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Joint Council on Aging Aircraft
Joint Group on Pollution Prevention

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Lead-Free Solder Project Meeting Minutes
14 December 2004
Teleconference & WebEx

Comments:

Attached please find the minutes for the December 14, 2004 Lead-Free Solder Project teleconference. Please further distribute as necessary.

Attendees:
Please Note: We had some difficulties in recording the names of the meeting attendees. Please let me know if names are missing from the list so we can accurately record the meeting attendees.

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<u>MEMORANDUM FOR RECORD</u>

Subject: – Teleconference, Summary and Minutes – December 14, 2004

Next Meeting: February 22, 2005, IPC/APEX; for those LFS consortia members attending the IPC/APEX February 22-24, 2005 Anaheim California. A meeting room has been reserved for the JCAA/JG-PP LFS Project consortia.
Next Project Meeting: March 8 time frame, Location TBD

Minutes:

1. **Opening:**
   Mr. Kurt Kessel opened the meeting welcoming the attendees and stating the purpose of the Teleconference was to review the Lead-free Solder testing accomplished to date. Also open for discussion were future meeting dates. As an administrative point, Mr. Kessel pointed out that the e-mail listing has grown so big that some computer systems detect the incoming email as spam and block its delivery. To combat this problem Mr. Kessel has broken the list down to several lists to be sent out separately. If anyone is left off the list or needs a copy of the complete list, contact Mr. Kessel to make arrangements. With that, Mr. Kessel introduced Dr. Thomas Woodrow (Boeing Phantom Works) to brief the results and status of the vibration, thermal shock, and thermal cycling tests -20^{o}C to 80^{o}C.

2. **Vibration:** Associated Presentation: 121404Woodrow.pdf; *"JCAA/JG-PP No-Lead Solder Testing Status"*

   Dr. Woodrow opened by explaining that he had prepared a schematic of the test board (slide 2). This will be a helpful tool when discussing component failures and component locations on the boards. Dr. Woodrow continued with his presentation beginning with an overview of the vibration test. A laser system was used to calculate the strain across the pathfinder board. This provided almost 1200 calculated strain measurement points on the board. The highest strain is in the very red and very dark blue regions of the board (slide 4). One region is in tension and the other in compression. It was expected that the board would fail in these two regions. Slide 5 shows the pathfinder board with all failures color coded. Components tagged with red, orange, and yellow are the first components to fail. The failures follow the patterns from slide 4. The first failures tend to be down the middle of the board and along the edges. This is consistent with what was expected. Slide 6 shows the status of the test vehicles. All the boards have been tested. All wires were inspected to ensure failures were not caused by a failure in the wires. All test vehicles were inspected specifically to check leaded parts for broken leads. This was done because a broken lead would show as a solder joint failure. To prevent any faulty analysis, all observations made while inspecting the boards was documented.

   Dr. Woodrow went on to explain that most of the quad flat pack (QFP) components probably failed due to lead failures, not solder joint failures. Data collected from QFP components with broken leads is useless if you want to know when the actual solder joints failed. The PLCC, DIP, and other leaded components did not have lead breakage issues. Dr. Woodrow continued with slide 7, which shows a picture of the fixture with the boards installed. Slide 8 shows the percentage of component failures on the manufactured boards for each level of the test. As a reminder, the level of vibration was ramped up every hour of the test. At the end of the manufactured test there was approximately 70 percent total component failure. Slide 9 shows similar results for the rework boards, with approximately 75 percent total component failure by the end of the test. Dr. Woodrow cautioned not to compare the data between the manufactured boards and the reworked boards. The manufactured and rework boards are made from different laments so they have different resonance frequencies and it might not be feasible to compare the two sets of data.

Dr. Woodrow continued explaining that slide 10 shows how the leads cracked on the QFP components. Also, the corner leads tended to break in two places and fly away. All of the data generated for the QFP components is suspect due to the lead breakage issue. Slide 11 shows that the TSOP components had a strange failure mechanism. The TSOP components (U12, U26, and U16, U29) oriented parallel to the short side board edge, where the wedge locks are located for securing the boards into the vibration fixture, tended to “unzip” along one side. All the solder joints would pull out of the solder (slide 11) and bounce around until the joints on the other side of the components would snap off (slide 12). The TSOP components (U24, U25, U39, U40, and U61, U62) oriented perpendicular to the short side board edge did not fail in this manner. Slide 13 shows the results of testing form a QFP-208 component located at U3 on the rework boards. This particular component tended to fly off the boards consistently. The pads look like there is no solder on some of the pad (slide 13). Dr. Woodrow stated that he did not know why there was a lack of solder on the pads and this issues needs to be looked at more closely. Slides 14-18 are a color-coded summary of a much larger data sheet. The color-coded summary shows which solder was ranked the highest or which solder lasted the longest in the test. Dr. Woodrow did point out that for the TSOP components the data was inconsistent and the results seemed to be dependent on the orientation of the part. The orientation of the TSOP components on the board could possibly determine which solder performs the best. There is not enough data on this particular issue to obtain a conclusive understanding of the issue.

Dr. Woodrow stated that the final report for the vibration testing is being put together and should be released in January 2005.

3. **Thermal Shock** Associated Presentation: 121404Woodrow.pdf; *“JCAA/JG-PP No-Lead Solder Testing Status”*

Dr. Woodrow stated that all testing has been completed as of the week of December 6, 2004. The data still needs to be plotted and the report written. The charts presented (slides 21-23) show Weibull plots that represent solder performance. Dr. Woodrow briefly reviewed a portion of the thermal shock test data. Slide 21 shows a Weibull plot of the CLCC component data from the manufactured boards, which is one of the few component types that failed. In review of slide 21, SnAgCu performed the worst, with SnAgCuBi performing better and SnPb performing the best. Slide 22 shows a Weibull plot for the TSOP data from the manufactured boards. The only TSOP components that failed were the ones with SnAgCuBi solder joints contained with Pb. This is an expected result, based on ternary alloy formation. Some of the other solder types are beginning to fail on the right side of the plot (slide 22) but there are not enough data points to obtain good data for these solders. Slide 23 shows a Weibull plot for the TSOP data from the rework boards. Dr. Woodrow explained that the TSOP components with SnAgCuBi solder that was reworked (red triangles, slide 23) did not perform well at all. This is probably caused by Pb contamination from residues left on the board during the rework operation. These results can be expected. Some surprising results that came from the testing were the TSOP components with SnPb solder that were reworked with SnPb solder (yellow circles, slide 23). These reworked TSOP components did not perform very well and it is not understood why. Another surprising result was the TSOP components that were reworked with the SnAgCu solder alloy (orange ovals, slide 23). These components performed just as well as the TSOP components that were not reworked.

Slide 24 shows the results of a chemical analysis that was performed on the lead contaminated joints to get a better idea of how much lead is actually in the joints. Dr. Woodrow explained that everything looked very consistent except for the QFP-208 components in the very last row (slide 24). These particular components had a very high content of copper. The reason for why these components had such a high copper content is unknown. This issue needs more attention when we do cross-sectioning.

4. **Thermal Cycling (-20°C to 80°C):** Associated Presentation: 121404Woodrow.pdf; *"JCAA/JG-PP No-Lead Solder Testing Status"*

Dr. Woodrow stated that the testing has completed about 1500 cycles and failures are just starting to be generated. The testing is expected to run through another 8500 cycles until enough failures are generated. Testing could last to the end of next year in order to get enough data for the Weibull plot.

Question and Answer for Dr. Woodrow:

Q. Clive Simmonds: On some of the components there looks to be some thermal degradation of the components (slide 11). Did you do any visual checks as well as the actual joints themselves for component damage?

A: Dr. Woodrow: The components were looked at and nothing unusual was documented. There were no cases of failures of internal wire bonds, but the plastic outside may need to be looked at later.

Q. Bob Vanderwiel: Can you make any conclusion about which solders are best? Are they acceptable?

A: Dr. Woodrow: It's a mixture. In most cases the SnPb is the best. In some cases the no-lead looks better. In most cases the SnPb in the vibration test is slightly better. Thermal cycling remains to be seen. It is component dependent. We need a model to extrapolate some field life time data to determine individual acceptable uses.

Q. Lety Campuzano-Contreras: On the U3, did all the parts fail from the rework boards?

A: Dr. Woodrow: 11 of 15 fell off the rework boards. None fell off the manufactured boards.

Q. Andy Ganster: Were all the U3 QFP components reworked by hand?

A: Dr. Woodrow: The components were first removed using a hot air machine then hand soldered by one individual.

Q. Bill Stone: What was the vibration environment that these boards were subjected to?

A: Dr. Woodrow: Go to the jgpp.com website to view the test plan. Jim Blanche, NASA-MSFC, wrote the procedure. We ramped up the PSD level every hour. This compressed our test time to just a few days.

Q. Dan Gosselin: What was the differentiator in your 1, 2, and 3 color-coded ranking of the solders (slides 14-18)?

A: Dr. Woodrow: My own opinion. Need to wait until the results are published before solid conclusions can be made.

5. **Thermal Cycling (-55°C to 125°C):** Associated documents: JGPP RC 1000 Cycles Failure Map 12-17.doc & JGPP RC 1000 Cycles Failure Summary and Table 12-17.doc *Please Note:* There was an initial error in the data results when Mr. Hillman reported the data at the December 14, 2004 telecon. This issue has since been resolved and the information contained in the above referenced documents is the correct information for the component failure percentages.

   Mr. Dave Hillman reported that they have completed approximately 1200 thermal cycles on the boards. Mr. Hillman fully expects to have a complete analysis of the data results for the APEX meeting next spring.

   Mr. Hillman reported the tests are developing "fluffy" issues as termed by Mr. Hillman. With the SACB alloy, the Bismuth is causing joints to grow scales and fuzz very similar to other industry testing results. The U3 QFP components are acting very funny. This may be a case of the choice of alloy, but since there is so many parameters only generalizations can be discussed until the Weibull plots can be run and some cross-sectioning accomplished. As an estimate, Mr. Hillman predicts that the 63 percent failure rate would be achieved between 2000 and 2100 thermal cycles.

   Mr. Hillman reported that the capacitor/resistor side-boards are not being run currently with the main test vehicle. The side-boards changed the thermal profile in the oven to great. The testing of the side-boards will be completed, but will lag behind the testing of the main boards. Testing is expected to be completed in the March time frame.

   Comment: From Peter Van Zante to Thomas Woodrow concerning the U3 part. Previously, Dr. Woodrow reported that the U3 part fell off the rework boards, but not the manufactured boards. Mr. Van Zante reported that during this thermal cycle testing they were losing the U3 part from the manufactured and rework boards.

6. **Combined Environments Test:** Associated presentation: RaytheonCET 14 Dec 04.pdf; *"JCAA/JGPP Lead-Free Solder Project"*

   Mr. Jeff Bradford briefed the Combined Environments Test and thanked Mr. Bill Russell for his support in preparing the briefing. This status report is based on a preliminary analysis of the results of approximately 400 cycles on the manufactured boards and 300 cycles on the rework boards. The test is -55°C to 125°C cycling at 23°C per minute. The test starts at 10 Gs RMS and increases 5 Gs every 50 cycles. This is a change from the Joint Test Protocol (JTP) which said every 100 cycles. Originally, the plan was to do 300 cycles or until significant failures were obtained.

Mr. Bradford reported that for the manufactured boards (slide 4); currently there is not enough failure data to do a sound statistical analysis. On the manufactured boards there are 822 components with 251 failures after 366 cycles which correlates to 31 percent failures of total components. Solder paste with SnPb TSOP components on the Bismuth paste failed 100 percent. The results also show a lot of BGA failures. Overall, the SnPb paste is performing much better then the SAC or Bismuth alloy.

Mr. Bradford continued, stating that on the rework side (slide 5); again there are too few joints that have failed after 300 cycles to do a sound analysis. Most have failed on un-reworked components. The SnCu TSOP-50 components that were reworked with Bismuth containing solder have failed 100 percent.

Mr. Bradford presented defect maps (slides 6-11) to help understand where the failures are occurring. What the results show is that the SAC CLCC-20 components and the SnPb CLCC-20 components on the SAC paste seem to fail a lot more than other combinations. Mr. Bradford explained that for the rework boards, a lot of the SAC and Bismuth finished components failed. For the BGA-225 and the CLCC-20 components the failures are probably due to the SnPb profile used to solder those components. The assumption is that the components were not hot enough to melt the Bismuth or the SAC alloy. We need to take as closer look at the rework process. Weibull plots were displayed for review.

Mr. Bradford concluded that basically, there are too few failures to date to make a good Weibull plots out of the data. There are some general appearances that the SAC and SnPb CLCC-20 components with SAC paste are less reliable then the other combinations. Our plan is to continue testing the manufactured and reworked boards as the budget and the Ana-Tech event detector availability allows.

Question and Answer for Mr. Bradford:

Q. Dave Hillman: Would you say that the fact that we have too few failures is not a bad thing, it is data?

A: Mr. Bradford: The whole purpose of the CET was to get failures faster, not to extend out and do long term testing. A short term, fast test that can prove out the design of the lead-free alloy is the goal.

7. Salt Fog, Humidity, and Mechanical Shock

Mr. Lee Whiteman was unavailable for the teleconference. Mr. Kessel displayed the testing status table, updated November 15, 2004, and distributed with the December 14 LFS telecon agenda. Mr. Kessel will contact Mr. Whiteman to get current data and update the testing status table for inclusion into the meeting minutes. As of the last status from Mr. Whiteman, both the Salt Fog and Humidity tests have been completed. X-ray analysis is being done to better understand why the components failed. A report is scheduled to be completed by the end of 2004. The Mechanical Shock test won’t be started until mid-Jan 05.

8. **Surface Insulation Resistance (SIR) and Electrochemical Migration Resistance (EMR):** Associated presentation: JGGPEMRSIR(revB).pdf; *"Joint Group-Pollution Prevention Lead Free Soldering Study EMR & SIR Test Results"*

   Mr. Dale Swanson briefed the SIR and EMR tests starting with slides 8 & 9. The first step is pre-conditioning, followed by 500 hours of actual testing, for a total of 596 hours. Slide 10 shows the first set of the EMR test results. Mr. Swanson pointed out that two of the boards with SAC alloy showed evidence of dendrites. Slides 11 & 12 show photographs of the tested coupons, Mr. Swanson pointed out that on slide 11, the SAC alloy shows some dendrite patterns. Slide 12 shows copper with no bake showing some tarnish, but no dendritic growth or contamination. The bottom picture on slide 12 seemed to show some evidence of contamination believed to be oven induced and not representative of a true failure because of dendritic growth directly due to the environmental conditions. Mr. Swanson continued, explaining that slide 13 shows the second run of EMR test data. Additional failures for the SnAgCuBi alloy where 4 out of 6 boards tested showed evidence of dendritic growth. The SnCu material also showed evidence of dendritic growth. The next slide, slide 14 continues the second run test results showing dendritic growth for the SnAgCu alloy as well and one failure for the SnPb alloy. The next few slides (15-19) show some representative failures for the second run of results.

   Mr. Swanson stated that the general idea is that the SnPb samples in both the wave and solder reflow had dendritic growth and dendrites across multiple traces. SnAgCuBi is not the best choice from the stand point of the corrosion of dendritic growth. In general the SnAgCu solder alloy was the best alloy tested, because it had the least amount of dendritic growth.

   Mr. Swanson continued with the SIR testing, explaining that slide 21 shows the general test conditions and distribution of test samples for SIR testing. Slides 22-29 show the organization of the results from the SIR testing. Mr. Swanson briefed that for the tray two results (slides 25-26), two boards with SnAgCuBi solder alloy showed evidence of dendritic growth in the SIR testing. Slide 26 shows one board with SnPb material showing evidence of dendritic growth. Mr. Swanson concluded that the general observation (slides 29-30) when it comes to SIR testing in terms of the actual numbers of SIR data, lead-free candidates seemed to perform comparable to SnPb materials.

   Question and Answer for Mr. Swanson
   Q. Dave Hillman: Will you have a report out early in the year.
   A: Dale Swanson: Yes, that is the plan.

9. Future Conferences and Meetings

APEX, IPC Printed Circuit Expo, Designers Summit February 22-24, 2005 Anaheim, California:
A meeting room has been reserved for February 22, 2005, 4:00 PM to 8:00 PM at the APEX Conference. This will allow those available to meet and review test data.

Proposed Face-to-Face, week of March 8, 2005 location TBD:
The next face-to-face LFS project meeting is proposed for the March 8' 2005 time frame. This meeting would allow the group to prepare for the April 2005 IPC/JEDCE 8th International LF Conference on Electronic Components and Assemblies, which may serve as the initial data report-out for the JCAA/JG-PP LFS Project consortia.

Mr. Dave Hillman is looking into hosting the meeting at the Rockwell Collins Facility located in Cedar Rapids, Iowa.

IPC/JEDCE 8th International LF Conference on Electronic Components and Assemblies April 18-20, 2005 San Jose, California:
A request has been made to the conference organizers, to allow the JCAA/JG-PP consortia 4 hours to present the initial data report-out for the JCAA/JG-PP LFS Project.

SMTA International 2005, September 25-29, Rosemont, IL) :
Paul Vianco is the lead for the lead-free portion of the conference. He will need a format of what we plan to present prior to the holidays. We are requesting another 4 hours at this conference. Mr. Hillman will write something up and forward it to Mr. Kessel.

10. New Business: Associated presentation: Kirkendall Voids.pdf; *"Effect of Thermal Aging on Board Level Drop Reliability for Pb-free BGA Packages"*

Dr. Tom Woodrow wanted to make the JCAA/JG-PP LFS consortia aware of work being done by TI, IBM and others, to address an abnormal failure mechanism in SAC parts that they build. Mr. Woodrow explained that the abnormal failure phenomenon is seen almost 100 percent of the time for a particular component believed to be CSP. Mr. Woodrow continued, explaining that the phenomenon occurs when the part is thermally aged. Once the component is thermally aged, instead of lasting 90 shocks, the part fails on the first shock. Mr. Woodrow stated that Boeing is interested in researching this phenomenon further. If the consortia agree, Boeing would like to perform a vibration test on the boards with the CSP and Hybrid components. Dr. Woodrow would like 4 SAC boards, 2 to age and 2 to leave as is and 2 SnPb boards to use as a control. After a lengthy discussion the group agreed that this would be a good use of the extra boards.