Application Research of Snap Curing CSP Underfill

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Abstract

CSP underfill commonly acts to protect solder bumps of fine pitch CSP and enhances the reliability. This paper presents four snap curing underfills (≤2min@150℃or≤5min@120℃), tested on SnPb assemblies, to investigate on underfill processing, flux compatibility, and analyze the influence on 0.5mm pitch CSP reliability through drop and accelerated thermal cycle (ATC) test.

Key words: underfill, CSP, reliability, compatibility

1. Introduction

The primary application of underfill is used in Flip Chip, by filling with epoxy resin under chip. After resin curing, it will form a protective adhesive to decrease thermal expansion (CTE) mismatch among silicone chip, solder ball and PCB [1, 2] hence, finally making the higher reliability of solder joints comes true. As handhold products such as mobile phones, PDA and so on, dramatically are developed, there is a move towards wide use of fine pitch CSP. Therefore, the probable drop shock damage in use will result in a risk to reliability. Upon that, as shown in Figure 1, the CSP underfill gradually acts to enhance the reliability and overcomes the drop shock.

The properties of conventional CSP underfill have some disadvantages, such as long curing time, high pre-heat temperature, rework difficulty, poor flow and short pot life. Underfill manufacturers are developing a new generation snap curing underfill to overcome the disadvantage of conventional CSP underfill.

This paper now presents four snap curing underfills, tested on SnPb assemblies, to investigate on underfill processing, flux compatibility, and analyze the influence on 0.5mm pitch CSP reliability through drop testing and accelerated thermal cycle (ATC) testing.

Figure 1 Underfill application in end consumption products

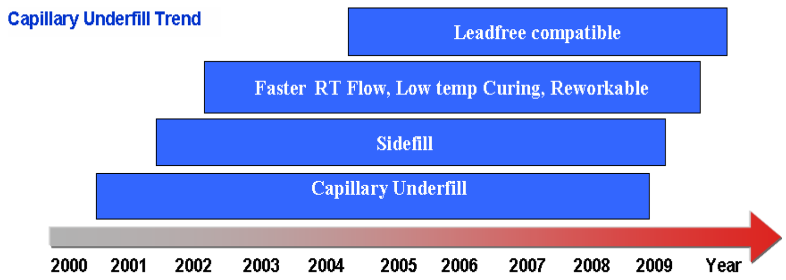


Figure 2 Underfill roadmap from Loctite

2. Experiment

Underfill materials

Table 1 lists the four snap-curing underfill materials with different specific properties tested in this study.

Table 1 Experimental snap curing underfill materials properties

Underfill	A	B	C	D
Chemical type	Epoxy	Epoxy	Epoxy	Epoxy
Viscosity @25℃ (cps)	2200	350	1400	160
Pot life /days (25℃)	14	10	10	5
Curing	1min @ 150℃; 5min@120℃	2.5min @ 110℃ 1.5min @ 140℃	1min @ 150℃ 2min @ 130℃	5min @ 120℃ 1min @ 150℃
Pre-heating tem℃	70-80	Room tem	75—90	Room tem
rework able	Yes	Yes	Yes	Yes

Test vehicle and Package

The test vehicle employed in this study is a CTBAG component with eutectic tin-lead (63Sn-37Pb) solder and a daisy chain structure. The component is 0.5mm pitch, with 228 bumps, a 12mm×12mm body size, a 10mm×10mm die size, a 0.24mm die thickness and a 0.67mm molding thickness. The package for this study is shown in Figure 3.

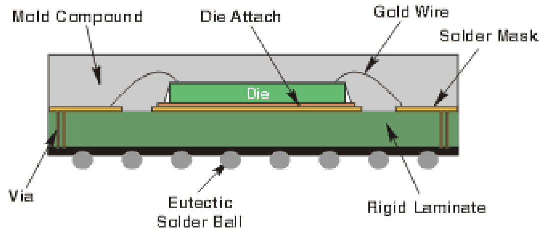


Figure 3 Schematic of component

The component pads are designed as no solder mask define (NSMD), with 10mil size. All solder balls are connected by a daisy chain which could be continually monitored during the test. The daisy chain the on component side is given by Figure 4. The test board is FR-4 PCB with 200mm×110mm size and 1.6mm thickness while the surface finish is Organic Solderability Preservatives (OSP).

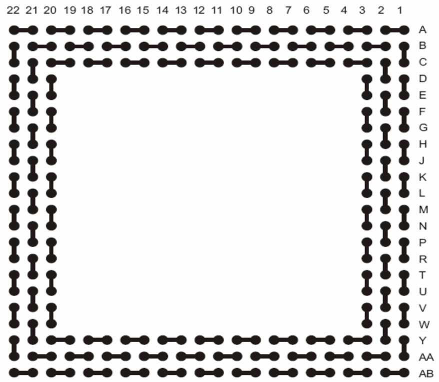


Figure 4 Daisy chain of Component side

Experiment design

The test presents four underfill materials processing and their compatibility with solder paste, drop test and accelerated thermal cycle reliability (ATC). Additionally, for the purpose of comparison with underfill vehicle, no underfill test samples were also assembled. The details of the experimental design is shown as Table 2.

Table 2 Summary of experimental design

Test number	Underfill	Assembly	Compatibility	ATC	Drop
1＃	-		-		
2＃	A				
3＃	B				
4＃	C				
5＃	D				

Notes

- Means No involved in experiment

√ means done in the experiment

3. Assembly

Underfill pre-heat and curing parameters

Before test vehicles assembling, underfills' flow and cure performance had been tested. The four underfill material best pre-heating temperatures and curing conditions are given in Table 3.

Table 3 Preheat and curing parameters of underfills

Underfill	Flowing perfomance	Curing performance
A	70℃	120℃, 4min 150℃, 1min
B	30℃-40℃	120℃, 3min 150℃, 0.5min
C	70℃	120℃, 3min 150℃, 0.5min
D	Room Temperature	120℃, 4min 150℃, 1min

Assembly process

The test vehicles assembly consisted of printing, picking, reflowing, dispensing and underfill curing. The reflow profile was chosen based on SnPb processing with a peak temperature of 230℃ and soak time 60s over 183℃.

Underfill dispensing was completed with a dispense machine with a 23-gauge needle. Table 3 gives preheat temperature. Underfills cure was implemented in the reflowing oven. According to four underfills curing performance, the cure parameter is 150℃ for 90s, as displayed in Figure 5. After curing an optical microscope was used to observe the underfill curing situation. All the components sides were completely full of underfill.

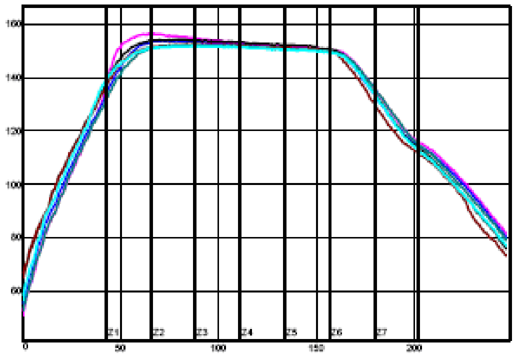


Figure 5 Reflow profile of underfill curing.

4. Underfills' Compatibility with flux

The compatibility of underfill with solder paste is analyzed by cross section. The detailed results are shown by Figure 6. Underfill A and C show good compatibility, resin totally cured and lfew voids observed in the solder balls. Underfill B has less compatibility. Although the resin cured well some small voids emerged among the solder balls. However, Underfill D presents a negative result as the epoxy resin between the solder balls is not cured fully and is like gel showing very poor compatibility.

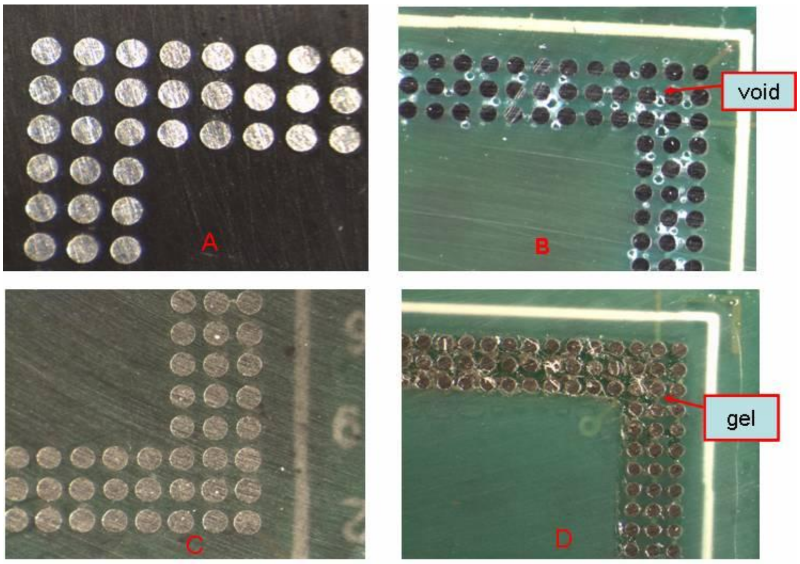


Figure 6 Comparison of underfill's compatibility with solder paste

5. Drop test

The test vehicle for board level drop test is shown as Figure 7. Test condition is an acceleration of 2900G peak with 0.3msec duration and no rebound. The drop upper limit is subjected to 100 cycles by measuring the daisy chain resistance to judge failure or not.

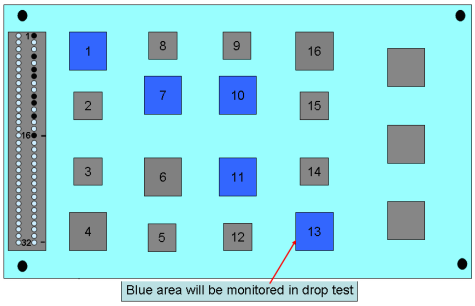


Figure 7 Schematic of drop test vehicle

Drop test results and discussion

As shown in Table 4, test sample with underfill have longer life than without underfill. In this experiment, underfilled samples have no failure until 100 drops. Unfortunately, all of the no underfill samples failed. The details of the failure cycles is presented in Table 5. It should be emphasized that underfill D also passed the drop test even with very poor compatibility with flux.

The cross-sectioned samples are observed through scanning electron microscopy (SEM). No underfill samples have large and clear cracks. These cracks are detected near the component side of the joint and propagate crossing through the bulk solder near the intermetallic layer as shown in Figure 8. The underfill samples were also analyzed by cross section and SEM. The 10# location component is observed which is probably easiest to fail during drop test. SEM shows underfill solder balls have no crack as displayed in Figure 9.

Table 4 Drop test analysis

Underfill	sapmles	comptibility	Results	SEM analysis
without	4	——	All failure(detailed datas are shown in table 5)	Large crack
A	5	good	No failure	No crack
B	4	Less	No failure	No crack
C	5	good	No failure	No crack
D	5	poor	No failure	No crack

Table 5 No underfill samples drop life

underfill	CSP No.			
	#7	#10	#11	#13
Without	60 drops	6 drops	35 drops	2 drops

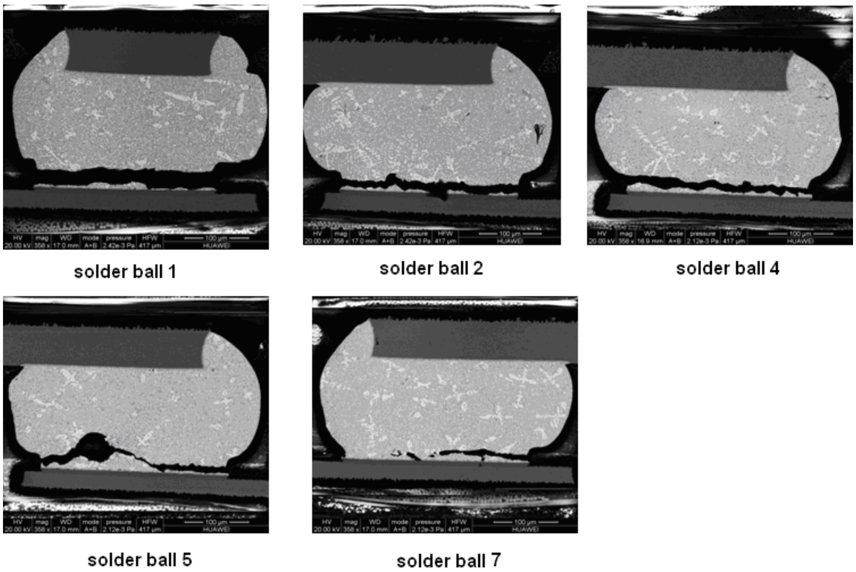


Figure 8 Cross section of no underfill solder joint after drop test

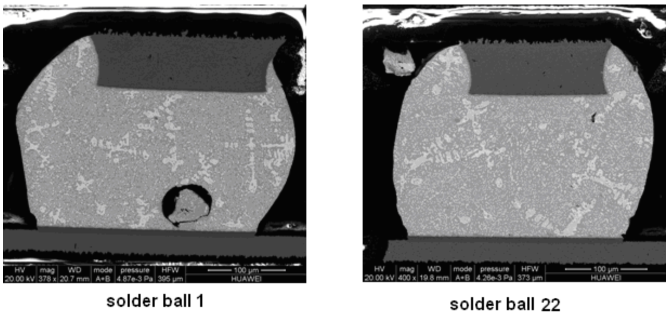


Figure 9 Cross section of Underfill solder joint after drop test

6. Thermal cycles testing

A total of 40 samples, including 4 underfills and no underfill controls with 8 replicates each, were subjected to accelerated thermal cycles testing. The temperature cycle test ranged from 0℃ to 100℃ with 15 minute dwell time. Single cycle is one hour. The daisy chain resistances are continuously measured throughout the entire test .The test vehicle is shown in Figure 10.

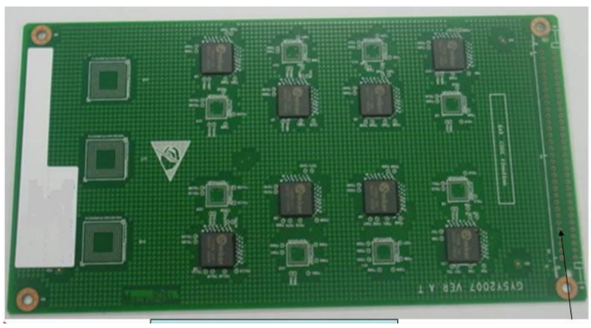


Figure 10 Picture of ATC test board

ATC results and discussion

The ATC test results are given in Figure 11. After 2100 cycles, for underfill B, only 3 sample failures were found Other underfill materials failed in different cycles. In overall, underfill samples has longer life than those without underfill. Typically, it seems that the underfill’s Tg has positive effect on the ATC results. The higher the Tg of the underfill the less thermal distortion during the ATC temperature range from 0℃ to 100℃. As shown in Table 6, underfill B has the longest cycle life of over 2100 cycles.

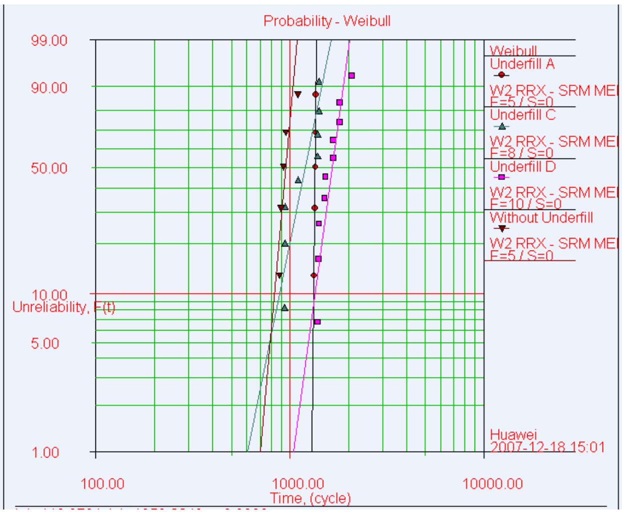
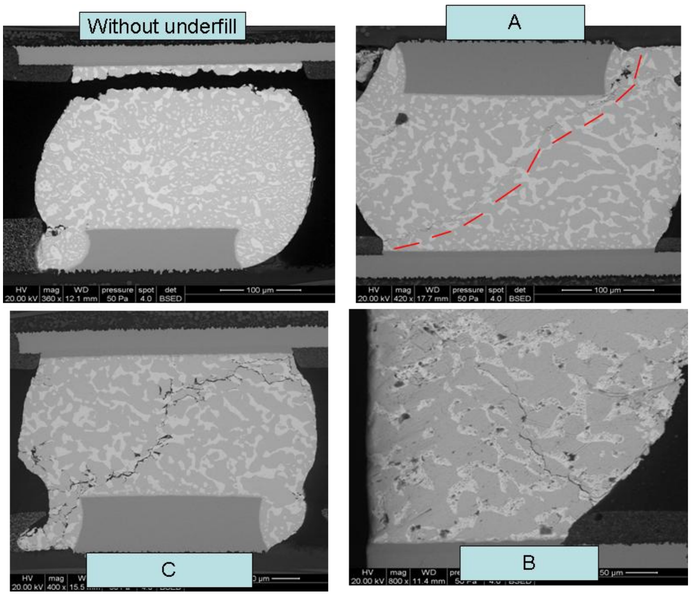


Figure 11 ATC Weibull plot of test vehicles with underfills and without underfills

Table 6 ATC data and Underfills' Tg

Underfill type	No underfill	A	B	C	D
N63	981	1358	>2100	1273	1712
Tg (℃)	-	26	105	15	60

SEM was used to observe the cross section of the failed samples as is shown in Figure 12 and 13. It definitely shows solder fatigue failure. The cracks without underfill initiate from component side of joint and propagate to the bulk solder near the intermetallic layer. Solder cracks with underfill are very small and extend at 45degree along the crystallization phases. Around the cracks one can see the solder structure.



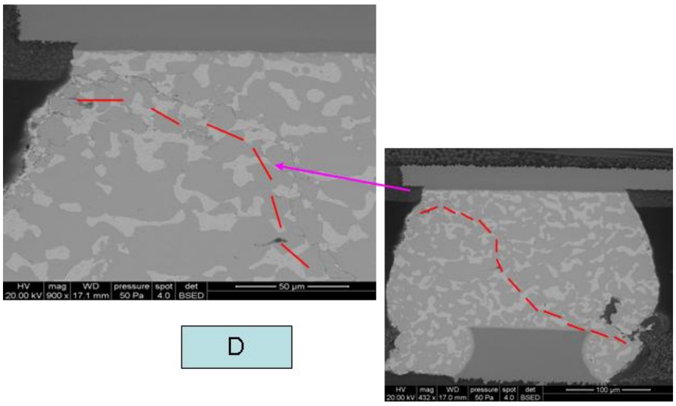


Figure 12 Cross section of solder bumps after thermal cycles.

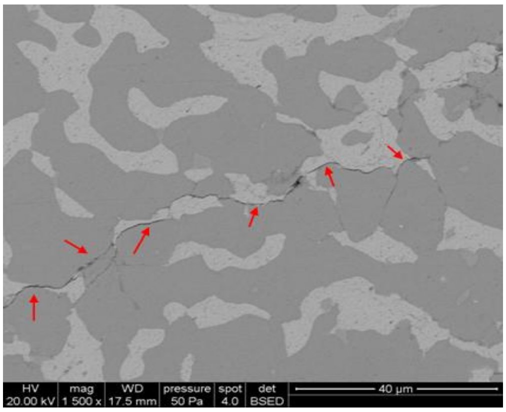


Figure 13 Solder cracks with underfill along crystallization phases

Influence of underfill voids on solder extrusion

Underfill B presents less compatibility with solder paste with some voids around the solders. This voids' influence is specially analyzed after ATC test. All the test samples under ATC experiments are observed by X-ray. As shown in Figure 14, it obviously shows that underfill B exhibits more solder extrusion than underfill A, C, D and no underfill. Solder extrusion is solder which has been forced to cross over underfill void under thermal distortion.

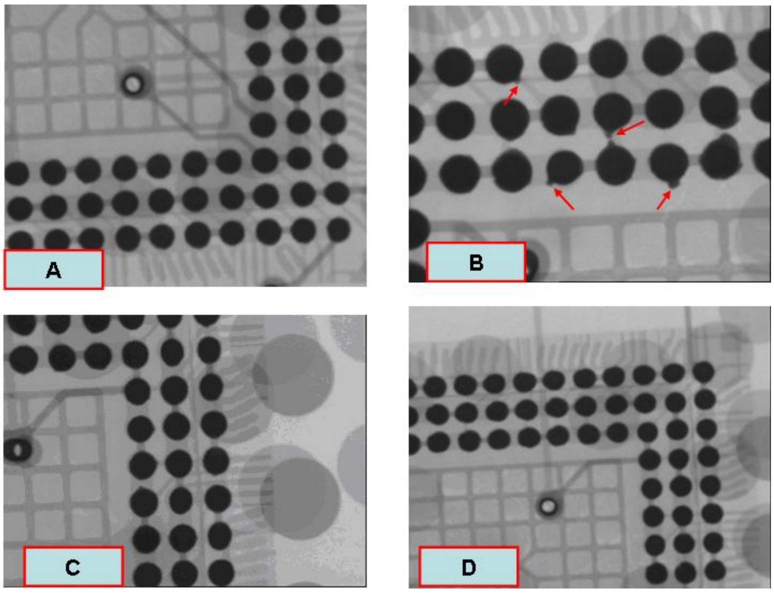


Figure 14 X-ray observe test samples after thermal cycle

Further study on underfill B samples through cross section has found that solders run into the underfill voids. Solder extrusion is shown in Figure 15 and 16. The solder extrusion mechanism could be explained as following. Solder bumps are tightly enwrapped by cured epoxy resin, the solder bumps distortion will be less when the adhesive fixes their shape. In contrast, the void which is close to bumps is lacking adhesive contact to protect the solder ball. This results in stress concentration and the solder undergoes serious thermal pressure and strain. As the thermal cycling test continues the solder gradually moves into the void forming a solder extrusion.

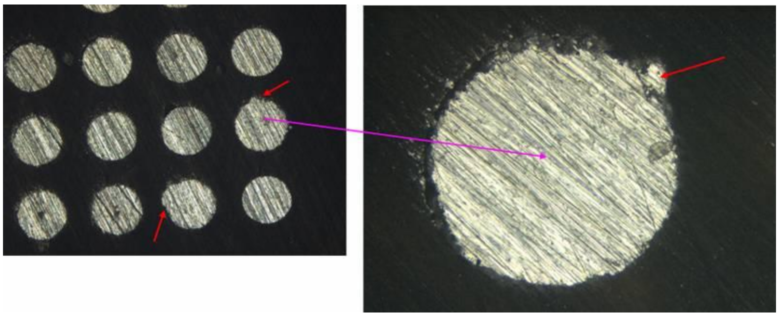


Figure 15 cross section of underfill B sample.

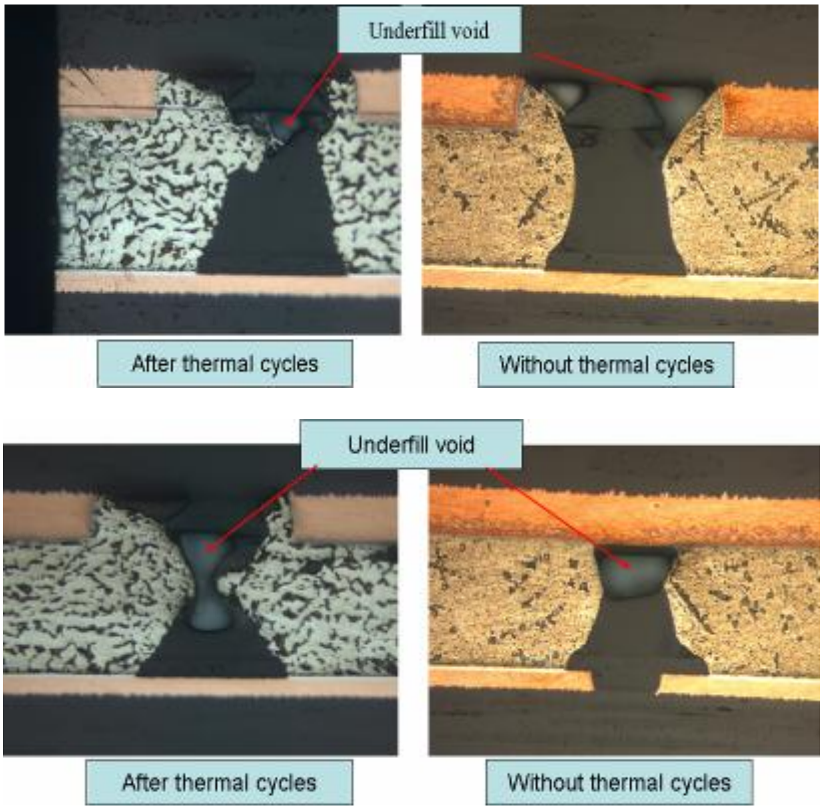


Figure 16 Cross-section of underfill B after ATC and before

Samples with more underfill voids will have more chances to form solder extrusion. In this ATC test although some voids are seen in underfill B sample the voids do not seem to have a negative effect with thermal cycling. It must be stated emphatically that more voids cause vulnerability to electrical shorts and shorting failure in very fine pitch with solder extrusion.

7. Conclusion

Underfills show different compatibility with solder paste. Underfill D has very poor compatibility, but the result of drop test and accelerated thermal cycle test indicates that it did not have a negative effect. Underfill B has less compatibility with some voids forming close to solder balls. Underfill A and C have good compatibility.

Drop and thermal cycle test results disclose that test samples with underfill have longer life than those without underfill. The extent of improvement in performance has a close correlation with the underfill material's Tg. Underfill B has highest thermal cycles to failure, i.e. over 2100, and it has the highest Tg.

Additionally, we have seen that the voids formed by incompatibility of the underfill and solder paste may cause solder extrusion in long term thermal cycling. It is important that this phenomena receive significant attention in applications seeing thermal cycles.

Reference

[1] Lau, J. H., Flip Chip Technologies, McGraw-Hill, 1996.

[2] Suryanarayana, D., et al., "Enhancement of Flip- Chip Fatigue Life by Encapsulation", IEEE Transactions on Components, Hybrids, and Manufacturing Technology, Vol.