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Avoiding Lead-Free Brittle Failures

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Yet another shortcoming of RoHS-mandated lead-free solders, besides their higher cost and increased environmental damage, is the brittleness of lead-free solder joints compared with ductile tin-lead solder joints. Brittle joints are most commonly discovered when you drop your cell phone. The brittle joints are the ones that break. Brittleness can occur at any stage in the life cycle, and it is hard to detect, since any current test is destructive.

For many years, bump shear testing has been a standard measure of bump quality for flip chip. The shear test pushes against the side of a bump, close to the board surface, with an increasing force until it is dislodged. The total force required to shear the bump is a measure -- of something.

Most often the shear occurs in the bulk of the solder bump itself, as a ductile fracture of the solder, so the governing limit is the strength of the bump material. The test then yields little about interface strength and intermetallics in the underlying joint. Defective joints are revealed by fracture occurring in the interface between the bump and UBM, or even between the UBM and the pad.

This is satisfactory for discovering defective joints, but conventional bump shear testing under steady pressure is not a good simulation of the non-linear forces of a drop, nor does it convincingly determine the likelihood of brittle failure.

Cell phone manufacturers go to great lengths to add packaging to protect the solder joints from breaking, in part because testing to identify potentially brittle joints before they break is difficult and costly. The gold standard is drop testing -- assembling die to boards and then dropping them.

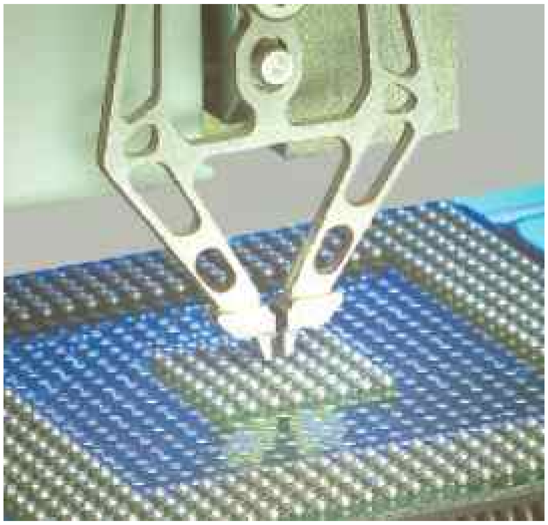
It's called the "gold standard" because this approach is costly in both money and time. Further, the test results are "golden" only for the lot tested. Subtle changes in bump, board, UBM, or pad metallurgy or processing may change the results from lot to lot.

The Holy Grail of brittle failure detection would be a simple, low-cost, reproducible, predictive in-line test. Unfortunately, we're not there yet.

Presently the best commercial candidate is the high-speed cold ball pull test. Dage, (www.dage-group.com) the die-shear experts, have been the leader in developing and promoting this test. The pulling force, unlike ball shear, is entirely tension in the vertical direction.

The high speed, which can be greater than 1 meter per second, increases the rate of strain applied to the solder balls, transferring more force to the ball-to-UBM joint, rather than testing only the solder itself. [1]

Figure 1 shows the pulling jaws of the Dage 4000HS machine, which clamp against the sides of the ball. A pneumatically controlled rising table accelerates the test unit to speeds up to 1.3 meters/second before a fixed mechanical stop halts the motion.



Dage 400HS jaws aligned for high-speed pull test.

Figure 2 illustrates conceptually how the high-speed force is applied. [2] The ball is aligned to and grasped by the jaws. The table is retracted, accelerated and then abruptly halted by the stop, transferring the pull force to the ball, and stressing the ball to pad interface.

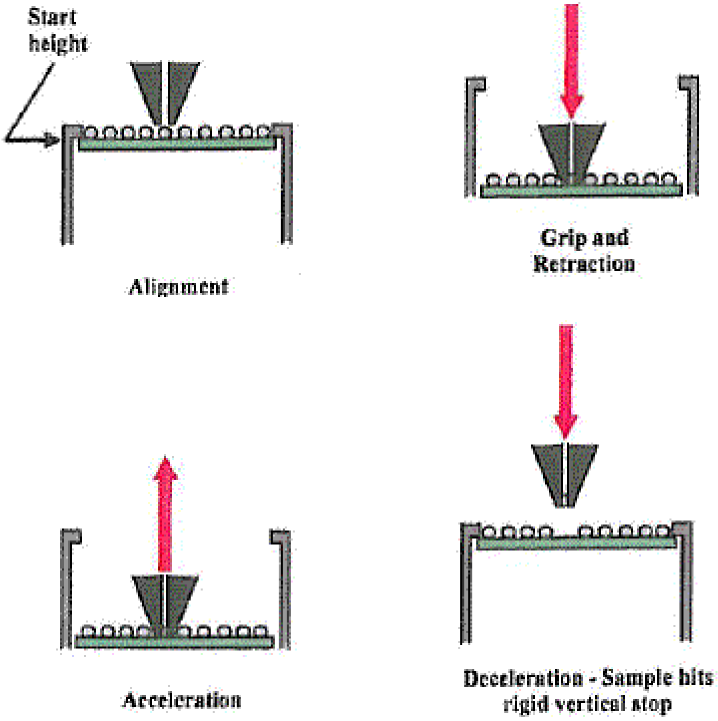


Figure 2. Conceptual view of high-speed bond pull test sequence.

Figure 3A is a microscope view of a pad after ductile failure, leaving solder traces on the pad. Figure 3B shows brittle failure, with separation in the intermetallic layer of the pad joint. [1]

Although the differences here are clear, there is a wide middle ground where the failure is partly ductile and partly brittle. These generally are judgment calls by a trained inspector, who may categorize them as "Mostly Ductile" or "Mostly Brittle."

Figure 3a. Ductile fracture

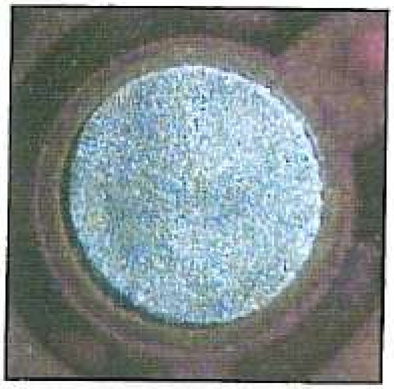


Figure 3b. Brittle Fracture

One limitation on the test then is the subjective nature of the results. A second limitation is that the correlation of cold ball high speed pull failures and drop-test failures depends on the geometry of the assembly as well as the metallurgy and processing, and must be established with sometimes differing degrees of confidence for each specific part and perhaps for each lot.

Dr. Thorsten Teutsch of Pac Tech, the industry leader in electroless nickel underbump metallization, recently presented results of fast-pull testing with different lead-free solder formulations . [3] He reported that the high-speed pull test is a suitable tool for measuring intermetallic performance on WLCSP devices with ball of at least 250 microns diameter.

He also found that SAC105 solder joints show significantly fewer brittle failures under his pull test than SAC 305 or SAC 405 joints. The Pac Tech investigation is continuing.

In conclusion, the high speed pull test is a useful tool in addressing brittle lead-free solder joints, but the question of how to make best use of this tool to anticipate and prevent brittle failures requires further study.

References

[1] Peter Borgeson & Bob Sykes, "Predicting Brittle Fracture Failures," SMT October 2005

[2] Bob Sykes, "Lead-Free BGA Reliability: High Speed Bond Testing and Brittle

Fracture Detection," Global SMT & Packaging, October 2005.

[3] Thorsten Teutsch, "ENIG vs. ENEP(G) Under Bump Metallization for Lead-Free WL-CSP Solder Bumps - a Comparison of Intermetallic Properties Using High Speed Pull Test, " IMAPS International Conference on Device Packaging, Scottsdale, Arizona, March 17 - 20, 2008.

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