CSP/BGA BOARD LEVEL RELIABILITY

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Abstract

Different aspects of advanced surface mount package technology have been investigated for aerospace applications. Three key areas included the assembly reliability of conventional Surface Mount, Bali Grid Arrays (BGAs), and Chip Scale Packages.

Reliability of BGAs was assessed as part of a consortium effort led by the Jet Propulsion Laboratory. Nearly 200 test vehicles, each with four packages, were assembled and tested using an experiment design. The most critical variables incorporated in the experiment were package type, board material, surface finish, solder volume, and environmental condition. The BGA test vehicles were subjected to thermal and dynamic environments representative of aerospace applications. The test vehicles were monitored continuously to detect electrical failure and their failure mechanisms were characterized.

A MicrotypeBGA consortium with industry-wide support was also organized to address technical issues regarding the interplay of package type, I/O counts, PWB (Prited Wiring Board) materials, and manufacturing variables. This paper will present only the most current thermal cycling test results for plastic BGA packages with 313 and 352 1/0s as well as failure mechanisms for ceramic BGA packages with 625 1/0s and plastic packages with 313 1/0s. The board level reliability of CSP assembly will also be reviewed and projected.

Introduction

BGA is an important technology for utilizing higher pin counts, without the attendant handling and processing problems of the peripheral leaded packages. They are also robust in processing because of their higher pitch (0.050 inch typical), better lead rigidity, and self-alignment characteristics during reflow processing.

BGAs' solder joints cannot be inspected and reworked using conventional methods and are not well characterized for multiple double sided assembly processing methods. In high reliability SMT assembly applications, e.g. space and defense, the ability to inspect the solder joints visually has been standard and has been a key factor in providing confidence in solder joint reliability.

To address many common quality and reliability issues of BGAs, JPL organized a consortium with sixteen members in early 1995[1]. Diverse membership including military, commercial, academia, and infrastructure sectors which permitted a concurrent engineering approach to resolving many challenging technical issues.

Emerging Chip Scale Packages (CSPs) are competing with bare die assemblies and are now at the stage Ball Grid Arrays (BGAs) were about two years ago. These packages provide the benefits of small size and performance of the bare die or flip chip, with the advantage of standard die packages. Availability of board level solder joint reliability information is critical to the acceptance of CSPS as alternative packages. This paper will present test data and projection for BGA and CSP assembly reliability.

Ball Grid Array Program

Test Vehicle Configuration

The two test vehicle assembly types were plastic and ceramic packages. Both FR-4 and polyimide PWBS with six layers, 0.062 inch thick, were used.

Plastic packages covered the range from OMPAC to SuperBGAs (SBGAs). These were:

- Two peripheral SBGAS, 352 and 560 I/O
- Peripheral OMPAC 352 1/0, PBGA 352 and 256 I/O
- Depopulated full arrayPBGA313 1/0s
- 256 QFP, 0.4 mm Pitch

In SBGA, the IC die is directly attached to an oversize copper plate providing better heat dissipation efficiency than standard PBGAs. The solder balls for plastic packages were eutectic (63 Sn/37Pb).

Ceramic packages with 625 1/0s and 361 1/0s were also included in our evaluation. Ceramic solder balls (90Pb/1 OSn) with 0.035 inch diameters had a high melting temperature, These balls were attached to the ceramic substrate with eutectic solder (63 Sn/37Pb). At reflow, package side eutectic solder and the PWB side eutectic paste will be reflowed to provide the electro-mechanical interconnects.

Plastic packages had dummy and daisy chains with the daisy chains on the PWB designed so as to be able to monitor critical solder joint regions. Most packages had four daisy chain patterns, 560 I/O had five, and the QFP had one.

Package Dimensional Characteristics

Package dimensional characteristics are among the key variables that affect solder joint reliability. Dimensional characteristics of all packages were measured using a 3D laser scanning system for solder ball diameter, package warpage, and coplanarity[1].

Test Vehicle Assembling

Full assembly was, implemented after process optimization from the trial test. The following procedures were followed:

. PWBS were baked at 125°C for four hours prior to screen printing.

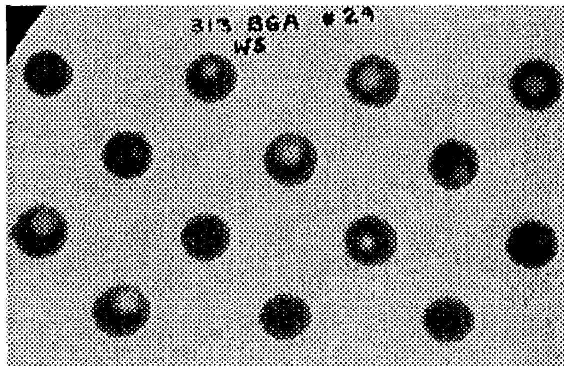
. Two types of solder pastes were used, an RMA and a water soluble.

. Pastes were screen printed and the heights were measured by laser profilometer. Three levels of paste were included in the evaluation: Standard, high, and low. Stencils were stepped to ***50%*** to accommodate assembling ceramic, plastic, and fine pitch QFP packages in the Type 2 test vehicle.

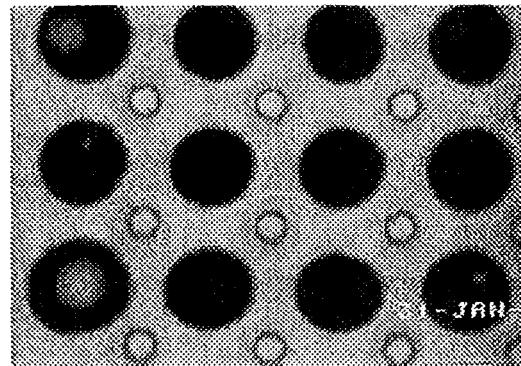
. A 10 zone convection oven was used for reflowing.

. The first assembled Test Vehicle (TV) using an RMA reflow process was visually inspected and X-rayed to check solder joint quality.

. All assemblies were X-rayed

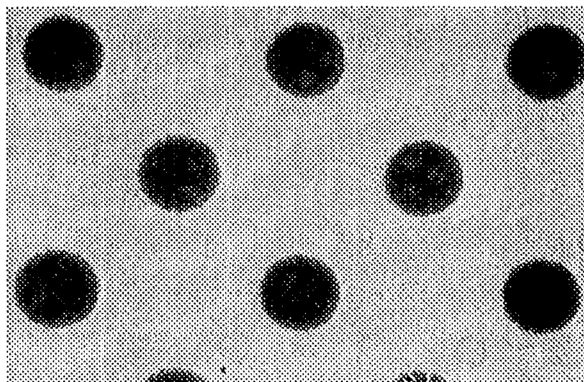


a) Excessive Voids in PBGA 313

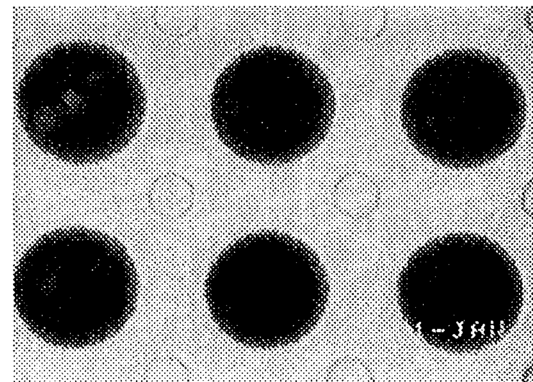


b) Excessive Voids in SBGA 352

Figure 1 Excessive Voids for Water Soluble Paste with an *RMA Reflow* Profile



a) Reduced Voids in 313 PBGA



b) Reduced Voids in 352 SPBGA

Figure 2 Voids for Water Soluble Paste with a *Water Soluble Reflow* Profile

- Interchangeability of reflow profile for RMA and Water Soluble (WS) solder pastes was examined. One TV with water soluble solder paste was reflowed using the RMA reflow profile. These solder joints showed much higher void content than expected (Figure 1), as well as signs of flux, residues.
- For water soluble paste, a new reflow profile was developed based on the manufacturer's recommendation. This reflow process was used for the remaining test vehicles.
- Figure 2 shows X-ray images when a WS reflow profile was used for the WS solder paste. These joints showed much lower void levels.

Two test vehicles were assembled:

- Type 1, ceramic and plastic BGA packages with nearly 3001/0s
- Type 2, ceramic and plastic BGA packages with nearly 600 1/0s. Also utilized were a 256 leaded and a 256 plastic BGA package for evaluating and directly comparing manufacturing robustness and reliability.
- Assemblies with water soluble flux were cleaned in an Electrovert H500. Those with RMAs were cleaned using Isopropyl Alcohol (IPA) and a *5%* saponified.
- All fine pitch QFPs had to be reworked for bridges.

Thermal Cycling

Two significantly different thermal cycle profiles were used at two facilities. The cycle A condition ranged -30 to 100"C and had increase/decrease heating rate of 20C and dwell of about 20 minutes at the high temperature to assure near complete creeping. The duration of each cycle was 82 minutes.

The cycle B condition ranged -55 to 125°C. It could be also considered a thermal shock since it used a three regions chamber: hot, ambient, and cold. Heating and cooling rates were nonlinear and varied between 10 to 15 °C/min. with dwells at extreme temperatures of about 20 minutes. The total cycle lasted approximately 68 minutes. BGA test vehicles were continuously monitored through a LabView system at both facilities.

The criteria for an open solder joint specified in IPC-SM-785, Sect. 6.0, were used as guidelines to interpret electrical interruptions. Generally once the first interruption was observed, there were many additional interruptions within 10% of the cycle life. In several instances, a few non-consecutive early interruptions were not followed by additional interruptions till significantly later stages of cycling. This was found more with plastic packages.

Damage Monitoring

For conventional SMT solder joints, the pass/fail criteria for high reliability applications relies on visual inspection at 10x to 50x magnifications. For BGA, only edge balls, those not blocked by other components, were visually inspected. A series of single assemblies cut from the test vehicles were used for both visual and SEM inspection to better define visual criteria

for acceptance of solder joints as well as to monitor damage progress under different cycling environments.

Both board and package interface cracking was observed with increasing number of cycles. Figure 3 shows typical failures for the two cycling conditions. Failure under the A conditions were generally from the PWB and for the B conditions were from the package sites. Failure mechanism differences could be explained by global or local stress conditions. Modeling indicates that the high stress regions shifted from the board to the package themselves when stress conditions changed from the global to local. The A cycling, with slow heat/cooling ramping, allowed the system to reach a uniform temperature, damages could indicate a global stress condition. The B cycle, with rapid heat/cooling, damages could indicate a local stress condition.

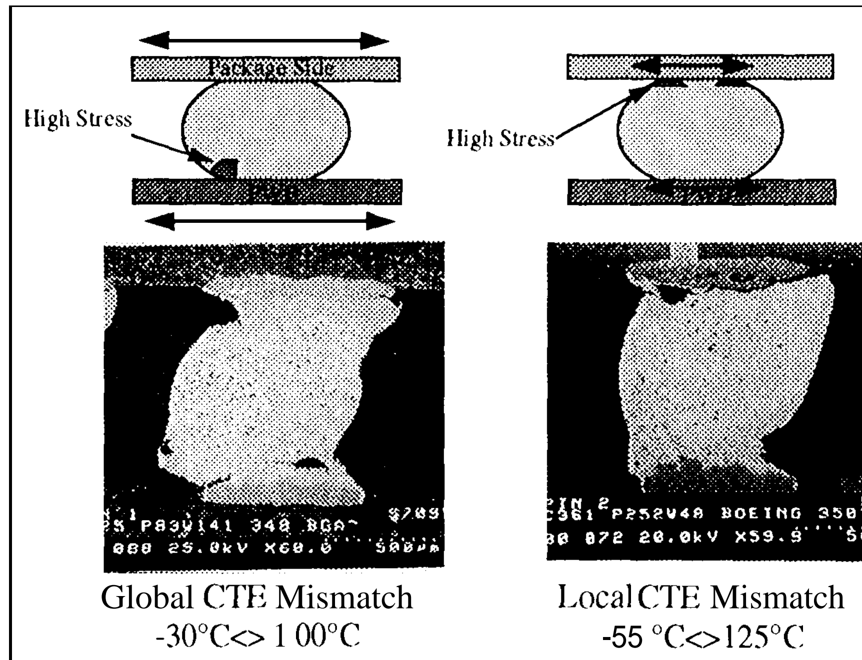


Figure 3 Cross-sections of Failure Sites for CBGA 625 after 350 cycles **under A (-30°C to 100°C) and B Conditions**

Among the plastic packages, the PBGA313 with depopulated full array balls was first to fail under both B and A thermal cycling conditions. Figure 4 shows various cross- sections of this package's balls from corner to the center at **4,682** A cycles. These photos are for the balls under the die where most damages occur due to local CTE mismatch. Photos with and without voids were also included for comparison. Voids appear to have concentrated at the package interface under the die. Cracking propagation occurred at package or board interfaces for sections with or without voids. The sections with voids were opens indicated by seepage of mounting materials into voids. Except for the interface connecting cracks, there appeared to be no crack propagation among the voids.

The solder joints for this package were also visually inspected to identify indicators of defects. There were none apparent. Even when these were inspected at lOOx by SEM, no gross damage was observed, as evidenced from the top left SEM photo of Figure 4.

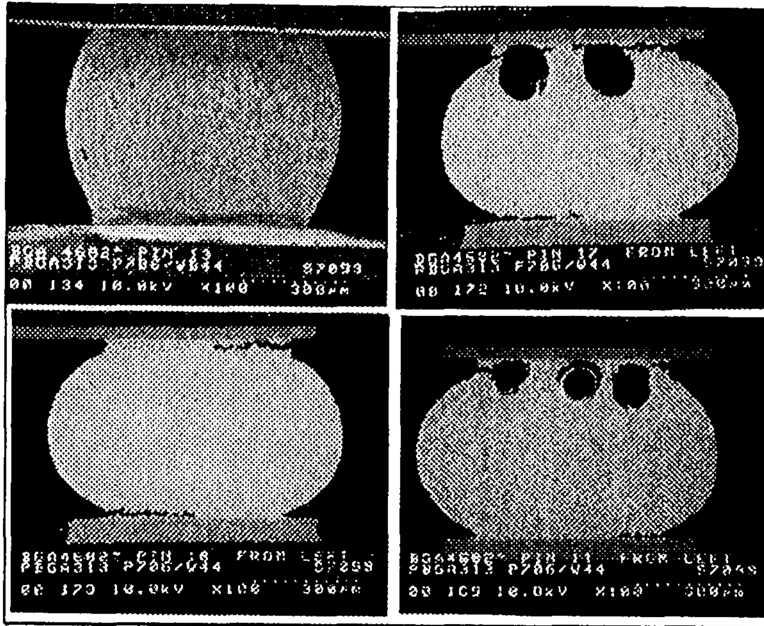


Figure 4 SEM and Cross-sections of PBGA 313 after 4,682 cycles under A (-30°C to 100°C) Conditions

Thermal Cycling Results

Figure 5 shows cycles to first failure for PBGA 313 and SBGA 352 subjected to B cycling for assemblies on polyimide and FR-4 PWBs. The most current PBGA 313 assemblies that failed under cycle A conditions are also included in the plots for comparison. These assemblies include those reflowed with low, standard, and high solder paste levels

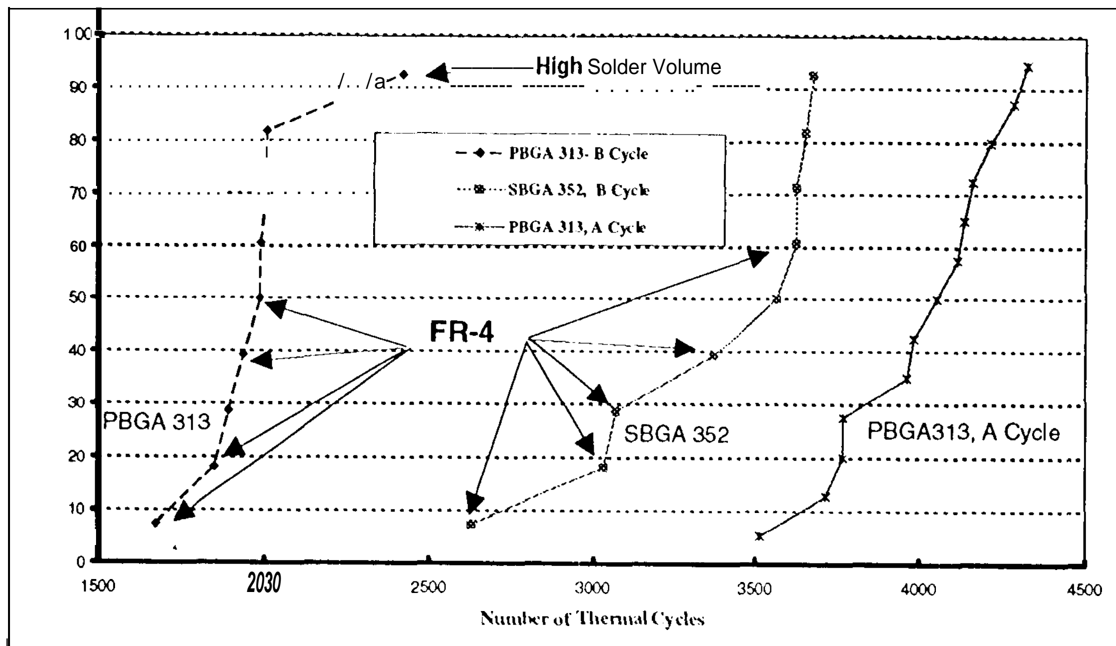


Figure 5 Cycles to Failure for PBGA 313 & SBGA 352 Assemblies (-55°C to 125°C, A) & (-30°C to 100°C)

The cycles to failure were ranked from low to high and failure distribution percentiles were approximated using median plotting position, F_i= (i-0.3)/(n+0.4). Weibull parameters will be generated when all failure data are gathered.

CSP Board Level Reliability

Introduction

CSPs are defined as packages that are up to 1.2 or 1.5 times larger than the perimeter or the area of the die, respectively. Many manufacturers now refer to CSPS as packages that are the miniaturized version of their previous generation. This packaging accomplishes many purposes, including the following:

- Provides solder balls and leads that are compatible with the PWB pads for reflow assembly processes, whereas aluminum pads do not.
- Redistributes the tight pitch of the die to the pitch level that is within the norm of PWB fabrication. The small sizes of CSPS do not permit significant redistribution and the current cost-effective PWB fabrication limits full adoption of the technology, especially for high I/O counts.
- Protects the die from physical and alpha radiation damages, and provides a vehicle for thermal dissipation and ease of die functionality testing.

CSPS generally have been categorized based on their fundamental structures. These are:

- Interposer packages with either flexor rigid substrate
- Wafer level molding and assembly redistribution
- Lead On Chip (LOC) packages.

Currently, most of this data are those that were generated for package qualifications by manufacturers with very limited published information available on assembly reliability. These data are of limited value to the end user since often they have been collected under significantly different manufacturing and environmental conditions or for packages with different pin counts.

Assembly Reliability for Conventional Packages and Those Projected for CSPS

Reliability of conventional SM packages has also been investigated at JPL[2]. Cycles to failure test data points and their Weibull distributions for 28-, and 20-pin LCC, and 68-pin gull wing assemblies are shown in Figure 6. Thermal cycling ranged from -55°C to 100”C with a 246 minute duration. The failure distribution percentiles were approximated using a median plotting position and the two-parameter Weibull cumulative failure distribution was used to fit data.

For the trend comparison purpose, projected cycles to failure for low count CSPS are also included. Results are those gathered from literature and projection based on a modified Coffin-Manson relationship. Being an emergent technology, these packages are being continuously evolved and therefore the CSP reliability results plotted might not be representative of the most' current version of these packages.

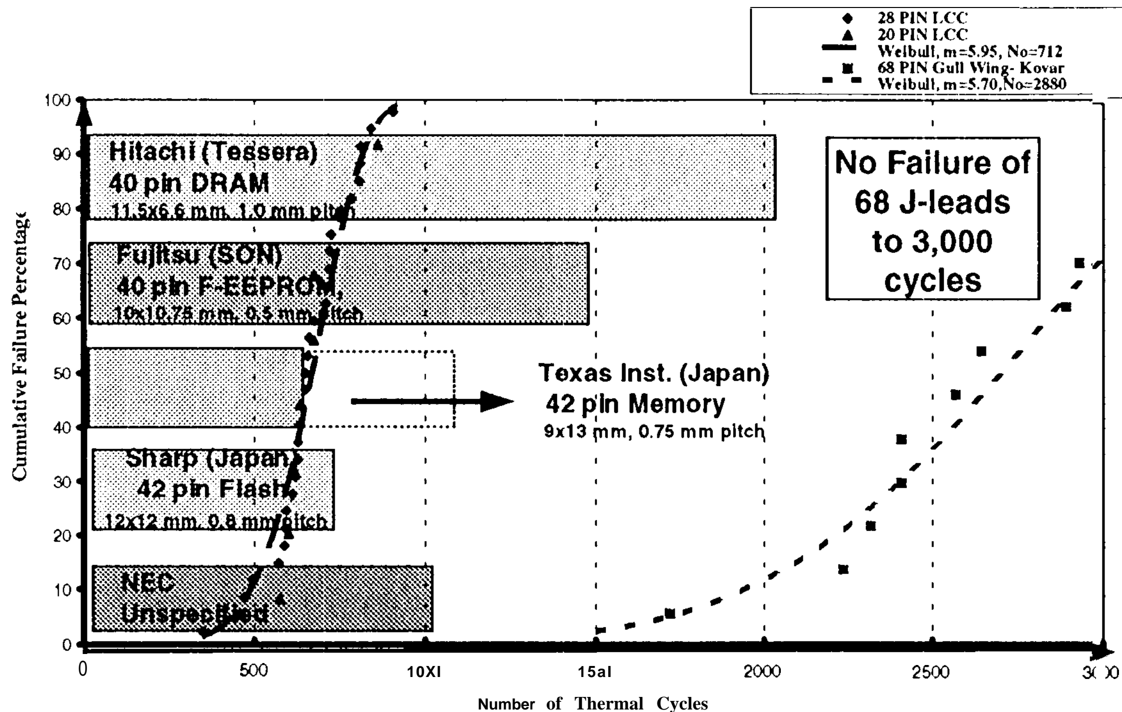


Figure 6 Projected Cycles to failures for Low Pin Count CSP Assemblies and Cumulative Failure Distributions for Conventional SM Package Assemblies Tested at JPL (-55°C to 100°C)

Consortium to Assess CSPs' Board Level Reliability

For wider applications of CSP technology, the potential user will need design reliability data for its design since often they have no resources, time, or ability to perform complex environmental characterizations. JPL has formed a consortium with the objectives of addressing many technical issues regarding the interplay of package types, I/O counts, PWB types and materials, surface finishes, and manufacturing variables for the quality and reliability of assembly packages

Currently, the JPL-led MicrotypeBGA consortium has completed design of its first test vehicle and is in assembly process stage. It is anticipated that more than 300 test vehicles will be assembled and subjected to various environmental conditions representative of space and military as well as commercial applications.

Conclusions

BGA Packages and Assembly Reliability

- As expected, ceramic packages failed much earlier than their plastic counterparts because of their much larger CTE mismatch on FR-4/Polyimide boards. Cycles to electrical failure depended on many parameters including cycling temperature range and package size (1/0).
- Ceramic packages with ***625*** 1/0s were first to show signs of failure among the ceramic (CBGA 361) and plastic packages (SBGA 560, SBGA 352, OMPAC 352, and PBGA 256) when cycled to different temperature ranges.
- Joint failure mechanisms for assemblies exposed to two cycling ranges at two facilities were different. Ceramic assemblies cycled in the range of -30°C to 100"C showed cracking initially at both interconnections with final separation generally from the board side through the eutectic solder. The board side joint showed signs of pin hole formation prior to cracking and complete joint failure. This failure mechanism is similar to those reported in literature for O°C to 100°C thermal cycles.
- The PBGAs with 313 1/0, depopulated full arrays, were first among the PBGAs to fail with both cycling ranges. It has been well established that this configuration, with solder balls under the die, is not optimum from a reliability point of view.
- Solder volume is generally considered to have negligible effect on plastic package assembly reliability. One PBGA 313 package that was assembled with a high solder paste volume under cycle B exposure showed the highest number of cycles to failure. This will be assessed when data for cycle A become available.
- The 352 SBGA with no solder balls under the die showed much higher cycles to failure than the F'BGA 313 when subjected to cycle B conditions.
- For cycle B conditions, plastic package assemblies (PBGA 313 and SBGA 352 on polyimide) generally failed at a higher number of cycles than those on FR-4.
- For plastic packages, crack propagation occurred at either the package or board interfaces for sections with or without voids. Generally, voids were concentrated near the package interface. There appeared that there were no crack propagation among the voids, except for those connected at the interface.

CSP Assembly Reliability

. The board level reliabilities of most CSP packages are comparable or better than their LCC with similar I/O counts. These packages, however, are not as robust as leaded packages including gull wing and J-1eads.

- Board level solder joint reliability information is critical to the acceptance of CSPS as alternative packages. It is the objectives of the JPL-led Microtype BGA consortium to help in developing this aspect of technology infrastructure.

References

1. Ghaffarian, R.,"CBGA/PBGA for Highly Reliable Applications", The NEPCON West '97 Proceedings, Feb. 25-27, 1997.
2. Ghaffarian, R.,"The Interplay of Surface Mount Solder Joint Quality and Reliability of Low Volume SMAs", NEPCON WEST Proceedings, Feb. 1996.

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