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iNEMI Statement of Work (SOW)
Packaging TIG
Primary Factors in Component Warpage

Version 3.0

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Basic Problem Statement

Component warpage remains an ongoing issue for SMT assembly, especially for ball grid array (BGA) organic packages. The amount of component warpage that occurs during the surface mount reflow process can vary greatly and is believed to be a strong function of the package design and materials properties. The warpage problem is compounded by the vast differences in package technologies, designs, and materials sets. If the extent of the warpage is below certain limits, corrective measures can be taken during SMT assembly to accommodate the variations. However, defects such as poor wetting and head-in-pillow (HnP) continue to occur and typically are related directly to excessive component warpage. The transition to Pb-free manufacturing and assembly has exacerbated this issue because of the increased reflow temperatures for Pb-free assembly. It is thus beneficial for the industry to address warpage issues collectively and investigate the key factors that can contribute to component warpage.

Previous Related Work

Published works and past experiences have demonstrated that a variety of factors can contribute to warpage related issues. These factors can be grouped in 3 major categories:

- Package construction
- Material properties
- Process history

It is apparent that the warpage behavior of a given component during the SMT process will be the result of all of these factors, but for the purposes of corrective action, it would be of great value to identify the factors most critical to warpage. In terms of corrective action, it is likewise important to identify the factors that are reasonable candidates for modification or control. The following list defines factors which may be associated with warpage.

- Package Construction:
  - Package type
  - Package size
  - Die size and die-to-package ratio
  - Package aspect ratio
  - Cored vs. coreless substrate
  - Substrate build up layers and thickness
  - Lamination process
  - Die attach method
  - Assembly process variations
- Material Properties:
  - CTE / Modulus / Tg of molding compound and underfill
  - CTE / Modulus / Tg of substrates layers
  - CTE / Modulus / Tg of die attach
- Processing History:
  - Precondition
  - Bake
  - Moisture exposure
  - Number of reflows
  - SMT assembly process profile variations (e.g., peak temperature, RTS/RTH, cooling rate)

The scenarios below depict common warpage issues.

Example 1:

- **Package Type** – "Chip Scale" flip chip area array
- **Interconnection Technology** – Flip chip
- **Solder Type** – Pb Free (SAC305)
- **Body size** – Proprietary (not for public disclosure)
- **Service Life** – 3-5 years, intermittent operation
- **Failure Type** – System level Accelerated Life Testing

- **Mean Time to Failure** –200-300 hours during qualification testing (primarily during power cycling)
- **Substrate Technology** – Double sided coreless substrate
- **Substrate to Die Ratio** – 1.3/1
- **Failure Rate** – 10%
- **Failure Analysis** – One corner of CSP consistently showed opens
- **Root Cause Analysis** – Large ground circuits in one corner cause package to bow away from system board during reflow; system board warpage determined to be a factor
- **Solution** – Minimize differences in top and bottom layers in offending corner
- **Result** – Corrected ALT issues and subsequent analysis of assembled product shows not sign of marginal joints
- **Qualification Criteria Used** – Unknown/not provided - package qualifications passed with no issues reported

Example 2:

- **Package Type** –BGA
- **Interconnection Technology** – Flip chip
- **Solder Type** – Pb Free (SAC305)
- **Body size** – Proprietary (not for public disclosure)
- **Service Life** – 5-7 years; intermittent operation
- **Failure Type** – Field
- **Mean Time to Failure** – 3000-4000 hours
- **Substrate Technology** – Multilayer laminate core with build-up layer on die surface for signal/ground redistribution
- **Substrate to Die Ratio** – 2/1
- **Failure Rate** – 3-5%
- **Failure Analysis** – Fractured peripheral solder joints causing intermittent opens during operation; system board warpage at failure locations determined not to be significant
- **Root Cause Analysis** – Package warpage at periphery warping away from system board during reflow causing incomplete and weakened solder joints which passed static room temperature and elevated temperature system tests; product passed normal ALT qualification testing
- **Solution** – Adjust manufacturing operation to increase solder paste volume at periphery and reduce solder paste volume in the under die to compensate for package warpage
- **Result** – Field failures due to poor solder joints eliminated

- **Qualification Criteria Used** – Unknown/not provided - package qualifications passed with no issues reported

Example 3:

- **Package Type** – POP, BGA
- **Interconnection Technology** – Wirebond
- **Solder Type** – Pb-Free (SAC405)
- **Body size** – Proprietary (not for public disclosure)
- **Service Life** – 5-7 years continuous operation except for routine hardware and software maintenance (system is taken out of service during maintenance)
- **Failure Type** – Manufacturing
- **Mean Time to Failure** – Post assembly test
- **Substrate Technology** – Multi-layer laminate core with build-up layer on die surface for signal/ground redistribution
- **Substrate to Die Ratio** – 1.75/1
- **Failure Rate** – 5%
- **Failure Analysis** – Fractured solder joints in center of package
- **Root Cause Analysis** – Package and system board warpage in opposite directions
- **Solution** – Added additional solder to central pads
- **Result** – Manufacturing failure rates fell within acceptable limits; field reliability data is being collected; no failures occurred during ALT
- **Qualification Criteria Used** – Unknown/not provided - package qualifications passed with no issues reported

Scope of Work

This is intended to be a multiphase project. The initial phase will include the following:

- Based on information gathered during the project formation phase, specific factors will be identified that are believed to affect the warpage performance of area array or ball grid array components (packages).
- Using the list of specific factors as the baseline, a survey will be developed to rank the importance of these factors based on component user and manufacturers' experience and on observations from manufacturing operations, field engineering, and repair facilities.
    - Survey respondents will be asked to provide any additional factors beyond those listed initially.
    - Input on corrective action, problem resolution, and measure of success will be collected.

- Survey results will be analyzed and this analysis of primary factors will be published. Results of the analysis could include a rank order of the primary factors or specific package types that are considered most problematic. The survey summary will be used to develop the next phase of the project, as well as being shared with other relevant iNEMI projects such as the Package Qualification Criteria to Ensure Acceptable Warpage Performance at 2nd Level Assembly project.
- Plans for additional phases of the project will be developed. Subsequent phases will accomplish the following:
  - Evaluate the identified factors for various package types based on participant input and interest and select the most critical ones for further investigation.
  - Select a set of component types as test vehicles for the next phase of the project.
  - Identify the characteristics of warpage for these components and establish a representative database for these during different reflow processes seen on typical SMT lines.
  - Develop recommendations for package structural design and material property selection to minimize warpage.

Purpose of Project

Increasing amounts of data suggest that existing evaluation criteria for component warpage is not sufficient to prevent defects seen on High Volume Manufacturing (HVM) SMT lines or during field application. However, to date the issues have not been given industry-wide visibility and traditional inspection and qualification methods (e.g., room temperature warpage only) are still being widely used. Component designers and manufacturers are sometimes not aware of the severity of warpage induced defects, and more feedback is needed for these components. The work outlined in this project will help identify primary factors that can contribute to the warpage performance for selected components during typical SMT processes.

Business Impact

This project will provide the following benefits to participating companies and the industry in general.

- A clear understanding of proliferation and severity of component warpage induced defects both on SMT lines and in field applications.
- The effects of package designs, material properties, and processing history on component warpage performance.
- General design guidelines for high-risk component types (as identified by the survey phase of this project) to reduce component warpage.
- Reduce defect rates such as non-wets and head-in-pillow on the SMT lines.
- Reduce field failures and returns caused by the forth-mentioned SMT defects.

Prospective Company Participants

AkroMetrix
ASE
Alcatel-Lucent
Boston Scientific
Cisco Systems
Dell
Doosan Electro-Materials
Dupont
Fujitsu
Guangdong Shengyi Sci. Tech
Hewlett-Packard
IBM
Intel
NGK
Quanta
Rogers Corporation
SEMCO
Zygo Vision Systems

Phase 1 Project Plan

Primary Factors in Warpage Project Tasks		Months			
Task		M1	M2	M3	M4
1.0	Based on preliminary information gathered during the formation phase create a list of specific substrate warpage factors that have been observed as causing problems				
2.0	Use the list from 1 above to establish as the baseline in the development of a survey to rank order the factors identified based on their experience				
2.1	Collect information from the project participants on additional factors beyond those listed				
2.2	Develop survey to identify the factors that have been determined to be problematic in both manufacturing and field operations				
3.0	Use the survey to collect observations from manufacturing operations, field engineering, repair facilities and other areas identified by the project team. Collecting input on how problems are being and have been addressed				
4.0	Analyze the survey results and publish a summary of the rank order of the primary factors. This rank order listing would be provided to the Qualification Criteria project team to assist in their development of qualification criteria				
5.0	Use the gathered information to show the problems caused by the package / system board interactions during SMT reflow are more pervasive than much of the industry is aware of				
6.0	Develop categories based on the survey results and team's knowledge, e.g., design, material properties, number of layers, core vs. coreless, and others as determined by the project team				

7.0	Investigate the development of a test board coupon that can be used in characterizing the dynamic behavior of substrate based packages
8.0	Develop project plans for additional phases
9.0	Identify conferences and/or workshops where a summary of the results can be presented
10.0	Document results of investigations and present summary to iNEMI membership

Detailed Task List:

Task 1.0 - Based on preliminary information gathered during the formation phase create a list of specific substrate warpage factors that have been observed as causing problems

- Resources
  - All project team members

Task 2.0 - Use the list from 1 above to establish as the baseline in the development of a survey to rank order the factors identified based on their experience

- Resources
  - All project team members

Task 2.1 - Collect information from the project participants on additional factors beyond those listed.

- Resources
  - All project team members
  - iNEMI Staff support to collect and sanitize any sensitive information

Task 2.2 - Develop survey to identify the factors that have been determined to be problematic in both manufacturing and field operations

- Resources
  - All project team members
  - iNEMI staff assistance in the development and execution of the survey

Task 3.0 - Use the survey to collect observations from manufacturing operations, field engineering, repair facilities and other areas identified by the project team. Collecting input on how problems are being and have been addressed

- Resources
  - All project team members
  - iNEMI staff assistance in the development and execution of the survey

Task 4.0 - Analyze the survey results and publish a summary of the rank order of the primary factors. This rank order listing would be provided to the Qualification Criteria project team to assist in their development of qualification criteria

- Resources
  - All project team members

Task 5.0 – Use the gathered information to show the problems caused by the package / system board interactions during SMT reflow are more pervasive than much of the industry is aware of

- Resources
  - All project team members

Task 6.0 - Develop categories based on the survey results and team's knowledge, e.g., design, material properties, number of layers, core vs. coreless, and others as determined by the project team

- Resources
  - All project team members

Task 7.0 - Investigate the development of a test board coupon that can be used in characterizing the dynamic behavior of substrate based packages

- Resources
  - All project team members

Task 8.0 - Develop project plans for additional phases

- Resources
  - All project team members

Task 9.0 - Identify conferences and/or workshops where a summary of the results can be presented

- Resources
  - All project team members

Task 10.0 - Document Results of investigations and present summary to iNEMI membership

- Resources
  - All project team members

Project Monitoring Plans

This is a Research project, i.e., given an idea or concept, research projects explore and investigate new processes. The outcome is a set of processes that could be used in a production environment if proven to be production worthy. These projects may include some preliminary reliability testing; however the main focus is on identifying and demonstrating the feasibility of a process.

Project monitoring plans are as follows:

- Ensure open lines of communication among participants
  - Weekly conference calls
  - Meeting minutes provided through e-mail
  - Follow-up with individuals on an as-needed basis
- Technical review at end of second month
- Track and document approximate man-months per quarter per team member (this will require the active members of the team to provide estimates).
- Track and document approximate number of people on the project per quarter (this can be tracked through iNEMI's WebEx account.)

Outcome of the project

- Technical paper/whitepaper
  - Summary of survey results
  - Publish categories based on the survey results and team's knowledge, e.g., design, material properties, number of layers, core vs. coreless, and others as determined by the project team
  - Provide input to the Warpage Qualification team for Phase 2 SOW development
- Presentation(s) at major conferences as determined by the project team

General and Administrative Guidelines

General and Administrative Guidelines for this project and all other iNEMI Projects are documented at http://thor.inemi.org/webdownload/join/gen_guidelines.pdf.