WLCSP AND BGA REWORKABLE UNDERFILL EVALUATION AND RELIABILITY

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ABSTRACT

Interest in using fine pitch SMT components has increased greatly in recent years due to the growth of portable, hand held electronics and due to miniaturization trends in consumer and industrial electronics markets. The reliability of those fine-pitch portable electronics products is a great concern particularly in the areas of impact and shock performance. For very fine pitch SMT components such as WLCSPs and BTCs without ground planes (0.5mm pitch or lower), underfills can be used to improve the impact and thermal cycle reliability. Historically, the target properties of underfills can be generally summarized as high glass transition temperature (Tg), high modulus (E) and matched coefficient of thermal expansion (CTE) to solder. However, the underfill selection and evaluation process has become increasingly complex, time consuming and cost prohibitive due to increasing product design constraints, introduction of new package materials, and ever changing from factor of semiconductor packages. With every new generation of package technology, one must factor into the underfill selection process, new solder alloys and soldermasks, thinner substrate core materials, finer pitches, and increasing package dimensions.

This paper continues our recent published work. Prior work presented the reworkable underfill evaluation process and several criteria were investigated which included underfill flow rate, flux compatibility, reworkability, solder extrusion, material properties such as viscosity, Tg, modulus and cure time. This paper conducts a deeper and wider study on the underfill/flux compatibility issues. It investigates the flux compatibility between four most popular commercial solder pastes and over six popular commercial CSP and BGA underfills. Two most compatible solder pastes were then selected to assemble the WLCSP and BGA rigid and flex circuits. Ten reworkable underfills from various venders were applied to the devices on these boards. The thermal cycle, temperature humidity aging, autoclave, and drop reliability tests were performed. The underfill and solder paste combination with the best performance for both rigid and flex boards were selected and applied to the production process.

Key words: Reworkable underfill, Underfill, Reworkability, Flux Compatibility, WLCSP, BGA

INTRODUCTION

Due to the demand growth for portable, hand held electronics products with a lighter weight, smaller size, higher performance in consumer and industrial electronics markets, the interest in using fine pitch SMT components, such as BGA, 0.4/0.3 mm pitch WLCSPs and WLQFN, 0201, 01005 components, and smaller components, has increased greatly in recent years. The usage of these fine-pitch and high-density packages and devices have had a tremendous impact on board-level reliability and assembly process. Against mechanical drop/shock and temperature cycling, solder joint reliability deteriorates as the result of smaller solder joint size with pitch reduction. Board level underfill (BLUF) has been known as a solution for handheld devices in providing solder joint with an additional mechanical protection against drop/shock.

Underfill is a polymeric material used to fill the gap between the IC chip and the organic board, encapsulating the solder joints. It enhances device reliability by distributing thermo-mechanical stresses caused by the coefficient of thermal expansion (CTE) mismatch between chip and board evenly over the whole package. Underfill absorbs the CTE mismatch and therefore reduces significantly stress to a more uniform distribution on solder joints. Conventional underfills are not reworkable after post cure. As a result, faulty packages are often disposed of if failure occurs. Reworkable underfill on the other hand, enables packages to be repaired, replaced, recovered or recycled. These materials can be thermally decomposed at a lower temperature and the decomposition residues can then be removed using commonly available solvents, without damaging the underlying electronic components. They have also evolved to be very easily used in board assembly line with fast flow, low temperature and instant cure [1, 2].

Historically, the target properties of underfills can be generally summarized as high glass transition temperature (Tg), high modulus (E) and matched coefficient of thermal expansion (CTE) to solder. In the past of decades, a lot of studies have been commissioned to evaluate the selection, application, assembly process and reliability of the commercial underfills at that time [3-17]. In the recent of years, however, as the increased product design constraints, updated new package materials, and changed new generation of package technology, the underfill selection and evaluation process has become increasingly complex, and many factors need to be considered and investigated usually.

This paper continues our recent published work. Prior work presented the reworkable underfill evaluation process and several criteria were investigated which included underfill flow rate, flux compatibility, reworkability, solder extrusion, material properties such as viscosity, Tg, modulus and cure time. This paper conducts a deeper and wider study on the underfill/flux compatibility issues. It investigates the flux compatibility between four most popular commercial solder pastes and over six popular commercial CSP and BGA underfills. Two most compatible solder pastes were then selected to assemble the WLCSP and BGA rigid and flex circuits. Ten reworkable underfills from various venders were applied to the devices on these boards. The thermal cycle, temperature humidity aging, autoclave, and drop reliability tests were performed. The underfill and solder paste combination with the best performance for both rigid and flex boards were selected and applied to the production process.

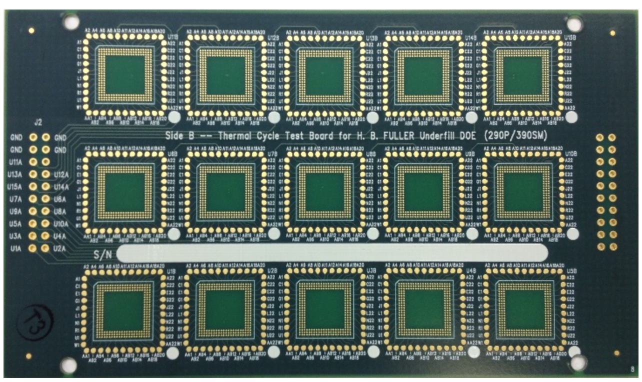

Figure 1. BGA test vehicle for underfill evaluation

TEST VEHICLE AND DEVICES

New designed and fabricated PCBs based on JEDEC standards, shown in Figure 1, were used as the test vehicle during this reworkable underfill evaluation. The dimension of these boards is 132mm x 77mm x 1mm. ENIG was used as the surface finish. In this board, one side was designed for thermal cycle reliability test and the other side was designed for drop reliability test. The layout design for both sides were the same and they used the same SMD pads. The only difference for the drop side is that via-in-pad was adopted and the traces were duplicated on the outer layer and one inner layer to avoid the trace failure during the drop test. There were 15 devices on each side. The devices used in this evaluation were Amkor CTBGA 228, as shown in Figure 2. This CTBGA (ChipArray Thin Core Ball Grid Array) daisy chain device has a 0.5mm pitch, and 12mmx12mm body dimension. The ball matrix is 22x22 with a perimeter ball alignment. The solder balls use SAC305 alloy and their diameters are 0.30 ± 0.05mm.

Figure 2. BGA device used in underfill evaluation

For the WLCSP underfill evaluation, the test vehicle was designed based on JEDEC standards as well, shown in Figure 3. The top of the boards was designed for Drop Test, and bottom side was for Thermal Cycle Test. The pad size was 225um. And the surface finish used ENIG. The device used for this test vehicle was CSPnl 196. It has a 5.56X5.56 mm die size, 0.725mm thickness, and 0.4mm pitch. The ball alloy is SAC405 and the UBM diameter is 0.201mm. The device has 196 I/O count and around 3.2 ppm/C CTE. The device structure is shown as Figure 4.

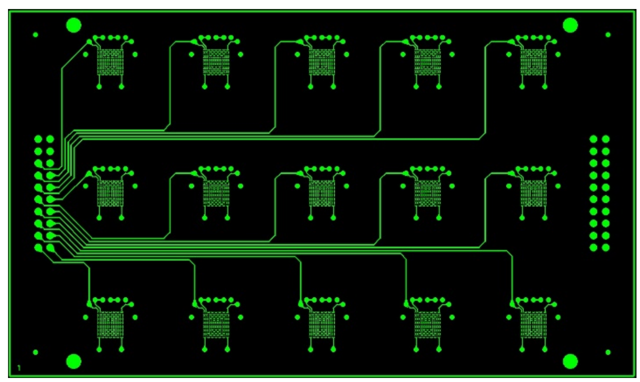

Figure 3. WLCSP test vehicle for underfill evaluation

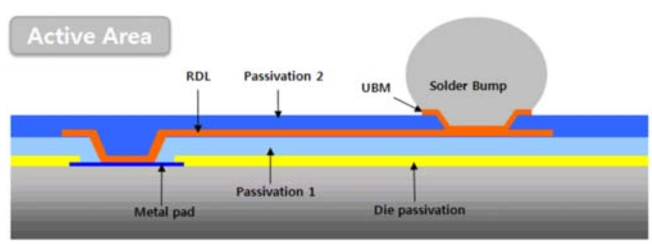

Figure 4. WLCSP structure

FLUX COMPATIBILITY

When underfill is applied to assembled circuit boards, flux residues may affect the reliability in two different ways. Being present on the solder bump, substrate or die, the thin films of flux residues can significantly reduce the interfacial adhesion between the underfill and the surfaces. Once the underfilled device is stressed by thermal shock, humidity or other factors, the underfill could delaminate from the surface, and stress concentrations occur on the solder joints leading to rapid failure. Fluxes can also affect reliability by physically impeding the flow of underfill material. Flux residue buildup in the gap between bumps or between the die and the substrate can narrow the gap to a point where the underfill cannot flow or the edges flow faster, encapsulating air and creating a void. To ensure a void-free underfilling, homogenous wetting of the underfill must occur on all surfaces. If wetting is not homogenous, voids in the uncured underfill may translate into reliability problems in the future.

The higher compatibility between flux and underfill, the less void will be occurred after the underfill is cured. In previous test, four underfills A, B, C, D were evaluated. A planar cross section was conducted for all underfilled samples to compare the void level nearby the solder joints or in the underfill. Figure 5 and 6 show the typical underfilled sample and the planar cross-sectioned image during this process.

Figure 5. Underfilled sample

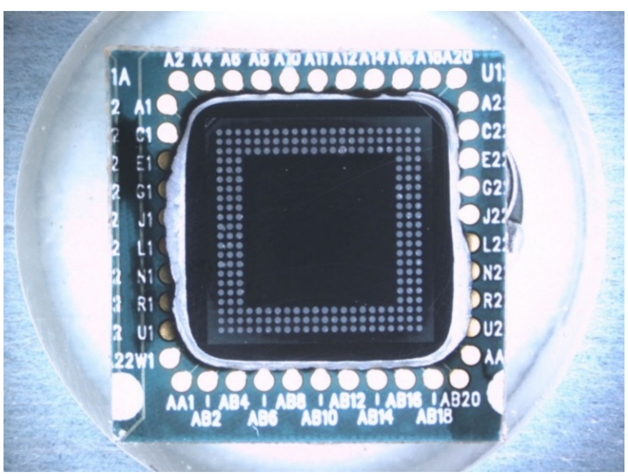
Figure 6. Planar cross-section image

Figure 7 to 10 show the detailed planar cross section images for material A to D respectively. It can been seen that material A & C have slight voiding around the solder joints and in the underfill. Material B has a very minimal voiding in the underfill, which shows that it has a better compatibility with the flux used in assembly. Compared with material A, B, & C, material D has more voiding around each solder joint. This suggests that material D has the compatibility issue with this specific solder paste. Among those 4 underfills, material D has the least favorable performance for the previous flux-underfill compatibility test.

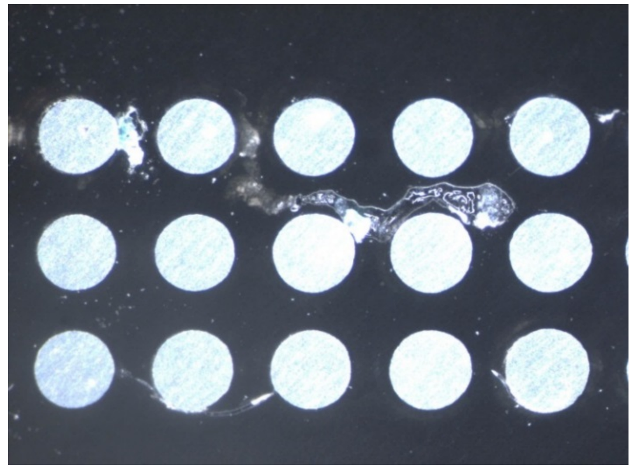
Figure 7. Detailed planar cross-section image for material A – Slight voiding

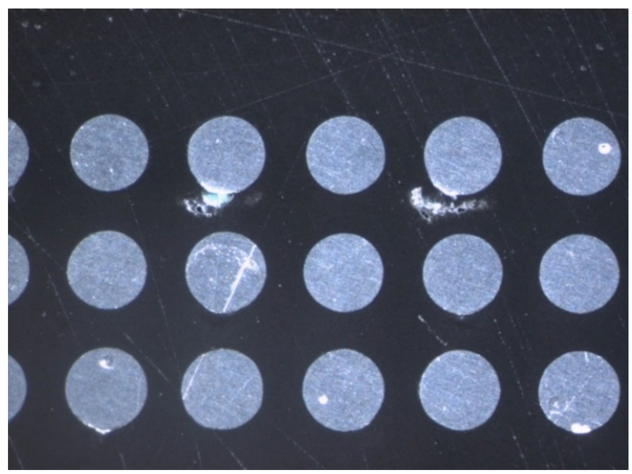
Figure 8. Detailed planar cross-section image for material B – Very minimal voiding

In this study, an easier and more effective way was approached. After various No-Clean solder pastes were printed on the CTBGA test vehicles (PCBs), 12X12mm glass slides were put above the solder to cover the device sites. Then the PCBs with glass slides were reflowed together in the reflow oven. The profiles were different based on the solder pastes. The glass slides will stick on the top of the solder joints with the flux residues. The different underfills then were dispensed into these glass slide-solder joint-PCB sandwiches. After the various underfills were cured, the flux underfill compatibility can be observed by comparing the images of flux residues after assembled, before cured, after cured, and after 2nd time reflow. Figures

11-19 show the images for three flux-underfill combinations.

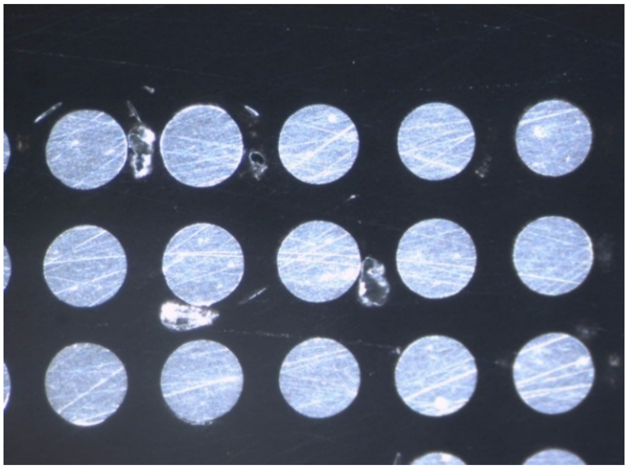

Figure 9. Detailed planar cross-section image for material C – Slight voiding

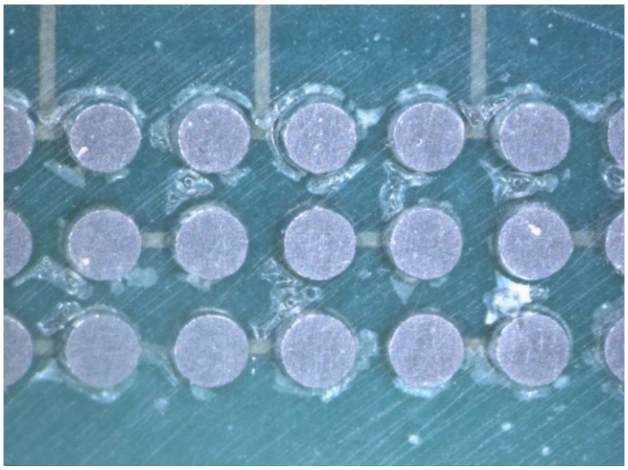

Figure 10. Detailed planar cross-section image for material D – More voiding, Voiding around each joint rather than random can signify compatibility issue with this specific solder paste

The criteria to judge the flux and underfill incompatibility is to check 1) Voids or delamination forming around the solder joints indicate incompatibility between the flux residue and underfill material. 2) Darker and lighter discolorations around the solder joints may be evidence of mixing or dissolution of the flux residue with or in the underfill which reduces voiding and delamination during cure and 2nd reflow. A score from 0-10 was judged based on these criteria. Table 1 lists the results for all underfill and solder paste combinations.

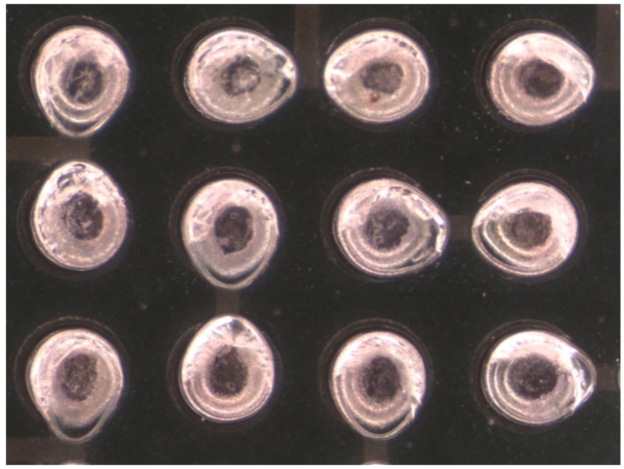

Figure 11. Assembled using Indium 8.9 paste

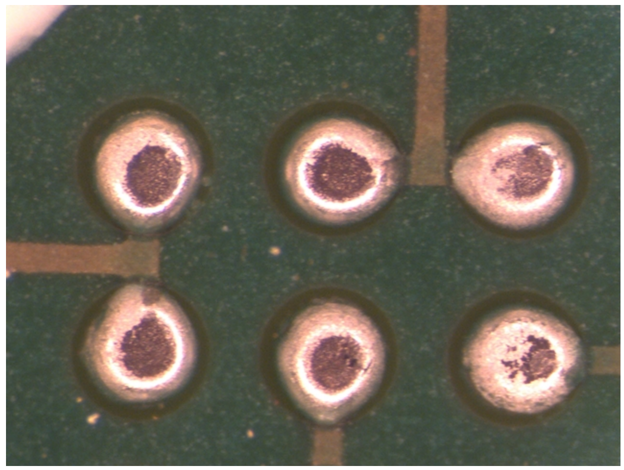

Figure 12. Underfill UF-B/Indium 8.9 before cured

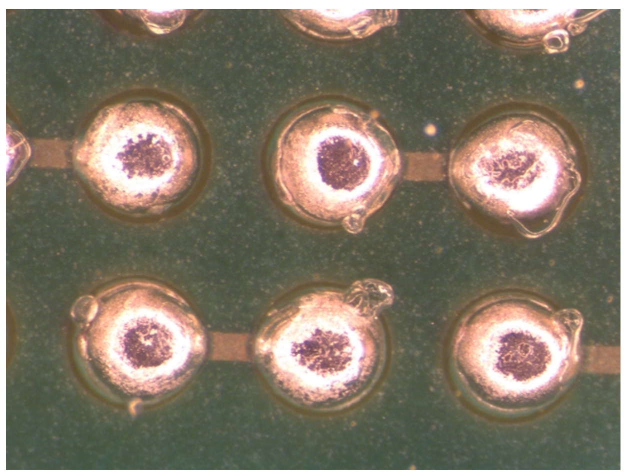

Figure 13. Underfill UF-B/Indium 8.9 after cured

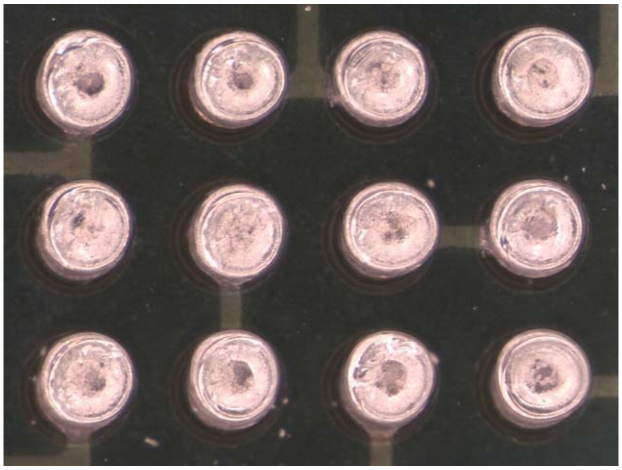

Figure 14. Assembled using Senju GRN360 paste

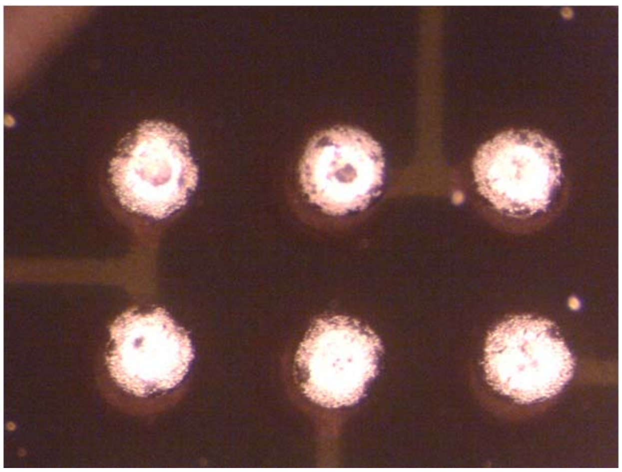

Figure 15. Underfill UF-C/Senju GRN360 before cured

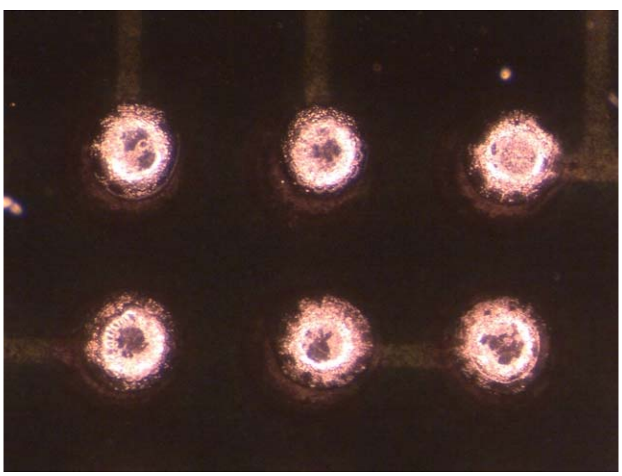

Figure 16. Underfill UF-C/Senju GRN360 after cured

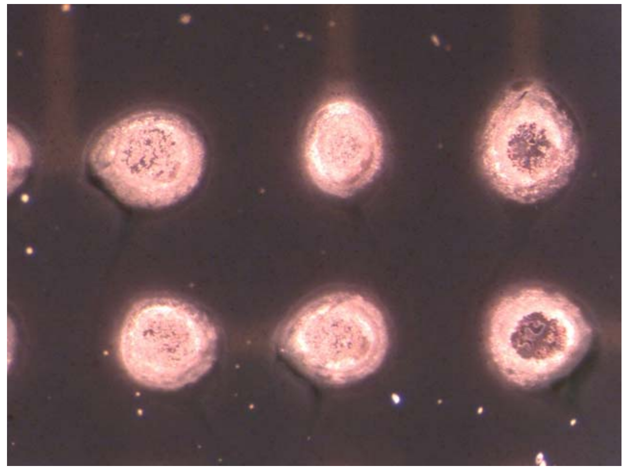

Figure 17. Underfill UF-G/Indium 8.9 before cured

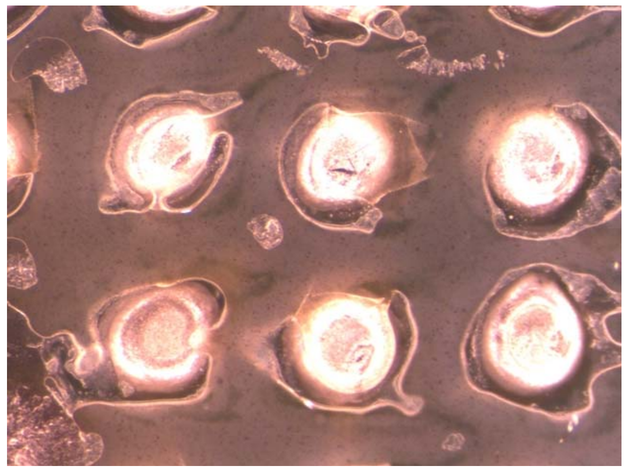

Figure 18. Underfill UF-G/Indium 8.9 after cured

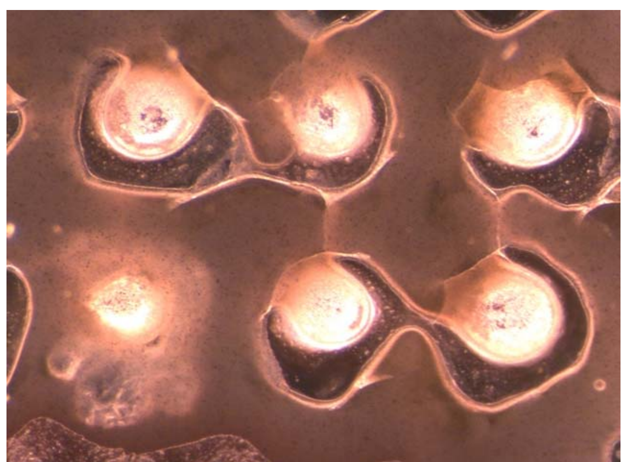

Figure 19. Underfill UF-G/Indium 8.9 after 2nd reflow

Table 1. Voiding or delamination due to flux residues for all flux – underfill combinations

	Voiding or Delamination Due to Flux Residues					
Solder Paste	Senju GRN360		Indium 8.9		Alpha OM340	
Product	**Post Cure**	**Post 2nd Reflow**	**Post Cure**	**Post 2nd Reflow**	**Post Cure**	**Post 2nd Reflow**
Score 0 = No Voiding 10 = Voids Bridging Solder Joints	[0-10]	[0-10]	[0-10]	[0-10]	[0-10]	[0-10]
UF-A	0		5		1	
UF-B	1		2		3	
UF-H	8		10		5	
UF-C	0		2		1	
UF-I	1	1	0		2	2
UF-J	3	5	5	5	2	3
UF-G	4	4	8	10	3	6
UF-K	0	0	1	1	2	2
UF-F	0	1	2	4	2	2
UF-L	0	0	0	0	0	0

RELIABILITY TEST AND RESULTS

After the flux underfill compatibility screening, five underfills and two NC solder pastes had been selected to conduct the reliability test and evaluation. The solder pastes were NC Indium and Senju pastes.

Reliability Testing – Thermal Cycle

Thermal cycling test was conducted for the underfilled daisy chain components CTBGA228 and CSPnl196. Two boards (30 devices) for each underfill were tested. The test conditions were: -40°C to 125°C, 15-10-15-10 minutes ramp and dwell time. All boards were probed every 100 cycles through 1000 cycles. The tests were extended till the daisy chains failed. After 1000 cycles, the boards were probed every 200 cycles. The criteria for the potential failure or reliability issue was the daisy chain resistance increased 30%. Figures 20-22 show the weibull plots of the reliability of these five underfills and Tables 2 & 3 shows the failure data for these CTBGA and CSPnl daisy chains.

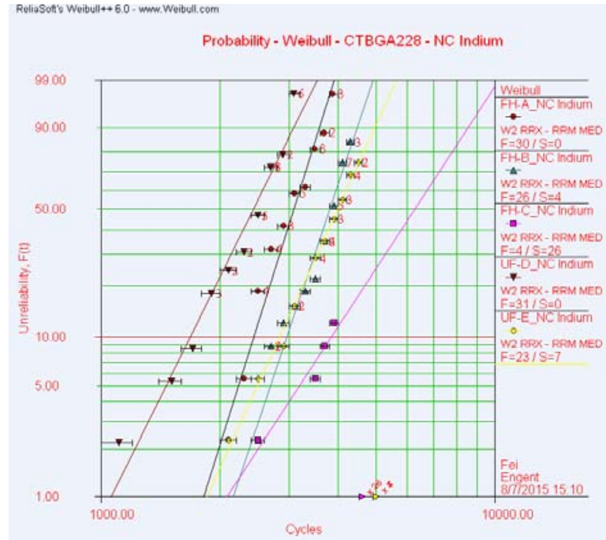

Figure 20. Weibull plot for CTBGA228 –NC Indium paste

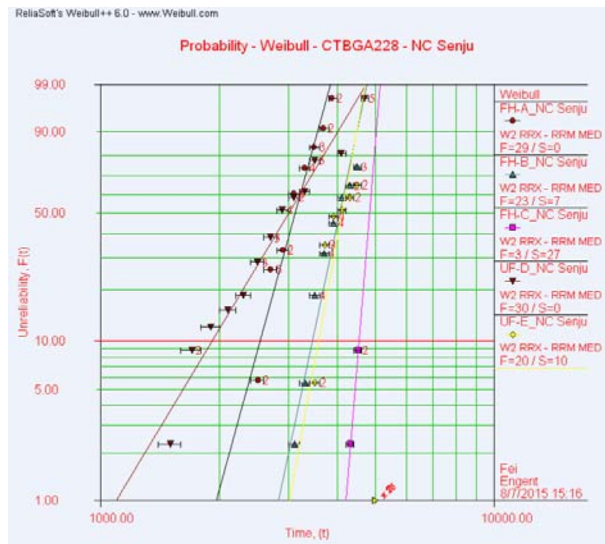

Figure 21. Weibull plot for CTBGA228 –NC Senju paste

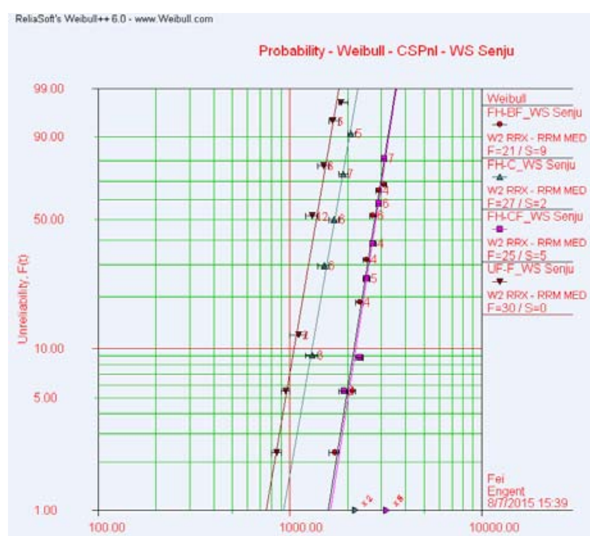

Figure 22. Weibull plot for CSPnl –WS Senju paste

Table 2. Thermal cycling failure data of CTBGA228 for two NC pastes

Solder Paste	Underfill	T1600	T1800	T2000	T2200	T2400	T2600	T2800	T3000	T3200	T3400	T3600	T3800	T4000	T4200	T4400	T4600
Senju GRN360	**UF-A**	0/29	0/29	0/29	0/29	0/29	2/29	8/29	10/29	18/29	23/29	9/14	12/14				
AATC1	**UF-B**	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	1/30	2/30	6/30	10/30	14/30	18/30	20/30	8/15
	UF-C	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	1/30	3/30
	UF-E	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	2/30	11/30	15/30	16/30	18/30	20/30
	UF-D	1/30	3/30	4/30	5/30	6/30	9/30	12/30	16/30	17/30	19/31	9/15	9/15	9/15	10/15	10/15	10/15
Indium 8.9	**UF-A**	0/30	0/30	0/30	1/30	2/30	6/30	10/30	13/30	18/30	19/30	10/15	12/15				
	UF-B	0/30	0/30	0/30	0/30	0/30	1/30	3/30	4/30	5/30	6/30	6/30	11/30	16/30	23/30	26/31	
	UF-C	0/30	0/30	0/30	0/30	0/30	1/30	1/30	1/30	1/30	1/30	2/30	3/30	4/30	4/30	4/30	4/30
	UF-E	0/30	1/30	1/30	1/30	1/30	2/30	2/30	3/30	5/30	5/30	9/30	11/30	14/30	17/30	21/30	23/30
	UF-D	2/30	2/30	5/30	7/30	9/30	14/30	22/30	24/30								

Table 3. Thermal Cycling failure data of CSPnl for two WS paste

AATC-1 Testing Solder Paste	Underfill	T800	T900	T1000	T1200	T1400	T1600	T1800	T2000	T2200	T2400	T2600	T2800	T3000	T3200
Senju WSG535	**UF-C**	0/29	0/29	0/29	0/29	4/30	4/30	10/30	23/30	27/31					
	UF-BF	0/30	0/30	0/30	0/30	0/30	0/30	1/30	1/30	2/30	5/30	9/30	15/30	20/30	19/30
	UF-CF	0/30	0/30	0/30	0/30	0/30	0/30	0/30	2/30	2/30	3/30	8/30	12/30	18/30	24/30
	UF-F	0/30	0/30	0/30	0/30	0/30	0/30	0/30	1/30	2/30	3/30	4/30	4/30	4/30	7/30

Table 4. Thermal Humidity Reliability data of CTBGA228 for two NC paste

Solder Paste	Underfill	T600	T800	T1000	T1200	T1400	T1600	T1800	T2000	T2200	T2400	T2600	T2800	T3000	T3200	T3400
Senju GRN360	**UF-A**	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
TH	**UF-B**	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-C	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-E	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-D	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
Indium 8.9	**UF-A**	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-B	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-C	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-E	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-D	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30

Table 5. Thermal Humidity and Hot Temperature Storage Reliability data of CSPnl for WS paste

TH Testing Solder Paste	Underfill	T0	T200	T400	T600	T800	T1000	T1200	T1400	T1600	T1800	T2000	T2200
Senju WSG535	UF-C	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-BF	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-CF	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-F	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
	UF-D	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30	0/30
HTS Testing Solder Paste	**Underfill**	**T0**	**T200**	**T400**	**T600**	**T800**	**T1000**	**T1200**	**T1400**	**T1600**	**T1800**	**T2000**	**T2200**
Senju WSG535	UF-C	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
	UF-BF	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
	UF-CF	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
	UF-M	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15
	UF-G	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15	0/15

Reliability Testing – Thermal Humidity and Hot Temperature Storage

Thermal Humidity test and Hot Temperature Storage (Aging) test were conducted for the underfilled daisy chain components CTBGA228 and CSPnl196 as well. Two boards (30 CTBGA and CSPnl devices) for each underfill were tested for Thermal Humidity test and one board (15 CSPnl devices) were tested for Hot Temperature Storage test. The test conditions for Thermal Humidity were: 85°C and 85% humidity, lasting at least 1000 hours. All boards were probed every 200 hours. The tests were extended to 3400 hours for CTBGA devices and 2200 hours for CSPnl devices. The test condition for Hot Temperature Storage were at 125°C for 1000 hours. The probe interval was 200 hours as well. In the final, the test were extended to 2200 hours. The criteria for the potential failure or reliability issue was the daisy chain resistance increased 30%. Tables 4 & 5 shows the reliability data for the device daisy chains during these tests. No failure was found for all tested underfill materials.

SUMMARY AND CONCLUSIONS

This work continues our previous work on the evaluation of the BGA and CSP reworkable underfills. Our prior work presented the reworkable underfill evaluation process and several criteria were investigated which included underfill flow rate, flux compatibility, reworkability, solder extrusion, material properties such as viscosity, Tg, modulus and cure time. This paper conducts a deeper and wider study on the underfill/flux compatibility issues. It investigates the flux compatibility between four most popular commercial solder pastes and over six popular commercial CSP and BGA underfills. Two most compatible solder pastes were then selected to assemble the WLCSP and BGA rigid circuits. Ten reworkable underfills from various venders were applied to the devices on these boards. The thermal cycle, temperature humidity, high temperature storage aging, reliability tests were performed. The results show that the underfill C performed better than underfill B & E, which have a similar reliability performance. Underfill A is the next one and Underfill D performed the worst. All underfills passed the thermal humidity test and high temperature storage test.

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