appear between the Cu wire and the NiPdAu plated leadframe.

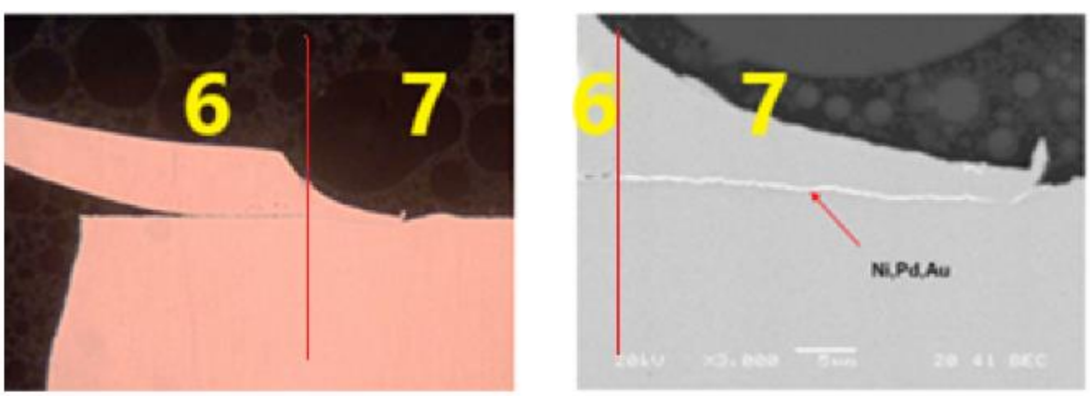


Figure 45 – Gaps Between Cu Wire and NiPdAu Plated Leadframe

D.3 Additional Guidance for Breaks in Thermosonic Stitch Bonds (cont'd)

Figure 46 shows a stitch bond made with Cu wire on a Ag plated Cu alloy leadframe.

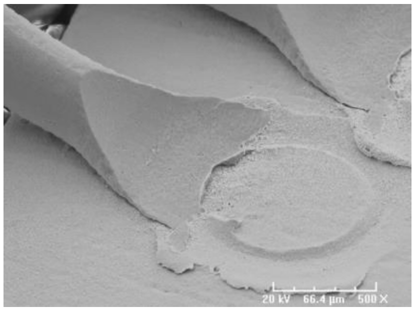


Figure 46 – Stitch Bond Made with Cu Wire on a Ag Plated Cu Alloy Leadframe

Figure 47 is an optical image (left) of a cross section of a similar bond from the same construction analysis report of the stitch bond shown in Figure 46, and a higher magnification SEM image (right) of that same cross section. A red line has been drawn in both images to show where the metallurgical bond between the stitch bond and the Ag plated leadframe ends and where the deformed wire not metallurgically attached to the plated leadframe begins. The amount of Ag splash in Figure 47 is not as significant as that seen in Figure 44.

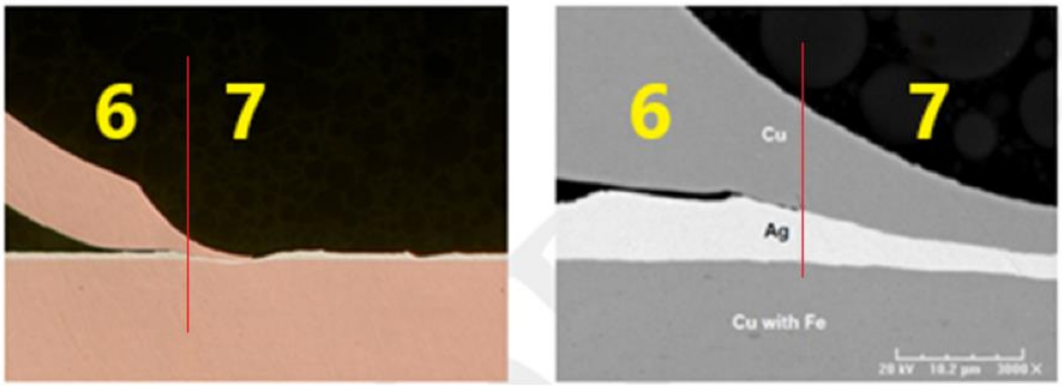


Figure 47 – Images from Construction Analysis Report of Stitch Bond Made with Cu Wire on a Ag Plated Cu Alloy Leadframe

Annex E (Informative) Additional Guidance Regarding Minimum Pull Force Specification Values and Process Control Requirements

The bond pull force obtained for the hook pull test is an indicator of the quality of the two metallurgical bonds made between the bond wire and the bonding surfaces as well as the wire's integrity; whereas for the clamp pull test it is an indicator of the quality of the specific bond being pulled and the portion of the wire attached to that bond. The bonds are expected to withstand a force higher than the tensile strength of the wire. The strength of the bond is a function of the wire material, the bonding surface, and the bonding parameters. A bond made from a wire of a specific alloy can have a range of pull values based on the metallurgy of the bonding surface and parameters of the bonding process. The minimum pull values stated in qualification standards (e.g., JESD47, Mil-Std 883 Condition 2011) are lower than the normal distribution of pull values as they apply to all wire alloys for a specific base metal (gold, aluminum, or copper), a range of bond surface metallization, and a range of bonding parameters.

For some combinations of wire alloy, bonding surface metallurgy, and bonding parameters the normal distribution of pull values may be significantly higher than its corresponding minimum pull value. For this reason, it is very important that for production pull testing (process monitoring prior to encapsulation) statistical process control (SPC) and maverick product management procedures as stated in JESD557 and JESD50 are incorporated to ensure that suspect bonds are not allowed to be shipped. In such cases where the normal distribution of pull values is significantly higher than the corresponding minimum pull value, a higher internal minimum pull value should be considered to help ensure that marginal product is not shipped.

A similar issue of concern is when the distribution of Failure Codes for a production lot varies significantly from its historical norm. The use of SPC and maverick product management procedures will help to identify such outlier lots and determine whether they should be shipped.

Some qualification standards (e.g., AEC Q006) require that pull testing be performed after performing reliability stress testing, and in some cases the stress testing is not performed by the device supplier. In such cases the customer or lab performing the (post encapsulation and post stress) pull testing will not likely have access to the historical data of the distribution of pull force values or Failure Codes for that product and thus can only assess the pull values obtained against the minimum pull forces required by the qualification standard.

Annex F (Informative) Factors that can Affect Wire Pull Outcome

Many factors can affect the pull force value obtained when performing wire bond pull testing. The key factors include the location where the hook is placed along the wire, the direction that the hook is pulled with respect to the bonding surfaces, and the angles made at each bond between the wire and the bonding surface. As it is hard to measure this angle (commonly called theta - Θ) it can also be defined by knowing the respective vertical and horizontal positions of each bonding surface and where the hook contacts the wire when pull testing begins.

In NBS (National Bureau of Standards) Technical note 726, “Testing and Fabrication of Wire-Bond Electrical Connections – A Comprehensive Survey”, the force diagram and force equations in Figure 48 are presented to calculate the force (tension) in the wire at each bond during pull force testing.

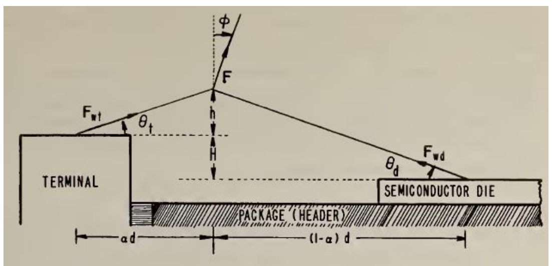


Figure 13. Geometric variables for the double-bond pull test.

$$F_{wt} = F\left\{\frac{\sqrt{1+\left(\frac{\alpha d}{h}\right)^2}\left[(1-\alpha)\cos\phi + \left(\frac{h+H}{d}\right)\sin\phi\right]}{1+\frac{\alpha H}{h}}\right\} \quad \text{and} \quad (5.3.4)$$

$$F_{wd} = F\left\{\frac{\sqrt{1+\frac{(1-\alpha)^2 d^2}{(h+H)^2}}\left(1+\frac{H}{h}\right)\left[\alpha\cos\phi - \frac{h}{d}\sin\phi\right]}{1+\frac{\alpha H}{h}}\right\}. \quad (5.3.5)$$

Figure 48 – Force Diagram and Detailed Force Equations

A copy of this document can be obtained from the NIST (National Institute of Standards and Technology) website:
https://nvlpubs.nist.gov/nistpubs/Legacy/TN/nbstechnicalnote726.pdf

Other variations of the above equation have been generated and published by multiple entities that replace the spatial values with the angle theta.

Obtaining the values for each of the variables in the above equations can allow for a fairly accurate calculation of the force at a bond, but obtaining those values is a very tedious and nearly impossible task if the intent is to perform these calculations for each bond wire to be pull tested. It is for this reason that the industry has decided to greatly simplify the whole process and assume that the pull force value is a rough, but an acceptable approximation of the force applied to each bond. With that said, the force value at a bond can be significantly higher if the bond angle Θ (theta) is very low. F.1 addresses this issue. Similarly, the values of the force applied at each bond diverge as the pull angle Φ (phi) increases. F.2 discusses this issue.

F.1 How Bond Angle Affects Pull Force

During the wire pull test the pull force value is distributed to each bond with both vertical and horizontal elements, as shown in Figure 49. The angle Θ (theta) that the wire makes with respect to the bonding surface at each bond affects the relationship of the pull force to the tension in the wire at each bond. As the angle Θ decreases the tension in the wire increases.

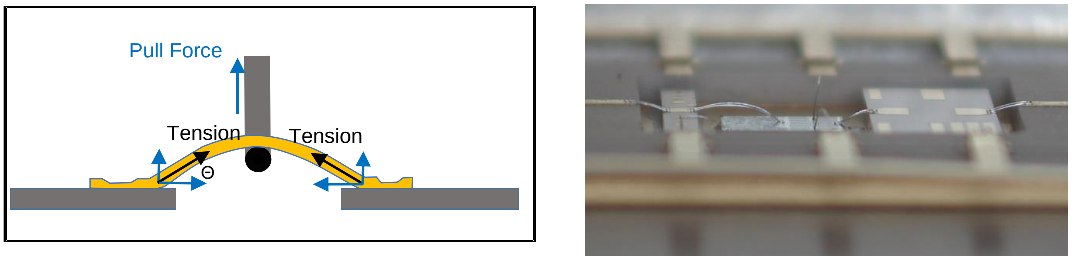


Figure 49 – Pull Force vs. Tension in Wire, an Example of Very Low Bond Angles

RF and other high frequency devices require low, flat wire loops (shallow bond angle) to reduce electrical impedance. Wire bond connections for an RF device are shown (right).

When both bond angle values are very low (< 30°) it is necessary to make a compensation to the value listed in JESD47 (Table 7-1) due to the effects of the shallow bond angle. The formula to be used to account for the effects of the shallow bond angles when both angles are the same shall be:

$$V_1 = V_2 \sin \Theta$$

Where:

V_1 = Compensated minimum pull force value.

V_2 = JESD47 Table 7-1 value for wire diameter tested.

Θ = Greatest calculated bond angle (See Figure 48).

If the pull force is perpendicular to the bonding surfaces, the angle Θ (theta) is the same for both bonds, the hook is at the midspan, and both bonds are at the same height, the following table can be used to determine the compensation needed.

F.1 How Bond Angle Affects Pull Force (cont'd)

The effective pull force at the bonds increases at an extraordinarily high rate with smaller angles Θ. When theta is less than 30° a compensation is necessary to ensure that passing bonds are not rejected. At 20° the compensation is roughly 1.5x and at 10° it is nearly 3x. Table 12 below contains the compensation necessary for several bond angles.

Table 12 – Compensation for Minimum Pull Force for Various Bond Angles

Θ theta (degree)	Θ theta (rad)	sin Θ (theta)	2x sin Θ (theta)	1/2x sin Θ (theta) (Compensation for minimum pull value - V2)
90	1.571	1.000	2.000	(No compensation required)
60	1.047	0.866	1.732	(No compensation required)
30	0.524	0.500	1.000	(No compensation required)
20	0.349	0.342	0.684	1.462
15	0.262	0.259	0.518	1.932
10	0.175	0.174	0.347	2.879
8	0.140	0.139	0.278	3.593
5	0.087	0.087	0.174	5.737
3	0.052	0.052	0.105	9.554
1	0.017	0.017	0.035	28.649

To help visualize the range of values for the angle Θ in Table 12, Figure 50 shows bond angles of 2°, 30°, and 85°.

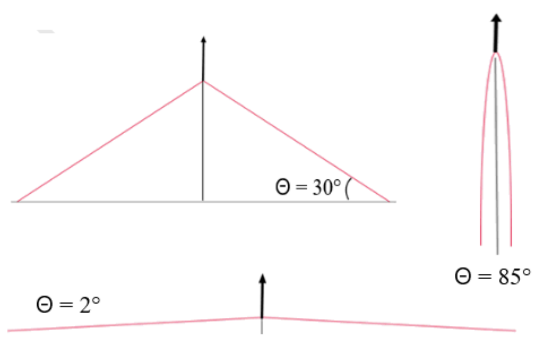


Figure 50 – Various Bond Angles with Respect to Their Bonding Surfaces

F.2 Pull Angle Affects Pull Force and Fail Mode

It is highly recommended that the pull direction be as perpendicular to the plane of the bonding surfaces as possible, as the force at each bond will begin to diverge in value as Φ (phi), the angle of pull force, increases. In addition, a change in the angle of the pull force could alter the failure mode.

F.2 Pull Angle Affects Pull Force and Fail Mode (cont'd)

To show how Φ affects the force at each bond (F_1 and F_2) in Figure 51, which is a simplified version of the force diagram in Figure 48, the calculations in Table 13 show the change in force at each bond (F_1 and F_2) as Φ increases. Table 13 also shows how the ratio of the two forces F_1 and F_2 varies as Φ increases.

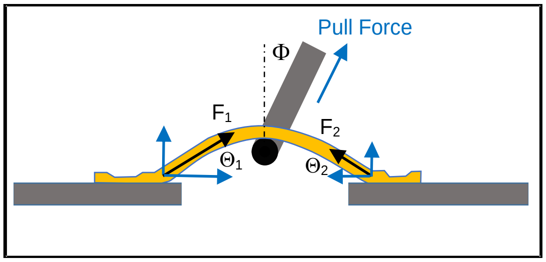


Figure 51 – How Pull Angle Affects Tension

To simplify the calculations and thus better highlight this issue, three assumptions have been made:

1) Θ_1 and Θ_2, the angle each bond makes with their bonding surface, are the same and are 45°;
2) both bonding surfaces are in the same plane; and
3) the pull hook is placed at the midpoint of the wire between the two bonds.

Using these assumptions, the equations for calculating the force at each bond from the free body diagram in Figure 50 is as follows:

$F_1 = F (\cos (\Theta_2 - \Phi))/(\sin (\Theta_1 + \Theta_2))$ and $F_2 = F (\cos (\Theta_1 + \Phi))/(\sin (\Theta_1 + \Theta_2))$

By setting $\Theta_1 = \Theta_2 = 45°$, the value of $\sin (\Theta_1 + \Theta_2) = \sin 90° = 1$.

Thus, the above equations reduce to:

$F_1 = F (\cos (\Theta_2 - \Phi))$ and $F_2 = F (\cos (\Theta_1 + \Phi))$

Table 13 – How Pull Angle Φ Affects Force Applied to Each Bond

Φ phi (degrees)	**cos ($\Theta_2 - \Phi$)**	**$F_1 = F (\cos (\Theta_2 - \Phi))$**	**cos ($\Theta_1 + \Phi$)**	**$F_2 = F (\cos (\Theta_1 + \Phi))$**	**F_1 / F_2**
0	cos (45)	**F_1** = 0.71 **F**	cos (45)	**F_2** = 0.71 **F**	**1**
10	cos (35)	**F_1** = 0.82 **F**	cos (55)	**F_2** = 0.57 **F**	**1.4**
20	cos (25)	**F_1** = 0.91 **F**	cos (65)	**F_2** = 0.42 **F**	**2.2**
30	cos (15)	**F_1** = 0.97 **F**	cos (75)	**F_2** = 0.26 **F**	**3.7**

Annex G (Informative) Background and Reasons for Choice of Minimum Pull Specification Values

When the joint JC14 and JC13 working group started to meet to develop this test method and generate the minimum pull values for copper wire bonds, it first reviewed the history behind how the original minimum pull values for gold and aluminum wire were generated for inclusion into Mil-Std 883, Condition D of Method 2011 over 50 years previously. Based on documents available it was determined that the three curves were generated using a very small data set of mostly ultrasonic wedge bonded aluminum and gold wires of just a few different diameters and extrapolated using engineering judgement. No evidence was found that showed that the curves were modified over time as thermosonic bonding of gold wire became widely used, as the metallurgical composition of gold and aluminum wires varied, as bonding surfaces changed with the introduction of new package types and materials, or even as new types of bonds (e.g., stitch on ball) and the use of ribbon wire were developed. Therefore, by default, the electronics industry has accepted the original values as valid for all gold and aluminum bonds manufactured over the past 50 years regardless of alloy, bonding surface, or bond type even though the pull force values are affected by these variables.

It was discussed how to set up experiments to gather pull data for copper wire bonds to generate the minimum pull values. When all of the variability in Cu wire alloys and coatings used today was assessed along with the variability of bond surface metallization and structures and the range of wire diameters (and ribbon dimensions); it was not feasible to perform a comprehensive set of experiments at this time.

Cu has been perceived by some to be a “stronger” material than Au, thus some believe that the minimum pull values for Cu wire should be higher than those for Au; however, the facts regarding material properties of all wire alloys used does not support this perception. A review of wire manufacturer literature of bond wire mechanical properties showed a wide range of mechanical properties for Cu wires based on the percent alloying, the other metals used for alloying, and the effect of any coating, and that range overlapped the range for Au wire. Even though the ranges overlap, it is recognized that the typical distributions of pull values for some Cu wires may be significantly higher than their minimum pull values. However, for these devices the potential exists that some pull force values may be below their typical distribution of pull values, yet above the required minimum pull value. It is for this reason that the need for strong SPC and maverick product procedures is recommended in this document.

Pull values can noticeably vary due solely to the length of the wire being pulled. Shorter wires tend to fail at lower pull values than longer wires with all other variables being the same. There is currently no requirement in this test method, or any other wire pull test method to document the length of the wire being pulled.

Based on the above-mentioned variables that affect the pull force value, and the fact that the electronics industry has been using the gold minimum pull values for copper wire for over 15 years, the resulting consensus was that for the initial release of this test method, the minimum pull values for gold wire would also be used for copper wire (all alloys and with or without coating).

The scope of this activity did not include proposing minimum pull values for post encapsulation wire pull, including post stress, as this activity will be covered by JC13 when it proposes the next update to Mil-Std 883, Method 2011.

Annex H (Informative) References

AEC Q006, *Qualification Requirements for Components Using Copper (Cu) Wire Interconnections*

JESD50, *Special Requirements for Maverick Product Elimination and Outlier Management*

JESD557, *Statistical Process Control Systems*

Mil-Std 883, *Test Method Standard - Microcircuits*; Method 2011, *Bond Strength (Destructive Bond Pull Test)*

Annex J (Informative) Differences between Revisions

This annex briefly describes most of the changes made to entries that appear in this standard, JESD22-B120.01, compared to its predecessor. If the change to a concept involves any words added or deleted (excluding deletion of accidentally repeated words), it is included. Some punctuation changes are not included.

F.1 Differences between JESD22-B120.01 and JESD22-B120 (December 2022)

Clause	**Description of changes**
Scope	References to clause 3 subclauses in (a) and (c) are deleted.
5	In 5.5.2, reference to a clause 3 subclause in (b) is deleted.

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Standard Improvement Form	**JEDEC**	**JESD22-B120.01**

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   - ☐ Test method number ____________ Clause number ____________

   The referenced clause number has proven to be:
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   - ☐ Other ____

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