COMPONENT LEVEL RELIABILITY FOR HIGH TEMPERATURE POWER COMPUTING WITH SAC305 AND ALTERNATIVE HIGH RELIABILITY SOLDERS

Thomas Sanders, Sivasubramanian Thirugnanasambandam and John Evans, Ph.D.
Auburn University, Department of Industrial & Systems Engineering
Auburn, AL, USA
sandete@auburn.edu

Michael Bozack, Ph.D.
Auburn University, Department of Physics
Auburn, AL, USA

Wayne Johnson, Ph.D.
Tennessee Tech University, Department of Electrical & Electronics Engineering
Cookeville, TN, USA

Jeff Suhling, Ph.D.
Auburn University, Department of Mechanical Engineering
Auburn, AL, USA

ABSTRACT

This experiment considers the reliability of a variety of different electronic components and evaluates them on 0.200" power computing printed circuit boards with OSP. Single-sided assemblies were built separately for the Top-side and Bottom-side of the boards. This data is for boards on the FR4-06 substrate.

Isothermal storage at high temperature was used to accelerate the aging of the assemblies. Aging Temperatures are 25ºC, 50ºC, and 75ºC. Select data from aging times of 0-Months (No Aging, baseline), 6-Months, and 12-Months will be presented.

The assemblies were subjected thermal cycles of -40°C to +125°C on a 120 minute thermal profile. The test was subject to JEDEC JESD22-A104-B standard high and low temperature test in a single-zone environmental chamber to assess the solder joint performance.

The principal test components are 5 mm, 6mm, 13mm, 15mm, 17mm, 31mm, 35mm and 45 mm ball grid array (BGA) packages with solder ball pitch varying from 0.4 mm to 1.27 mm. Most of the BGA packages are plastic over-molded, while the 31mm and 45mm packages are Super-BGAs (SBGAs). Several surface mount resistors (SMRs) are also considered in order to understand the effect of solder paste composition on paste-only packages.

The primary solder for package attachment in this experiment is standard SAC305. Two solders designed for high-temperature reliability are also considered.

Key words: BGA, PCB, Reliability, Solder, lead free, HALT

NOMENCLATURE

BGA	Ball Grid Array
EPA	Environmental Protection Agency
FC	Flip Chip
FR	Flame Retardant
HALT	High Accelerated Life Test
JEDEC	Joint Electron Device Engineering Council
OSP	Organic Solderability Preservative
PCB	Printed Circuit Board
RoHS	Restriction of Hazardous Substances
SEM	Scanning Electron Microscopy
SMR	Surface Mount Resistors
TC	Temperature Cycling

Symbols

Ag	Silver
Bi	Bismuth
Cu	Copper
Ni	Nickel
Pb	Lead
Sb	Antimony
Sn	Tin

Greek Symbols

β	Slope
η	Characteristic Life
ρ	Probability plot

Subscripts

T_g	Glass Transition Temperature

INTRODUCTION

Electronic packages are subjected to thermally-induced stress due to power cycling and a variety of other sources. It is therefore important to test the reliability of these packages under such conditions in order to determine applicable product lifetimes, etc. This is particularly vital in the case of products intended for use in harsh environments.

The semiconductor and packaging industries have been gravitating toward the use of smaller and more reliable packages to meet the growing market demand for hand held electronics. Simultaneously, industry has been moving away from the use of Lead (Pb) due to the increasing awareness of the health and safety concerns surrounding its use. This has forced a move away from Eutectic Tin-Lead (63%Sn, 37%Pb) solder.

Tin-Lead Eutectic Solder, which has been in use historically since at least the time of the Romans, was the traditional material used for solder interconnect since the inception of the electronics industry [1,2]. Due to a variety of advantageous material properties – such as a good melting temperature and suitability for both reflow ovens and wave soldering processes – Tin-Lead (SnPb) solder is extremely difficult to replace without affecting solder joint reliability. On the other hand, most electronic wastes (e- wastes) are not treated properly and significant health concerns exist for long-term exposure to lead even at low levels. In response to concerns about lead contamination from e-waste, new rules in Japan and regulations from the European Union (RoHS and WEEE) have forced the electronics packaging industry to use lead-free (Pb-free) solders [3, 4, 5].

Current industry standards for ball grid array (BGA) and solder interconnect reliability testing rely mainly on pass/fail electrical continuity functionality test criterion, with limited knowledge of factors contributing towards the failure. A variety of factors affect the reliability of the solder joints used in those electronic components. Chip dimension, chip structure, and BGA pad size are some of the factors to be considered, in addition to the principal factor of solder material properties.

Both the composition and microstructure of the solder joint will affect its bulk properties. These will determine a joints ability to provide the necessary mechanical and electrical connection and strongly affect the reliability of the joint. Although an initial microstructure will be present following assembly – which will involve one or more soldering steps – but this structure will continue to evolve over the lifetime of the joint.

The combination of disparate coefficients of thermal expansion (CTEs) and temperature changes can result excessive stress, leading to weakening of the solder joints and eventual component/package failure. During a Thermal Cycling (TC) test, solder materials are typically subjected to higher temperatures above half of their melting point (i.e. greater than 0.5 in terms of their homologous temperature), facilitating thermally driven evolution and failure mechanisms.

EXPERIMENTAL SETUP

Test Vehicle

The test vehicle (TC1-SRJ) was designed and constructed following the JEDEC specifications. The board dimensions are 173 mm x 254 mm with a board thickness of 5 mm (200 mil). The tool-hole diameter is 3.8 mm diameter and the distance from edge of package to the center of the holes is 7mm. There are 6 Copper (Cu) layers with 14,607 pins, 3590 through-hole, and 11017 SMT per board. The board plating/finish is organic solderability preservative (OSP).

Each board was designed to allow for placement of 249 components, although SMR components are daisy-chained together for readout through a single channel. A different design is used for the top and bottom side of the board. In total, there are 19 channel readouts and one ground for the top-side, and an additional 39 channel readouts on the bottom-side (ground shared). The test vehicle design is shown in Figure 1.

Two different board/substrate materials were tested: FR4-06 and Megtron6. The FR406 board material used in this experiment was a high-temperature multifunctional glass epoxy laminate with a glass transition temperature (Tg) of 170°C, whereas the Megtron6 board material used in this experiment was a high temperature Polyphenylene Ether blend with a glass transition temperature (Tg) of 210°C.

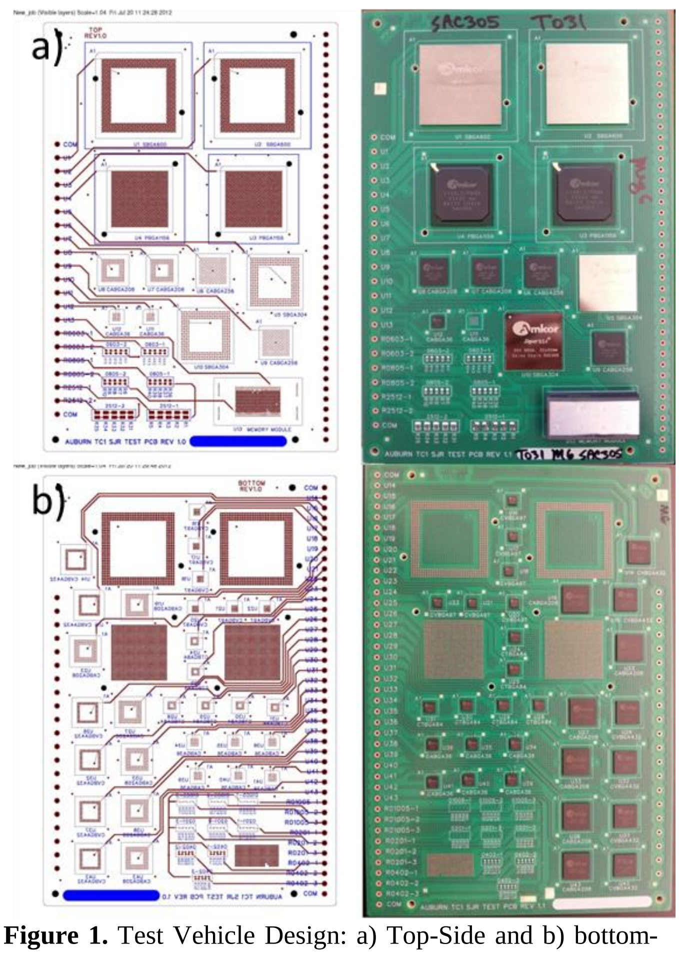

Figure 1. Test Vehicle Design: a) Top-Side and b) bottom-side of the TC1-SRJ test vehicle.

Surface Mount Assembly

The test boards were made by TTM Technologies (Time-To-Market Interconnect Solutions), Chippewa Falls Division. Dummy-die (daisy-chained) components were sourced from Practical Components. The ball grid array (BGA) design and wiring scheme follow a simple daisy chain structure. The test components were assembled at STI Electronics Inc. in Madison, Alabama.

A total of 880 boards were built: 720 boards of FR406 substrate material, and 160 boards of Megtron6 substrate material. There were also 30 additional FR406 intended for setup during build/assembly work. The boards are being built (assembled) in two groups. 660 boards were built as 'Top-side' boards, with only the top-side components assembled. 220 boards were built as 'Bottom-side' boards, with only the bottom-side components assembled.

This experiment is designed to evaluate the effect of long term isothermal aging of several lead-free solder alloys, including SAC105 and SAC305. The test matrix with the board groupings is shown in Figure 2, below. There are four (4) aging times (0, 6, 12, and 24 months) and three different aging temperatures (25°C, 50°C, and 75°C).

		Top Side		Bottom Side		Total	Aging
FR 406	SAC	30 [30,0,0]	74 [74,0,0]	10 [10,0,0]	25 [25,0,0]	99[99,0,0]	No Aging
	SnPb	14 [14,0,0]		5 [5,0,0]			
	Innolot	30 [30,0,0]		10 [10,0,0]			
Meg 6	SAC	15 [15,0,0]	30 [30,0,0]	5 [5,0,0]	10 [10,0,0]	40 [40,0,0]	
	SnPb	15 [15,0,0]		5 [5,0,0]			
FR 406	SAC	90 [30,30,30]	162 [44,44,74]	30 [10,10,10]	55 [15,15,25]	217 [59,59,99]	6 months
	SnPb	42 [14,14,14]		15 [5,5,5]			
	Innolot	30 [0,0,30]		10 [0,0,10]			
Meg 6	SAC	15 [0,0,15]	30 [0,0,30]	5 [0,0,5]	9 [0,0,9]	39 [0,0,39]	
	SnPb	15 [0,0,15]		4 [0,0,4]			
FR 406	SAC	90 [30,30,30]	132 [44,44,44]	30 [10,10,10]	45 [15,15,15]	177 [59,59,59]	12 months
	SnPb	42 [14,14,14]		15 [5,5,5]			
	Innolot	0		0			
Meg 6	SAC	15 [0,0,15]	30 [0,0,30]	5 [0,0,5]	10 [0,0,10]	40 [0,0,40]	
	SnPb	15 [0,0,15]		5 [0,0,5]			
FR 406	SAC	90 [30,30,30]	162 [44,44,74]	30 [10,10,10]	55 [15,15,25]	217 [59,59,99]	24 months
	SnPb	42 [14,14,14]		15 [5,5,5]			
	Innolot	30 [0,0,30]		10 [0,0,10]			
Meg 6	SAC	15 [0,0,15]	30 [0,0,30]	5 [0,0,5]	10 [0,0,10]	40 [0,0,40]	
	SnPb	15 [0,0,15]		5 [0,0,5]			
		Total Top Side =	650 [236,132,282]	Total Bottom Side =	219 [80,45,94]	Total Boards = 869[316,177,376]	

Number of Total Board [# aged at 25C, # aged at 50C, # aged at 75C]

Figure 2. Board Groupings

The principal test components are ball grid array (BGA) packages of 5 mm, 6mm, 13mm, 15mm, 17mm, 31mm, 35mm and 45 mm with solder ball pitch varying from 0.4 mm to 1.27 mm. Three different solder paste compositions were used, in combination with four different solder ball compositions. Various surface mount resistors (SMRs) and a limited number of land grid array (LGA) sockets were also used. Figure 3 summarizes the below summarize the component matrix for the TC1-SRJ test vehicle. The LGA socket was used to house the memory module, a pin grid array (PGA) which was attached by hand following assembly. Heat sinks for the 45mm and 35mm components were also added later by hand.

The three solder pastes used in this test were SnPb (eutectic), SAC305, and Innolot. The SAC305 ("Type 4") paste and the Innolot paste were provided by Cookson, while the SnPb eutectic paste was sourced from Kester. The screen printing machine used was a Speed line Technologies MPM Momentum. Two different aperture stencils were used for the top and bottom sides. The top-side stencil had a 127 microns (5 mil) aperture, while the bottom-side which houses the finer-pitch components had a 76 microns (3 mil) aperture. Bottom-side boards were double-printed in order to get adequate solder volume on the fine-pitch components. Two pick-and-place machines were used for the TC1-SRJ test vehicle assembly: the Juki KE-2080L and Juki FX3. Solder reflow was done using a Heller 1913 MKIII reflow oven. Two different reflow profiles were used: one for SnPb and the other for the SAC305 and Innolot solder pastes. A number of quality assurance steps were taken. The resistance of each daisy-chained circuit component was checked by hand following reflow in order to eliminate them from inclusion in further testing (excluding the socketed components, which were hand-assembled into the LGA sockets later). Post-assembly resistance testing showed a 100% yield. Boards were also visually inspected and x-ray analysis was used to determine typical solder-joint quality following reflow. Additional measurements were made of solder paste height and diameter. Finally, several components on one of the setup boards were sacrificed in a 'pry test' in order to assure the mechanical strength of the solder joints as reflowed. XRD voiding analysis and shear ("pry") testing also indicated excellent build quality.

Component	Ball Alloy	Pitch	Dimension
CVBGA97	SAC 305	0.4mm	5mm
CVBGA97	SAC 105	0.4mm	5mm
CVBGA97	SnPb	0.4mm	5mm
CVBGA432	SAC 305	0.4mm	13mm
CVBGA432	SAC 105	0.4mm	13mm
CVBGA432	SnPb	0.4mm	13mm
CTBGA84	SAC 305	0.5mm	6mm
CTBGA84	SnPb	0.5mm	6mm
CABGA36	SAC 305	0.8mm	6mm
CABGA36	Innolot	0.8mm	6mm
CABGA36	SnPb	0.8mm	6mm
CABGA36	"SAC-Y"	0.8mm	6mm
CABGA208	SAC 305	0.8mm	15mm
CABGA208	SAC 105	0.8mm	15mm
CABGA208	Innolot	0.8mm	15mm
CABGA208	SnPb	0.8mm	15mm
CABGA208	"SAC-Y"	0.8mm	15mm
CABGA256	SAC 305	1.0mm	17mm
CABGA256	SAC 105	1.0mm	17mm
CABGA256	SnPb	1.0mm	17mm
PBGA1156	SAC 305	1.0mm	35mm
PBGA1156	SAC 105	1.0mm	35mm
PBGA1156	SnPb	1.0mm	35mm
SBGA304	SAC 305	1.27mm	31mm
SBGA304	SnPb	1.27mm	31mm
SBGA600	SAC 305	1.27mm	45mm
SBGA600	SnPb	1.27mm	45mm
1206 SMR	100% Sn		3.2x1.6mm
1210 SMR	100% Sn		3.2x2.6mm
0805 SMR	100% Sn		0.8x0.5mm
0603 SMR	100% Sn		0.6x0.3mm
0402 SMR	100% Sn		0.4x0.2mm
0201 SMR	100% Sn		0.2x0.1mm
01005 SMR	100% Sn		0.1x0.05mm

Figure 3. Component Matrix

Test Setup

The electrical components for this experiment were daisy chained (dummy die) for electrical continuity testing and in situ, continuous monitoring throughout the thermal cycling (TC) test. The resistance for each component was independently monitored during the temperature cycle test. The assemblies were subjected to thermal cycles of -40°C to +125°C on a 120 minute thermal profile in a single-zone environmental chamber to assess the solder joint performance. The TC was based on the JEDEC JESD22-A104-B standard high and low temperature test. The ramp rate of 15°C per minute is a stipulated condition in the JEDEC JESD22. Depending on the thermal capacity, an appropriate condition in the range of 10 to 15°C can be selected, and for this test a ramp rate of 10°C per minute was selected for the single zone chamber. The single-zone thermal cycling chamber used was a Blue M ETC-16. Two chambers were used, one for the 0-Month ("No Aging") and 12-Month aging groups and a second chamber for the 6-Month aging group.

The boards were placed vertically in the chamber and the wiring passed through the independent access ports to the Labview-based monitoring system. The monitoring system utilized a Keithley 7002 switching system and Keithley 2000 and 2001 digital multi-meters (DMMs). Monitoring was accomplished by cyclically scanning the resistance on each channel. The monitoring system used a ground-switching system enabled by custom software and interface boards to monitor up to 3600 channels using a single switching system. Solder joint failure was defined as increase of electrical continuity greater than 100 ohms above baseline (uncycled) resistance. Channels that exhibited five (5) consecutive threshold-exceeding events were recorded as a failure in the monitoring system. Due to wiring limitations, the 6-Month aging group was hand-probed at ~50 cycle intervals, with failures corresponding to 'open' resistance values.

Each aging group will be subjected to 3000 thermal cycles. Data is presented for 3000 TC for the 0-Month (No Aging) group, ~2700 cycles for the 6-Month aging group, and ~900 cycles for the 12-Month aging group. The failure data was analyzed and the reliability of the solder joints was determined in terms of the characteristic life (η) and slope (β) from a two parameter Weibull analysis [3,6,7].

RESULTS AND DISCUSSIONS

Temperature Cycling Results

The temperature cycling test results below show some the highlights from the reliability data from the 0-Month (No Aging) group, 6-Month aging group, and 12-Month aging groups. For analysis purposes, it is sometimes convenient to look at the overall trends in the failure data and illustrate particular key points using data from 'representative' parts in cases when several components show similar overall behavior. Specifically, the failure trends are constant in all available data for the smaller plastic ball grid array packages (5mm – 17mm), so we will begin by illustrating overall trends using data from the CABGA 208 component.

The CABGA 208 component is found on both the top and bottom side of the board and within all groups, allowing for multiple comparisons across various experimental parameters. Below are a few key points from the failure data of this component.

When examining the effect of various solder paste [P] and sphere [S] combinations, the Characteristic Life values show the following pattern, listed from best to worst: (1) Matched Innolot ([P] + [S])*, (2) [S]SAC305 doped with [P]Innolot, (3) Matched SAC305 ([P]+[S]), and (4) Matched SnPb ([P]+[S])

* Note that Matched Innolot data is available only for the CABGA 208 and CABGA 36 components.
Unsurprisingly, under our thermal cycling (TC) test, components balled with SAC305 spheres are more reliable than equivalent SAC105 balled components. This pattern holds for both SAC305 and Innolot solder pastes. No difference is seen in the pattern of failures when comparing components found on the Top-Side of the board and the Bottom-Side of the board, with the exception of the SAC-Y (Bi doped) spheres.

Figures 4-6 show Weibull plots for the CABGA 208 component on the FR4-06 substrate. Note that every subgroup may not appear on each graph and color coding of groups varies. Data is from 75ºC aging unless otherwise marked. From the Weibull plots, there are three failure criteria that can be used to determine the reliability, i.e. first failure, mean life and characteristic life. The mean life and characteristic life is preferred than the first failure since they are statistically more accurate for life predictions [9].

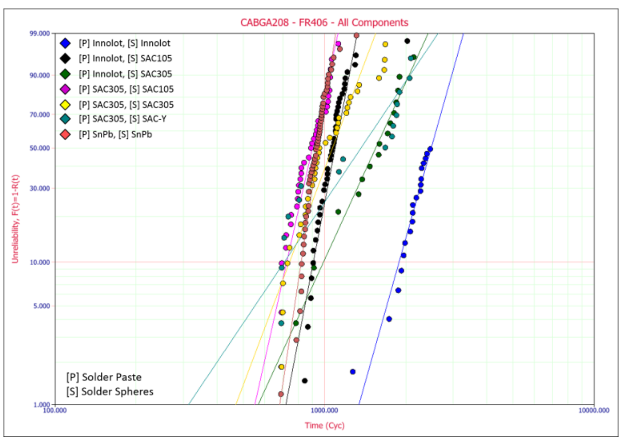

Figure 4. Weibull Plot: CABGA208 – FR4-06 – No Aging

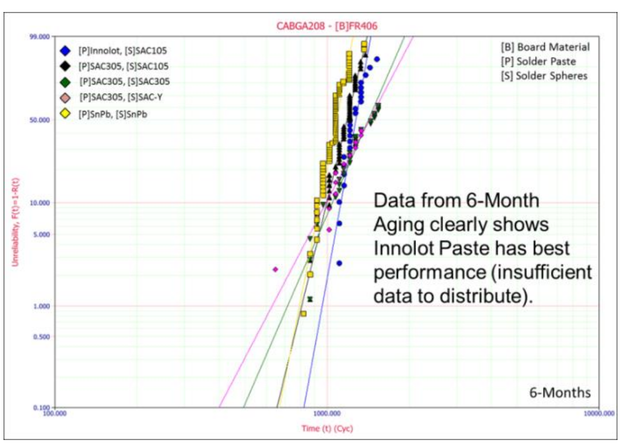

Figure 5. Weibull Plot: CABGA208 – FR4-06 – 6-Month

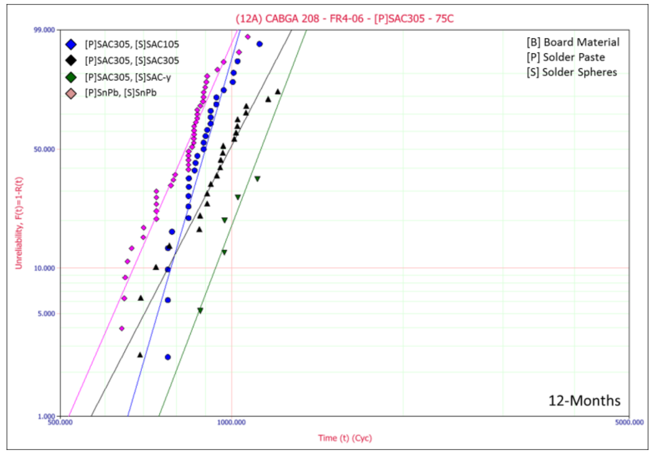

Figure 6. Weibull Plot: CABGA208 – FR4-06 – 12-Month

Figure 7 shows the trend in characteristic life based on the available solder material combinations for the CABGA 208 component on the FR406 substrate.

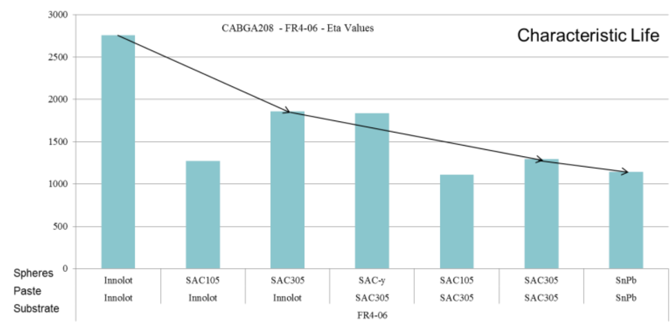

Figure 7. Characteristic Life: CABGA208 – FR4-06 – No Aging

When examining the effect of the substrate (FR4-06 vs. Megtron6), a clear trend emerges. Smaller (5mm – 17mm) plastic BGA components assembled on the FR4-06 substrate are universally more reliable than identical components assembled on the Megtron6 substrate, when controlling for all other factors. (See Figure 12 for a comparison across multiple packages.)

Other components, naturally, show somewhat different trends in their failure data. Although most of the plastic BGA paakcages follow all of the above trends, our largest PBGA package stands out in at least one regard. The PBGA 1156 is a 35mm component found only on the top-side of the board, with 1.0mm pitch. With a solid 34x34 I/O array, it has by far the largest I/O count in this experiment.

The key difference between the data from the PBGA 1156 and the other plastic packages is that there is not a significant improvement seen in the reliability of the solder joints when doping with Innolot paste for the PBGA 1156. Characteristic life values are similar for SAC305 and Innolot paste. (Note that this package fails later in testing, and data is only avialable for the the 0-Month and 6-Month aging groups.) Figure 8 shows the characteristic life values for the PBGA

1156 package on the FR4-06 substrate, 75ºC aging. Data is shown for components with and without heatsinks.

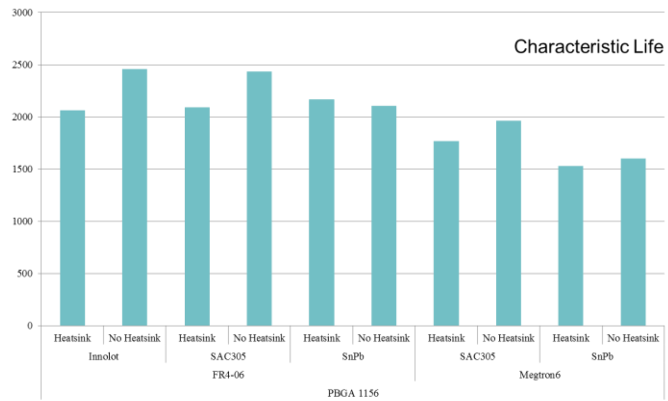

Figure 8. Characteristic Life: PBGA1156 – FR4-06 – No Aging

Another interesting difference can be seen in the failure data of the plastic packages discussed so far and the two Super-BGA (SBGA) packages tested: the SBGA 304 and the SBGA 600. These are cavity-down, metal-capped components, and so are structurally quite different from the previously discussed packages. The SBGA 304 package is a large-pitch (1.27mm) component found only on the top-side of the board. This package has a footprint of 31mm x 31mm. The SBGA 600 component has the largest footprint in this experiment (45mm x 45mm), and is found solely on the top-side of the board. Like the SBGA 304, this is a metal-capped package with large pitch (1.27mm).

Figures 9 and 10 show the characteristic life values for the No Aging group. The failure trends shown are mirrored in the 6-Month aging data. Data is shown for 75ºC aging. There are two key features that make this data stand out from what one might consider to be the 'normal trends' from the smaller plastic BGA components (5mm – 17mm, as represented by the CABGA 208).

One key difference is that – like the larger plastic BGA component (PBGA 1156) – solder joints doped with Innolot paste do not perform better than matched SAC305 joints. In fact, both the SBGA 304 and SBGA 600 show higher reliability with matched SAC305 paste/spheres that with SAC305-spheres doped with Innolot-paste. (This behavior is more evident for the SBGA 304 component.) A second key difference is that the reliability of these two Super-BGA packages is higher on the Megtron6 substrate than on the FR4-06 substrate in this experiment, which reverses the trend from all of the plastic packages, including both the smaller packages and the larger PBGA 1156.

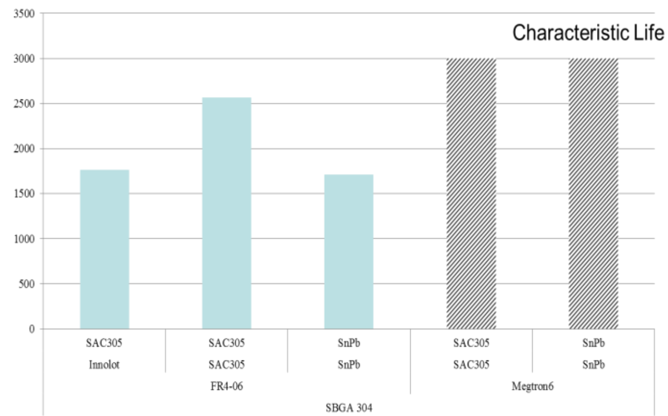

Figure 9. Characteristic Life: SBGA304 – No Aging. Hashed bars indicate that insufficient failure data exists to form a Weibull distribution.

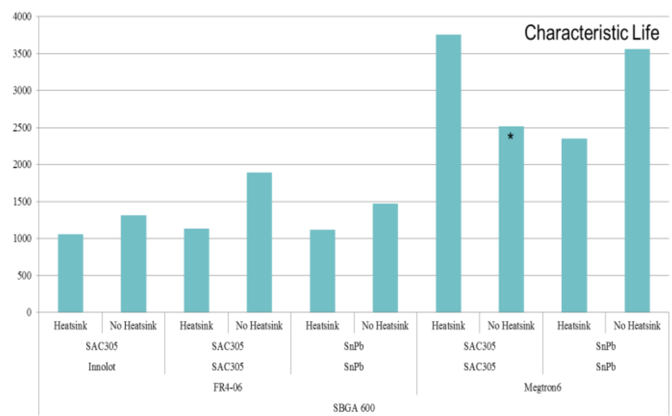

Figure 10. Characteristic Life: SBGA600 – No Aging. (* Some early failures are significantly affecting the characteristic life of this distribution.)

The overall differences in reliability trends are summarized in Figures 11 and 12, which show the comparisons highlighting the effect of paste-doping and substrate-material, respectively.

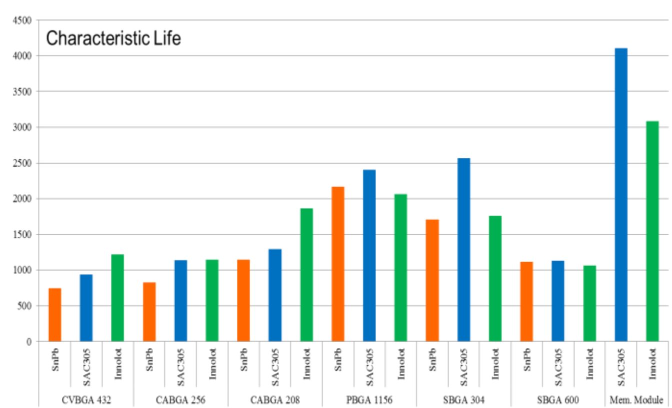

Figure 11. Weibull plot for (a) Comparison of different paste using SAC305 sphere in CVBGA432

For Innolot paste, SAC305 spheres have superior reliability to SAC105 spheres, as with other components. See Figure 9b.

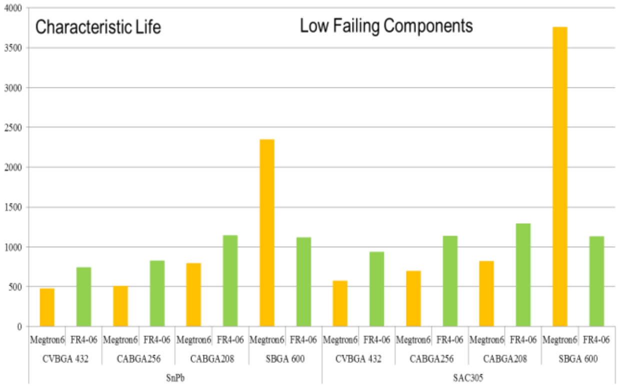

Figure 12. Weibull plot for (b) Comparison of different sphere using Innolot paste in CVBGA432

SUMMARY AND CONCLUSION

The failure data from this test was found to follow specific trends depending on the type and size of the component. The smaller plastic ball grid array (BGA) packages (5mm – 17mm) show failure data trends that are exemplified by the CABGA 208 (15mm) package. Regarding the effect of various solder paste [P] and sphere [S] combinations, the Characteristic Life values show the following pattern, listed from best to worst:

(1) Matched Innolot ([P] + [S])*,
(2) (2) [S]SAC305 doped with [P]Innolot,
(3) (3) Matched SAC305 ([P]+[S]), and
(4) (4) Matched SnPb ([P]+[S])

(* Note that Matched Innolot data is available only for the CABGA 208 and CABGA 36 components.)

A very clear trend also exists regarding the substrate effect: smaller plastic BGA components assembled on the FR4-06 substrate are universally more reliable than identical components assembled on the Megtron6 substrate, when controlling for all other factors.

A larger plastic BGA component, the PBGA 1156, shows similar failure trends in terms of most particulars. Howerver, one key difference exists. The PBGA does not show a significant improvement in joint reliability during Innolot paste doping.

Two Super-BGA components, the SBGA 304 and SBGA 600, also show differences in failure data trends to the smaller plastic ball grid arrays. These are cavity-down, metal-capped components, and so are structurally quite different from the previously discussed packages. Like the PBGA 1156, these packages do not show an improvement in reliability via Innolot paste doping (in fact, reliability is lower in the doped case). Moreover, both of the Super-BGA components show a reversal of the substrate-effect seen in the plastic packages and display higher reliabiltiy on the Megtron6 substrate than on the FR4-06 substrate.

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